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A CRITICAL ANALYSIS OF THE STATE OF THE ART IN CONTAINERIZATION

S. Berger, et al

Control Systems Research, Incorporated
Arlington, Virginia

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In order to provide a foundation for continuing development at MERDC, a critical analysis of the state of the art in commercial containerization has been performed. The report contains comprehensive coverage extending from the fundemental concepts, the operational environment, and damage analysis to evaluation of materials and assessment of design efficiency. Manufacturing methods are briefly included. The matter of maintenance was covered in sufficient detail to enable valid life cycle costs to be determined. Analysis of costs showed a rational justification for the preferences of the industry. Cost analysis includes examination of the several important sensitivity factors. The relative worth of minimum tare weight and useable cubic space was considered.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Intermodal Containerization						
Container Enviroments						
Damage Analysis for Containers						
Contruction Materials for Containers						
Design Efficienty for Containers						
Life Cycle Costs for Containers						

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A CRITICAL ANALYSIS OF
THE STATE OF THE ART IN CONTAINERIZATION

Contract No. DAAK02-70-C-0428

Prepared For

United States Army Mobility Equipment
Research and Development Center
Fort Belvoir, Virginia

November 1970

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Submitted By

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PREFACE

This report was prepared by Control Systems Research, Inc., under U.S. Army Mobility Equipment Research and Development Center Contract No. DAAK02-70-C-0428. The project was under the cognizance of the Materials Handling Equipment Branch (Mr. J. K. Knaell, Chief) of the Mechanical Equipment Division, Mechanical Technology Laboratory. Direct technical monitoring of the work was the responsibility of Mr. John A. Zwolinski, Code SMEFB-HM.

The Contractor has appreciated the workmanlike and stimulating manner in which the monitoring function was performed.

At CSR the working staff on the project has been: F. Heider, J. A. Lechus, R. L. Ralston, I. C. Watson, and S. Berger, with the latter serving as the Project Manager. Consulting services were provided to the company under this contract by Mr. Fred Muller, Jr., with whom some of the preliminary findings were discussed, and Mr. Semond Levitt, who contributed to several technical topics. An additional contribution was supplied by Marine Surveys Company, Inc., who compiled container damage statistics under a subcontract.

The cooperation provided by numerous transportation and industrial concerns and by industry associations has been excellent and is gratefully acknowledged. The cooperating organizations either responded to a comprehensive questionnaire or supplied vital information and data items. Appreciation is especially extended to the following:

United States Lines
American Export - Isbrandtsen
Prudential - Grace Lines
Matson Navigation
Moore - McCormack
American President Lines
Seatrain Lines
Atlantic Container Line
Sea Land Services
Dart Containerline
Farrell Lines
Container Transport International
Integrated Container Services

Southern Railway
Penn Central System
Santa Fe Railroad
Port of New York Authority
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Ship Tank Company
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Sears Roebuck - Operating Equipment
American Institute of Marine Underwriters
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Olin Aluminum
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Central Containers, Ltd.
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W. H. Miner
Met-L-Wood, Inc.
Allis Chalmers Material Handling Division
Silent Hoist and Crane Company
Clark Equipment Company
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Section 1

SUMMARY

1.1 This critical analysis of the state of the art in commercial containerization initially covers the concepts, equipments, and operations which constitute the environment with which reusable shipping containers must be compatible. It then proceeds to the technical areas of damage, materials evaluation, and design characteristics. Finally it deals with maintenance, which is an important cost element and then full life cycle costs.

1.2 The transportation companies have many unique patterns of operation which are a function of their trade routes, cargoes, mobile equipment (ships, trains, and highway gear), terminal facilities, and customer demands. Thus a well defined operating cycle for containers cannot be expected.

1.3 At one extreme there are fully developed terminal facilities and specially designed ships. Handling equipments engage containers by leveled spreader frames which incorporate twist locks to mate with sockets or apertures in the corner fittings of containers. Guides are provided to enable all motions of the containers and spreaders to align within workable limits and no human intervention is required in transfer cycles for guiding. Comparably mechanized equipments are used in transfers involving rail cars.

1.4 When containers are mated to chassis at the apron of a dock and maintained in a mobile state through the entire ground segment of their shipment cycle there are obvious advantages. The number of handling operations and handling equipments is an absolute minimum and there is no lost time in readying a container for movement. The associated disadvantages are the high investment cost for chassis and the land area requirement.

1.5 At the other extreme of unmechanized facilities and ships, the operating environment contains numerous additional hazards. Containers are subjected to forklift handling where the lift truck operator has poor visibility. Hoisting may be performed by slings or nonleveling spreaders. The probability of on-deck stowage is greater.

1.6 The total environment is treated comprehensively in the report even though much of the examination has been only in qualitative terms. Even if measured data had been available, it must be appreciated that it has statistical significance only in proportion to its time and space coverage. The field survey work within this study showed that operators implicitly recognize the operating problems associated with the total environment by a stepwise upgrading of ships, handling equipment, and facilities.

1.7 Standards issued by national and international organizations attempt to identify the loading conditions which must be resisted in service. The documents appear to be only a start toward development of container design criteria. For example loads on panels are idealized as uniform pressure loads, statically applied whereas service conditions include frequently occurring concentrated loads, impulsively applied -- with a much greater damaging potential.

1.8 The dimensional and maximum gross weight provisions of the standards have profound effect on container characteristics. The cube to allowable weight load does not match the average cargo densities in either North Atlantic or Pacific trade. Maritime Administration data show that cargo density averages 21 lbs/cu.ft. As a result standard 20-foot containers tend to be cube limited and many operators report that their container loads are indeed 90% cube limited. This is a contributing factor to the industry's selection of container designs. The cube/weight situation is improved in the case of standard 40-foot containers since the cube is roughly twice while the maximum cargo weight is one and a half that of the standard 20-foot unit.

1.9 There is a favorable consequence in structural performance of containers due to the apparent mismatch of container cube and cargo density. The structural load conditions specified in the standards documents are not rated by this study as conservative. However, if the container gross weight runs substantially below the maximum allowed value, then there is a degree of compensatory conservatism.

1.10 Nevertheless, containers and their contents do experience substantial damage. The report includes statistical data on 10,000 container movements during which the overall damage rate was 16%. Voyages which encountered extremely foul weather were excluded; thus a long term average value of damage would go even higher. The damage experience of containers moving on fully containerized ships was several percentage points less than for containers on partially converted ships.

1.11 Of the several container types, FRP/plywood panel containers clearly had a lower damage rate -- roughly 60% of the other types. While steel containers had the highest damage rate overall, aluminum and steel were very close.

1.12 The report contains detailed descriptions, including photographs, of various types and severity of container damage. Such items as punctured and dented panels, stiffeners of panels broken, lower longitudinal rails fractured, end frames collapsed, top torn off, and the like are included.

1.13 The materials in current use in container construction and in related applications are examined in detail. The properties which influence the efficiency of materials are highlighted. An overall evaluation is performed primarily on the basis of a cross-plot of cost/strength and strength/weight parameters and a consideration of corrosion resistance. The materials fall into unified families on the cross-plot, with the higher strength, higher cost materials being most advantageous.

1.14 Aluminum alloys are found to be most favorable for the application. They are in a medium position on cost/strength. The alloys in wide container use are 5052-H38 for sheet and 6061-T6 for extrusions, both of which are in a good position on the basis of strength/weight and resistance to the marine atmosphere. Alloy 7075-T6 would improve the strength/weight position even further but at a sacrifice in corrosion resistance. Since this is less critical in framing members, there is a conceivable weight saving to be gained. Aluminum forgings are covered since they could be used as corner fittings to overcome the weaknesses that were experienced with aluminum castings and enable a return to an aluminum end frame design which would save weight over present steel end frames.

1.15 Fiberglass reinforced plastics, as a group, are highest on the cost/strength scale. Their strength/weight ratios span a large region depending on the quantity and alignment of the glass fibers. Mat-based composition have a bi-directional strength characteristic but are lowest in strength/weight while filament wound constructions are uni-directional and highest in strength/weight. When combined in composite sandwich form with a plywood core, the resultant product is more favorable on cost/strength but loses a little in strength/weight. The material is ranked (in a subjective way) slightly less satisfactory than the aluminum alloys in resisting the marine environment. Improvement in this property could be had by using an epoxy matrix rather than the more widely used polyesters -- but at a cost penalty. FRP/plywood is found to have a mismatch in the face and core components due to inadequate spread in their modulii of elasticity. If the full strength of the FRP were to be used, the strain in the adjacent plywood would lead to failure. From a strength/weight viewpoint there may be an advantage, therefore, to matching FRP faces with alternate cores or applying aluminum or steel faces to plywood cores.

1.16 Steel is clearly in the best position on cost/strength and the higher strength compositions rank fairly well on the basis of strength/weight. However, mild steels (say 1020) are relatively poor in strength/weight. This explains the poor record of steel containers in damage experience -- for a steel member to be as strong as a comparable aluminum member, it would need to be more than twice as heavy. However, the weight differential between steel and aluminum containers is not enough to compensate for the ratio effect. Steels in the 150,000 psi strength range would provide an advantageous strength/weight position without any penalty in cost/strength. However, the position reached in the evaluation is that steel's position becomes much more favorable when resistance to corrosion can be drastically improved. Superior coatings currently available (covered in detail in the maintenance analysis) would be more cost-effective than conventional paint. Inherent corrosion resistance is an even more attractive approach, for example by using COR-TEN or structural grade stainless steel. The former involves no cost penalty but the degree of improved performance in a marine atmosphere cannot be accurately predicted.

1.17 Sufficient analysis of structural designs was performed to enable an overall assessment of the efficiency of designs. Panels (designed to meet the uniformly distributed pressure requirement) have a greater depth, lighter weight, and therefore better efficiency when stiffened aluminum sheet is used as compared to FRP/plywood. The weight ratio is about 1:2, with the latter averaging about 3.2 lbs/sq.ft. Efficient design to resist the (pressure) bending requirement nevertheless makes aluminum panels subject to failure from concentrated loads. The thin sheets may be readily penetrated and the stiffening posts offer additional surfaces to be caught by external obstructions.

1.18 Maintenance analysis is covered to include procedures, facilities, and personnel. Maintenance costs are developed so as to provide an input to life cycle costs. Two completely independent approaches to maintenance costs produced closely correlated results. FRP/plywood containers have a clear advantage being on the order of $75 per year. Aluminum containers have a maintenance cost about twice as high and steel about three and a half times as high. Superior damage resistance is obviously the origin of the advantage. Steel has the additional requirement of continuous surface protection which generates a periodic repainting requirement. The subject of galvanic protective coatings is considered and it appears that their extra expense over conventional paint application is warranted in order to extend the life of the coating.

1.19 Life cycle cost analysis shows that FRP/plywood containers are the preferred type. Annual maintenance costs are roughly the same order as the annual amortization of purchase price. Aluminum containers are slightly lower in amortization due to small (favorable) differentials in first cost and in mean useful life. However, the 1:2 advantage of FRP/plywood containers in annual maintenance cost dominates the final result. Steel containers are clearly not competitive. Amortization of purchase price is highest (due to the shortest mean useful life) and surface protection adds substantially to the maintenance cost along with the repair component. The total annual costs for containers of FRP/plywood, aluminum, and steel types are found to be, respectively: $286, $345, and $524.

1.20 The cost analysis results conform to observations made during the field survey work. Many steamship lines are specifying (or planning to so specify in their next procurement) FRP/plywood containers in order to bring maintenance costs down. Those lines which have had FRP/plywood containers in service have generally found their performance to meet expectations. Steel containers rank poorest on the life cycle cost comparison and do not appear in the procurement plans of steamship lines. Those lines which operate steel containers generally have leased them to fill gaps in their permanent fleet. Some lines procured small quantities of steel containers for use while building experience in container operations but did not adopt the type as a standard for the line.

1.21 Nevertheless there is an opposite opinion in the field. A number of the leading lines in containership operations report that they are satisfied with the performance of their aluminum containers and have no plans to change. A rational explanation for this seeming anomaly can be found in the further analysis of costs. The ranges of uncertainty in costs show that there is substantial overlap despite the clear ranking on most probable values. In fact, at the lower-cost extremity of the band of uncertainty there is a cross-over and aluminum ranks higher. Undoubtedly these well-established container operators are in the lower cost region.

1.22 Sensitivity analysis of cost elements is included. In general the overall rankings are relatively insensitive to reasonable variation in the cost elements. For example, if the number of cargo shipments per year decreases by 50% aluminum and FRP/plywood close on each other but do not cross over. At lesser utilization, maintenance costs go down but not enough for the lower annual amortization of aluminum to dominate the resulting total annual cost.

1.23 The impact of cube and tare weight variation is enlightening. The results show that for typical shipments an increase of 10 cu.ft. can produce $7.20 of additional revenue per cargo shipment cycle. This amount of cube is approximately what an FRP/plywood container can gain over a stiffened panel type of aluminum container. Note that the revenue gain is about the same as the maintenance cost. This result further enhances the first ranking position of FRP/plywood containers. The case of those lines preferring aluminum containers should also be considered. In general, they use non-standard dimensions which provide extra cube and thus should have a lower frequency of cube limited cargoes. This would lower the revenue to be gained from an additional unit of cube.

1.24 Recommendations are provided by the Contractor on the basis of the conclusions reached. These are intended to contribute to the effectiveness of USAMERDC's continuing development of containerization. The subjects covered are: service duty and design criteria, design optimization (with particular reference to eventual prototype procurement), and operational flexibility features for containers in military applications.

Section 2

INTRODUCTION

Technical activity in connection with foreseeable development and acquisition of reusable shipping containers by the Army is being centralized at the U.S. Army Mobility Equipment Research and Development Center. Various projects are both in the planning phase and in progress. It has become apparent to the planners that a critical analysis of the state of the art in commercial containerization would expedite the Army's program. It is widely recognized that the accomplishments in the commercial field over the past decade have been extensive in scope and add a substantial degree of efficiency to the transportation of many commodities. It has been expected that the examination of these accomplishments would enable the military efforts to avoid unproductive technical approaches and to promptly focus attention on the critical problems requiring improved solutions.

2.1 Objectives

The objective of this investigation is the critical analysis of the state of the art in containerization as it presently exists in the field of commercial, intermodal freight transportation. The containers referred to are of the demountable and reusable van type. The investigation emphasizes performance of the containers under service conditions. In documenting the state of the art, the underlying cause and effect relationships must be developed to relate service experience with the technical features of design and materials selection.

2.2 Scope

A broad scope has been assigned to the investigation. The examination of operating practices includes all elements of the transportation system so that interfaces which influence container characteristics would become apparent. Thus, the characteristics of the transport vehicles, terminal facilities, and materials handling equipments were covered.

The technical aspects of container design are the main thrust of the effort. Materials of construction are a controversial matter at this time in the industry. The examination of materials has been extended over the field to include materials in current use on containers and also those in related fields which might contribute to advancing the effectiveness of container designs. Design characteristics is a subject closely related to selection of materials and has been covered to a depth sufficient to disclose the interrelations with materials and an assessment of the efficiency of the designs from a structures point of view.

In the commercial field the overall measure of the efficiency of the several existing container types can be in economic terms. All cost elements required to reach valid comparisons of full life cycle costs are included as topics of study.

2.3 Data Sources

A survey of the industry was planned as the major source of information on operating experiences accumulated thus far in container operations. The transportation operators include steamship lines, railroads, and highway carriers. Individual companies (including maritime activity on the East and West Coasts) and trade organizations were covered. The industry structure -- in common with the mode of operation currently prevailing in many other fields -- makes use of independent contractors for the performance of maintenance and for the leasing of equipment. These non-transportation organizations were also surveyed.

On the matter of the container supplier's point of view, a number of manufacturing companies were surveyed. The materials suppliers were included. The latter ranged from basic raw materials to semi-finished products, as for example, fiberglass reinforced plastics laminated over plywood into panels the size of a container side. The industry associations in this area also cooperated.

The acquisition of data from the industry was facilitated by the use of a comprehensive questionnaire. In some cases the questionnaire was executed in writing by the respondent and in other cases it was the framework for an interview.

The industry responded to the data request in a very cooperative way. However, both the transportation and manufacturing segments of the industry are highly competitive and some of the companies felt that certain disclosures might jeopardize their proprietary interests. They therefore omitted some items from their response and supplied certain others with reservation. Accordingly, this study contractor has treated the results of the survey as proprietary data and made no disclosure of the questionnaire data other than to the Government's Contracting Officer Technical Representative. However, the general trends of the industry that were gleaned from the analysis of the questionnaire responses do appear at various places in this report. There is no association of any company with any operating or manufacturing practice or data unless the information item is available from the open journals of the trade.

It may be noted throughout the report that a substantial body of technical information is building up in technical transactions and in trade journals. Wherever such information has been introduced into the report, the source has been cited. There is an exception to this referencing practice, however, in the section presenting the materials evaluation. Much of the data on properties of materials are readily available in widely used handbooks and industry brochures. The data presentations included in the section are the minimum for a self-contained evaluation of the candidate container materials. It has not been considered necessary to cite the source for each data item presented. Additionally, it should be noted that some variability exists in materials properties even when the material is fully defined. For example, for an aluminum alloy having an alloy and temper designation in accordance with the American National Standards system, there may be a variation in properties with the thickness of the stock or between the same material in sheet and extruded form. Steels are specified by their composition limits which have enough range to produce differing properties. Wood has an additional element of variability in that its moisture content effects its density and strength.

It had been hoped that a companion project to that being reported herein would produce additional data for the materials evaluation. Various specimens of materials which might have application as container panels are being subjected to experimental evaluation at USAMERDC. Tests have been devised to simulate handling abuse experienced by containers. Unfortunately the results have not become available in time to be included here.

SECTION 3

DESCRIPTION OF CONCEPTS AND HARDWARE

This section provides some essential background material on the concepts and the various hardware items comprising intermodal containerization as it is being applied currently. This material is a technical introduction prior to the more detailed study of the operator's utilization and environment of the next section, and the container characteristics in the succeeding sections. Since the economics of ocean freight transport influence a steamship line's operating decisions and equipment selections, some notes are included on freight rates and operators' costs.

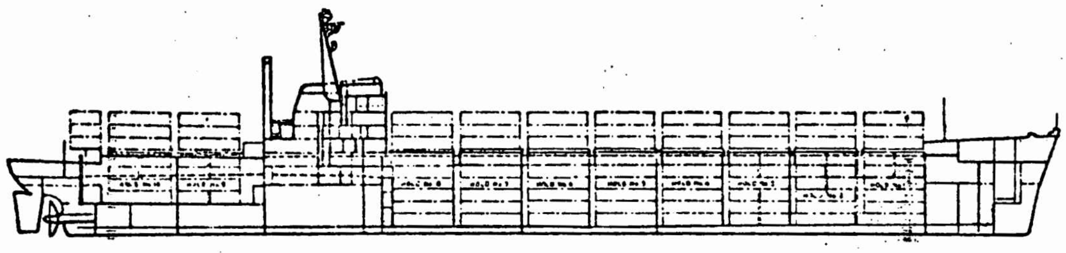
3.1 The Impact of Containerization

Containerization is basically the large scale unitization of cargoes by means of reusable, standardized boxes. There is considerable discussion in the field on just when the era of containerization began. The use of large vans has been traced back to the turn of the century. There is no point to be served in enumerating all the early efforts toward containerization. Certainly the concept is not new if we include the trend toward commodity unitization (as contrasted to break-bulk, or case-by-case, cargo handling). By the end of World War II, unitized loads on expendable or reusable pallets had come into wide use. Subsequently, the U.S. Army introduced its CONEX containers into service for a variety of freight transport applications.

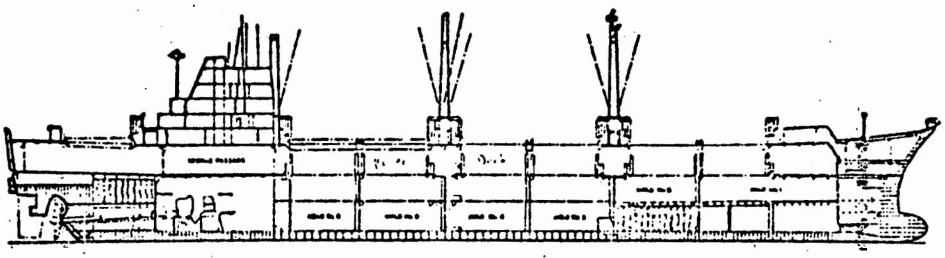
The standardization aspect of containerization is equally as vital to the success of this approach to cargo transport as is the use of large drafts. Standardization enables the arrangement of ships' stowage facilities, shipboard and/or shoreside handling gear, and connecting modes of transportation for maximum efficiency and speed in performing cargo transfers. Therefore, even though absolute standardization does not yet exist, the several large-scale commercial container operations have achieved standardization on their line to the point where intermodal transfers are expedited. The dual thrusts of larger scale unitization and improved intermodal transfers have thus converged in the present use of demountable, reusable vans.

The introduction of the first fully containerized ship into regular service is generally recognized as the beginning of the era of containerization. This was in October of 1957. The vessel, Gateway City, was operated by Pan-Atlantic Steamship Corporation, the parent organization of Sea-Land Service. Since then, Sea-Land has moved aggressively to expand its services, and as of early 1970 its fleet included 46 oceangoing ships and 35,000 containers. At this time, the major steamship operators are steadily increasing their containerized operations.

One of the most obvious results of the changeover to containerized cargo operations is in ship's characteristics. Whereas traditionally, cargo liners have operated most economically at speeds well below 20 knots, the high capital investment and reduced port time required by containerization have altered maritime cargo economics. Recently designed ships operate predominantly in the range of 22-26 knots. For example, the Mormacsea Class, which are combination roll-on/roll-off containerships, will have a cruising speed of 25 knots. The American Lancer Class of U.S. Lines will emphasize capacity -- carrying 1178 containers of the standard 20-ft. size. (Reference 3-1 contains additional data on distinctive current ships.) Inboard profiles for these two ships are shown in Figure 3-1. About one year ago, Sea-Land announced contracts for a group of containerships having a speed of 33 knots and carrying 1082 containers of 35-ft. and 40-ft. lengths.



Non-Self-Sustained Container Ship - American Lancer



Roll On/Roll Off Type - Mormacsea

Figure 3-1. Representative Advanced Merchant Liner Types

A summary of the extent of acceptance of containerization is presented in the figures of Table 3-1. These quantities are for American operators only. The total for all foreign operators is about equal to the aggregate of the domestic container population. It may also be noted in the table that a substantial number of units do not conform to the presently established dimensional standards. For the foreign units, the standard 20-ft. unit is dominant at about 70% of the total. Estimates on production quantities for the next several years have been prepared by the Truck Trailer Manufacturers Association. Their estimates, which they consider conservative, are: 20,000, 21,600, and 23,300 units (in roughly the same mix of sizes as the present population) for the years 70, 71, and 72 respectively.

TABLE 3-1

CONTAINER POPULATION IN PRESENT USE

Size	Length (feet)	Height (feet)	Width (feet)	Approximate Quantity
Standard — 20 feet	20	8	8	40,000
Oversize — 20 feet	20	8.5	8	2,500
Matson	24	8.5	8	8,000
Sea-Train	27	9.5	8	2,500
Sea-Land	35	8.5	8	30,000
Standard — 40 feet	40	8	8	4,000
Oversize — 40 feet	40	8.5	8	24,000

3.2 Economic Motivation Toward Containerization

A few observations on the forces driving the transportation companies toward the changeover to containerization will show some of the economic factors at work. The change in ships' characteristics previously noted was related to the reduced port time required for containerized freight operations. However, the ship operator's costs must be examined. A typical breakdown of costs prior to changeover to containerization is shown in Figure 3-2, taken from a Matson study (Reference 3-2).

These costs led that line to its decisions on the most economical size and required quantities of the van containers to be introduced into its fleet. The operating costs cover the movement of cargoes from

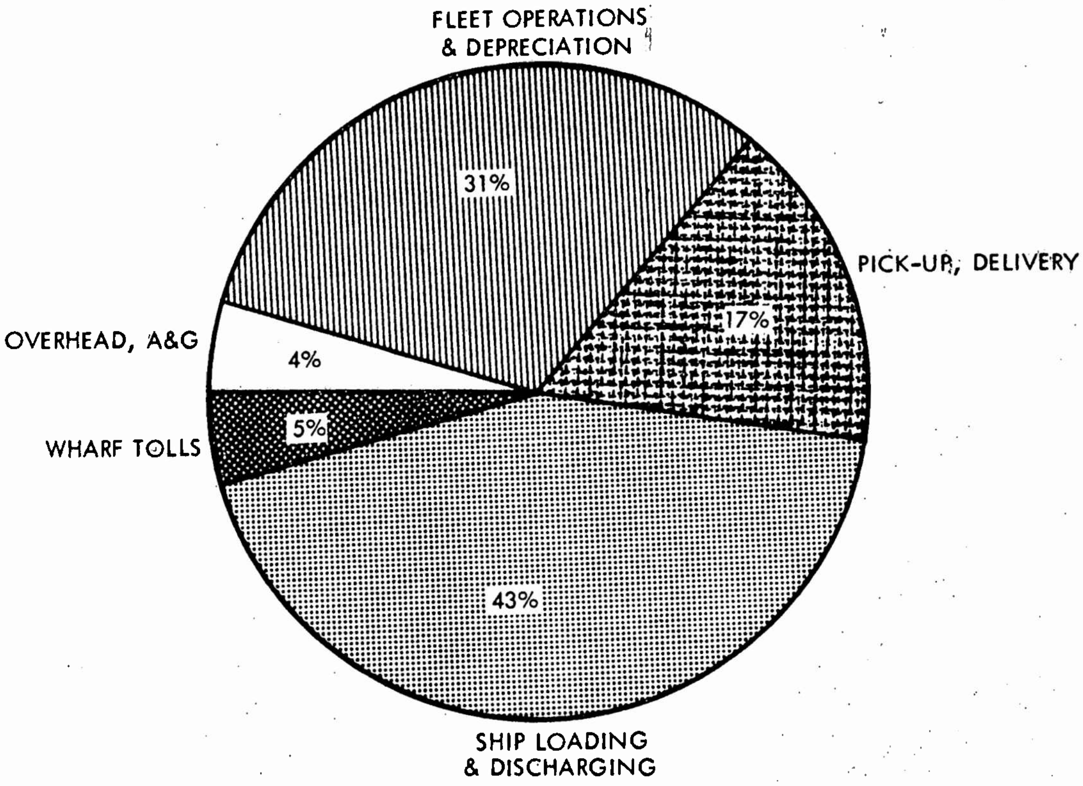


Figure 3-2. Breakdown of Ocean Freight Costs

point of origin in the port city area to the destination point in the far port area. The striking feature in the figure is that the category with the largest cost includes transferring the cargo aboard ship and off-loading operations. This reflects the steadily increasing wages paid to longshoremen with little or no increase in productivity. The Matson study was performed in 1958. Without mechanization in some form to improve productivity of longshoring, the results at this time would show an even larger proportion of costs devoted to cargo transfer. (The Matson study, as reported in the open literature, contained only relative proportions of cost for obvious reasons of safeguarding proprietary information.)

A very comprehensive study on costs of maritime shipments by Ernst and Ernst (Reference 3-3) also shows that cargo handling is the dominant item. Table 3-2 presents a brief sample of data from the referenced report which are applicable to the North Atlantic trade. The cost range is due to variations in the cost element. For example, wharfage and tolls are different in each port and cargo handling costs depend on the rate for each commodity. These data pertaining to 1964 are in general agreement with the Matson data. In fact, for some cases the ratio of cargo handling costs to total costs exceeds one-half. The cost range shown in the table for typical shipments contain

TABLE 3-2

RANGE OF UNIT SHIPPING COSTS

North Atlantic Trade Routes - Various Ports (Per Measurement Ton)

Item	Vessel	US (C-2) Cost Range	US (C-4) Cost Range	Norwegian Cost Range
Vessel Costs at Sea	w/subsidy	3.54	3.84	-
	w/o subsidy	6.09	6.48	4.23
Vessel Costs in Port plus Port Costs	w/subsidy	3.69 - 5.98	6.74 - 9.98	-
	w/o subsidy	5.49 - 6.87	10.94 - 16.91	5.71 - 11.60
Cargo Handling Costs	US Ports	9.28 - 13.56	7.88 - 11.64	8.58 - 9.79
	Foreign Ports	2.34 - 2.34	2.93 - 3.51	2.34 - 2.34
Total Costs	w/subsidy	18.85 - 24.42	21.97 - 28.39	-
	w/o subsidy	23.20 - 29.65	28.81 - 37.96	20.86 - 27.96

many variables, such as the type of packaging (cartons and bundles run higher than crated, bagged or drummed commodities) and the ports at which goods are loaded (Baltimore and Philadelphia are significantly less expensive than New York). The point is apparent, however, that cargo handling costs needed to be attacked to reduce the costs of ocean freight shipments.

The manner in which containerization contributes to lower shipment costs can be appreciated by examining only a few data from studies of the Maritime Cargo Transportation Conference of the National Academy of Sciences (Reference 3-4). The data show how increased capital investment and reduced application of manpower affect the cost of ocean freight movements. Figure 3-3 indicates that various degrees of mechanization have reduced unit cargo delivery costs, even though depreciation and interest are up -- a reflection of the investment in physical plant. Note that while the investment is approximately doubled, there is a reduction in cargo delivery costs of about 10%. While the reduction does not appear to be great, it should be realized that there is no optimization in that particular part of the analysis. A ship's speed of 14 knots was a fixed condition, and the results apply to an interport distance of 5,000 miles. For that particular ship, the cost reduction is greatest at even shorter distances. Other conditions of the analysis are that the base rate for break-bulk cargo handling is 18.75 long tons/gang-hour (average adjusted rate including nominal delays) and the fully containerized cargo operation takes place at a relative cargo handling rate (RCHR) of 8.0.

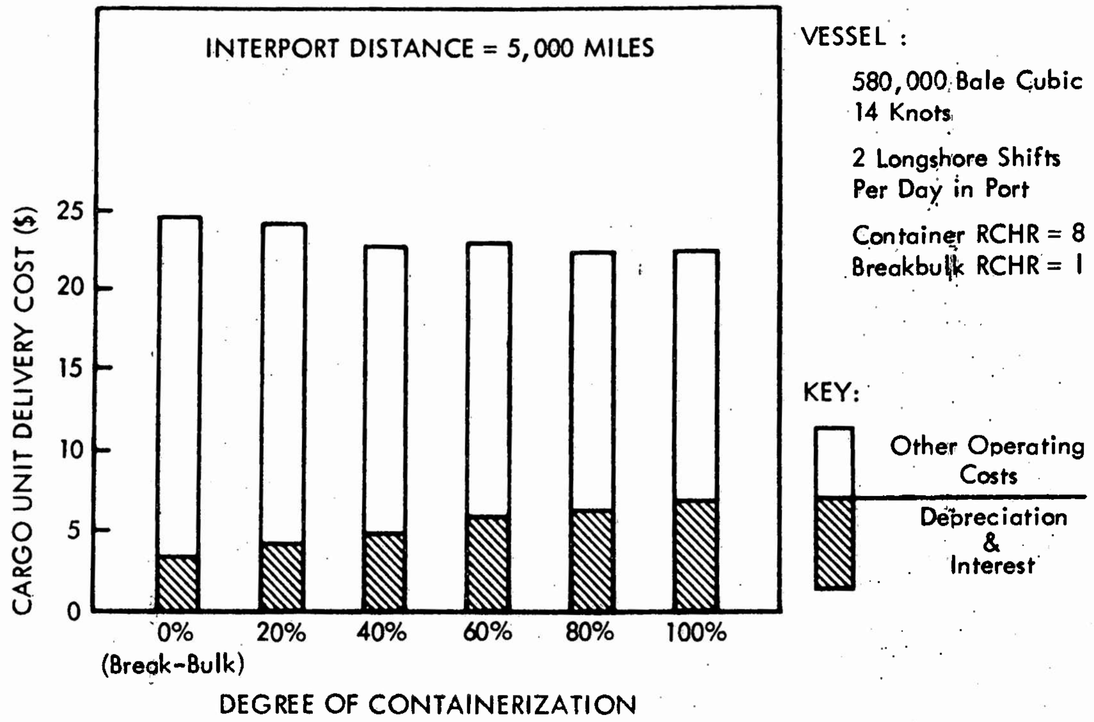


Figure 3-3. Containerization Effect on Shipping Costs

The reasonableness of the example cited in Figure 3-3 may be confirmed by further reference to the Matson data. Again, the conditions are peculiar to a set of operating conditions existing on a single line's trade. Nevertheless, the slope of cost reduction as the container capacity of the fleet increases in Figure 3-4 is similar in order of magniture to the cost reduction as the degree of containerization increases in Figure 3-3.

An important point that can be drawn from these data is that containerized freight movements show a cost advantage over break-bulk operations, but it is not so great as to allow any margin for needless cost elements. The containers themselves account for an appreciable part of the extra costs of the changeover. The cost of the containers can be estimated as follows. A cargo liner with a capacity of 800 containers (of the standard 20-ft. size) requires a minimum of 2,000 containers. The ratio of containers required to ship capacity lies between 2.5 and 3.0, depending on the inland movement distance and delay time at the port and shipper's facility. Thus, with an approximate price of $2,000 per container, the cost of a ship complement becomes $4 million. Since the useful life of the containers is roughly half the ship's useful life, that sum must be doubled. The result is that the cost of containers very nearly approaches the cost of ships. This estimate tends to support the values shown of Figure 3-3 where the depreciation and interest charge doubled for a fully containerized

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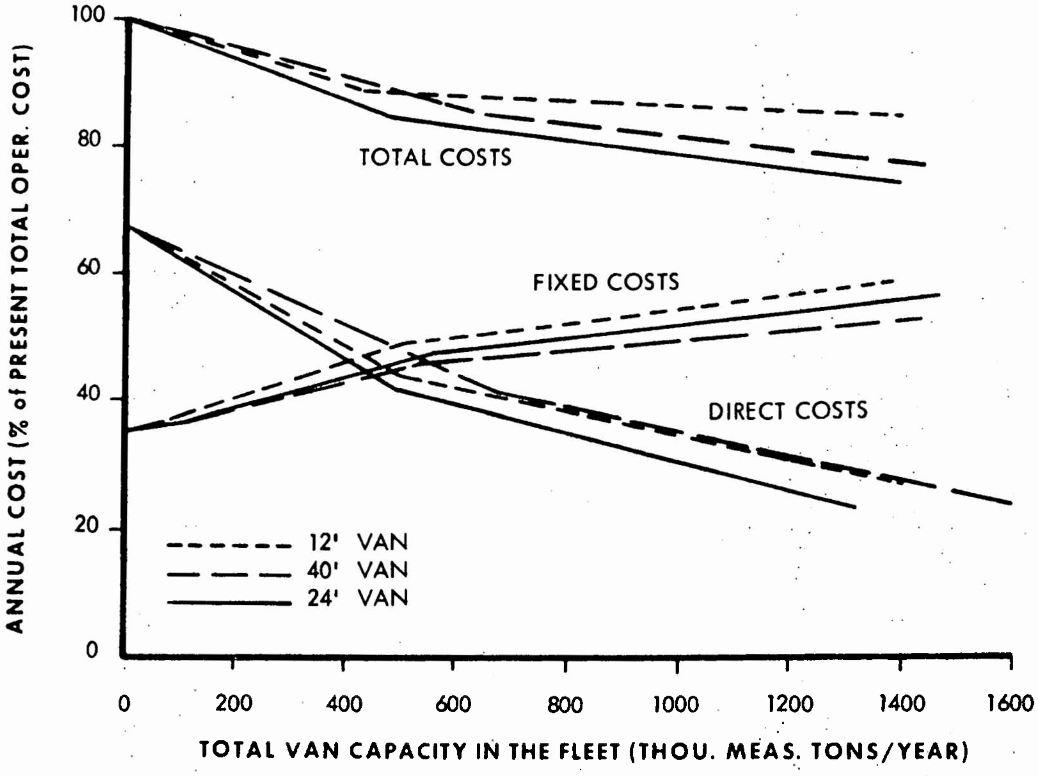


Figure 3-4. Variation in Steamship Operating Costs with Container Capacity

operation. This is an obvious explanation for the steamship lines' emphasis on keeping the cost of containers to the lowest possible level. This study, therefore, includes full consideration of the cost problem with respect to both acquisition and maintenance.

3.3 Container Facilities

Ports which can handle container shipments efficiently are distinctly different from the conventional general cargo facility. Containerships must have a fast turnaround capability. This is true whether the actual relative cargo handling rate is 8 or some similar number. Outbound cargoes must be immediately available, and inbound cargoes must be quickly offloaded to nearby parking spaces. The need for marshalling space for the shipload of containers leads to construction of port facilities with large open spaces close to the ships' berths. In some yards, the required space is held to a minimum by stacking the containers. However, Sea-Land, the pioneer line in containerization, attempts to maintain a chassis for each container not aboard ship, and to couple the container to its chassis immediately as the unit is offloaded from the ship. This mode of operation requires the maximum clear area at the port. The general arrangement at such a port facility is shown in Figure 3-5, a view of Sea-Land's operations at the Port of Oakland. Their Port Elizabeth arrangement is quite similar.

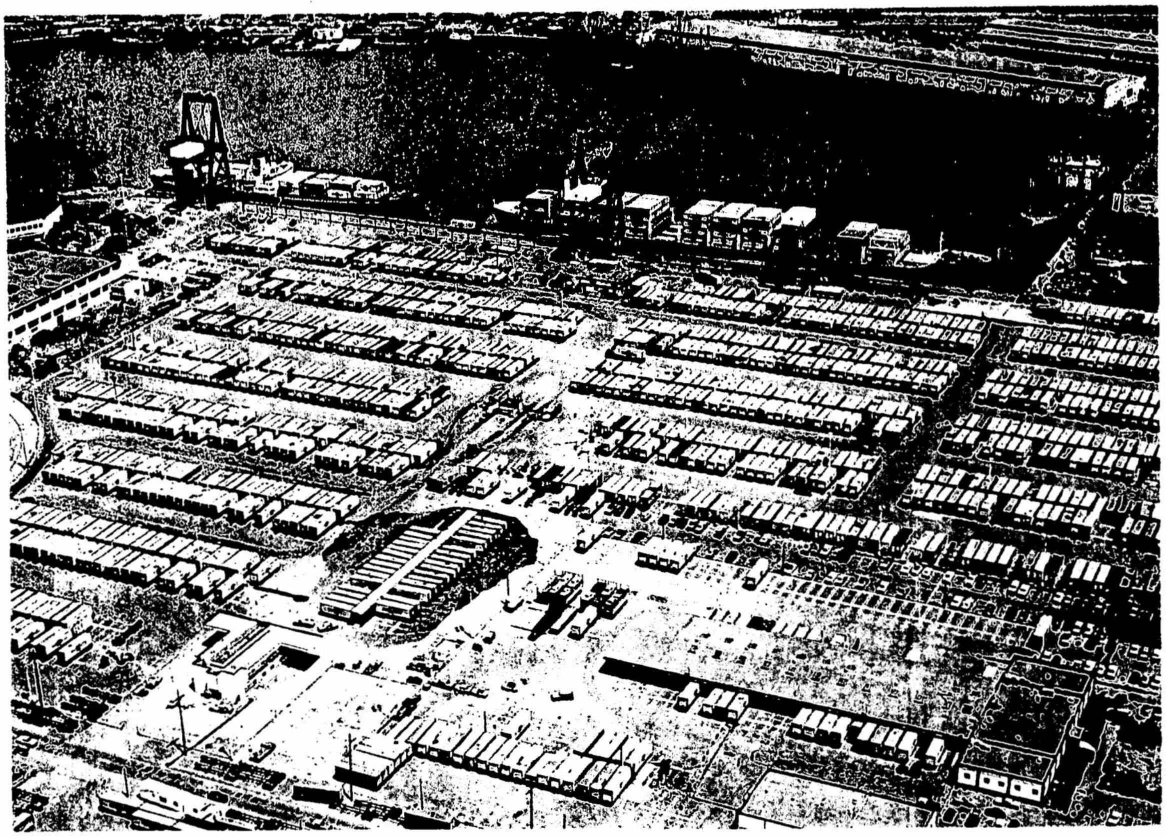


Figure 3-5. Container Facility at the Port of Oakland

It may be noted in the figure that the containerships are of the non-self-sustaining type, and that shore-based gantry cranes are used. These large cranes can handle 55,000-pound loads at a cycling rate of 1.5 minutes (the cycle includes both an off-loading and an on-loading). Rail mounting is used, and the cranes can quickly reposition themselves along the length of the ship. A close-up view in Figure 3-6 shows the spreader frame engaged to the container by automatic twist locks.

Many transfer operations are less highly mechanized. In these cases the container is landed on a dock by either a shore-based or deck-mounted gantry, conventional ship's heavy-lift gear, or shore-side mobile crane. The container is then engaged by transfer equipment such

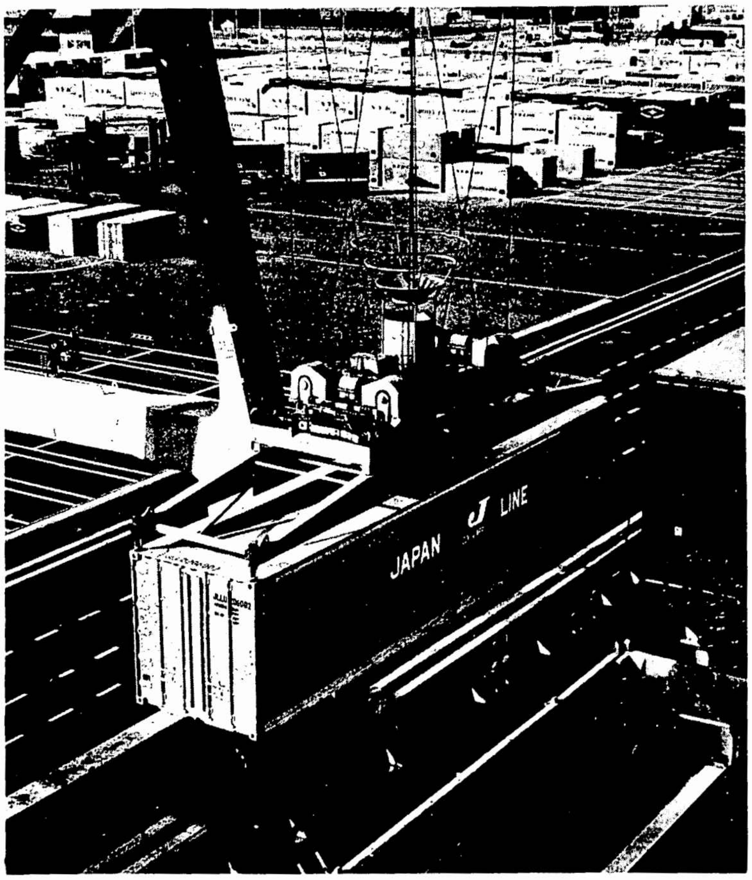


Figure 3-6. Container Handling by Fully Mechanized Gear

as a straddle carrier with an overhead spreader frame or a lift truck which may be either a side loader or front loader, and may use either an overhead spreader frame or lifting tines. See Figure 3-7 for an example.

3.4 Container Brief

The sheer number of containers makes the optimum selection of container characteristics of the utmost importance to transportation companies. The basis for incorporating these characteristics into container design is developed in succeeding sections. At this point a brief introduction is provided.

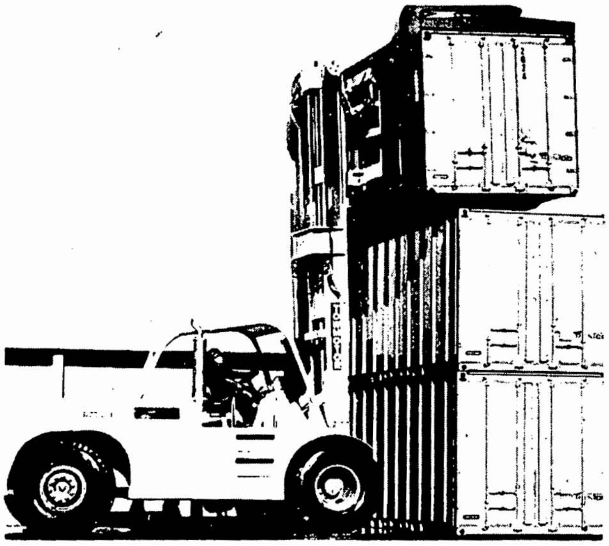


Figure 3-7. Typical Handling by Lift Truck

Containers are mostly produced by the companies of the truck-trailer industry. Their existing product line and manufacturing techniques put them in an advantageous position to move into container production. Nevertheless, there are some vital differences between containers and trailers. The most obvious difference is the demountable character of a container. When in the separated condition, the container loses the strengthening and rigidizing contribution of the chassis.

The loading conditions encountered in the various operating modes impose severe structural requirements on containers. Most of these conditions are not experienced by trailers. Several loading conditions which govern the design of containers are discussed below.

Stacking. Containers may be stacked six high in cells of containerships. Lateral restraint is provided by the vertical cell guides of the ship. The load force is applied at the corner fittings.

Lifting. Lifting may be performed by attaching lifting devices to the top corner fittings (most often the case) or the bottom corner fittings. Forklift pockets in the lower members of certain containers are also provided. Lifting a container at twice its rated capacity in order to account for dynamic amplification of stress response is a structural requirement.

Racking. Side forces are applied to the upper end frame members and resisted at the lower end frame members of the container due to inertia forces of stacked containers on ships' weather decks where guiderails do not provide continuous lateral restraint. (In this connection, it may be noted that in nearly all stowage arrangements of containers aboard ship, the long axis of the container is aligned with the ship's longitudinal axis.)

Restraint. Forces are applied in both directions through the container's bottom structure as a consequence of transient motions of the transport vehicle and the inertial reaction of the loaded container.

Wall Pressure. Forces are applied to the sidewalls and both ends of the container due to the bearing of the contents on the walls as the loaded container is accelerated under ship motion, retardation of rail cars, or the like.

Floor Pressure. Forces are applied to the container floor and its supporting structure due to the entry of a loaded warehouse lift truck.

Roof Pressure. During transfer and lashing operations aboard ship, there are times when the container roof must be used as a platform. This has led to a requirement that the roof be capable of supporting the weight of two men.

In the few cases where a loading condition is common to both container and trailer operating modes (for example, wall pressure), the container can be expected to experience a greater amount of stress. In short, the conditions of container service are rigorous, and any tendency to regard intermodal demountable containers as mere packing boxes is not justified when the details of the operational environment have been examined carefully.

With this background, it is possible to appreciate some of the features of conventional design practice of the container manufacturing industry. The main structural members are shown in Figure 3-8.

End Frames. End frames are provided at both the front (A) and rear (B). These generally are welded assemblies of steel members incorporating corner castings (C) with a standardized pattern of handling sockets. The stacking and racking requirements lead to fairly husky material thickness in end frames, and 1/4-inch material formed into a box section is a common design solution. Further details are contained in Figure 3-9 which shows a typical cross-section of a vertical member of the end frame.

Longitudinal Rails. Side rails (D, E) running longitudinally along the top and bottom of the container join the two end frames together and additionally mount the side panels (F). These members are either steel or aluminum, with the latter currently being the preferred material in the industry. Most of the rail to frame joints are

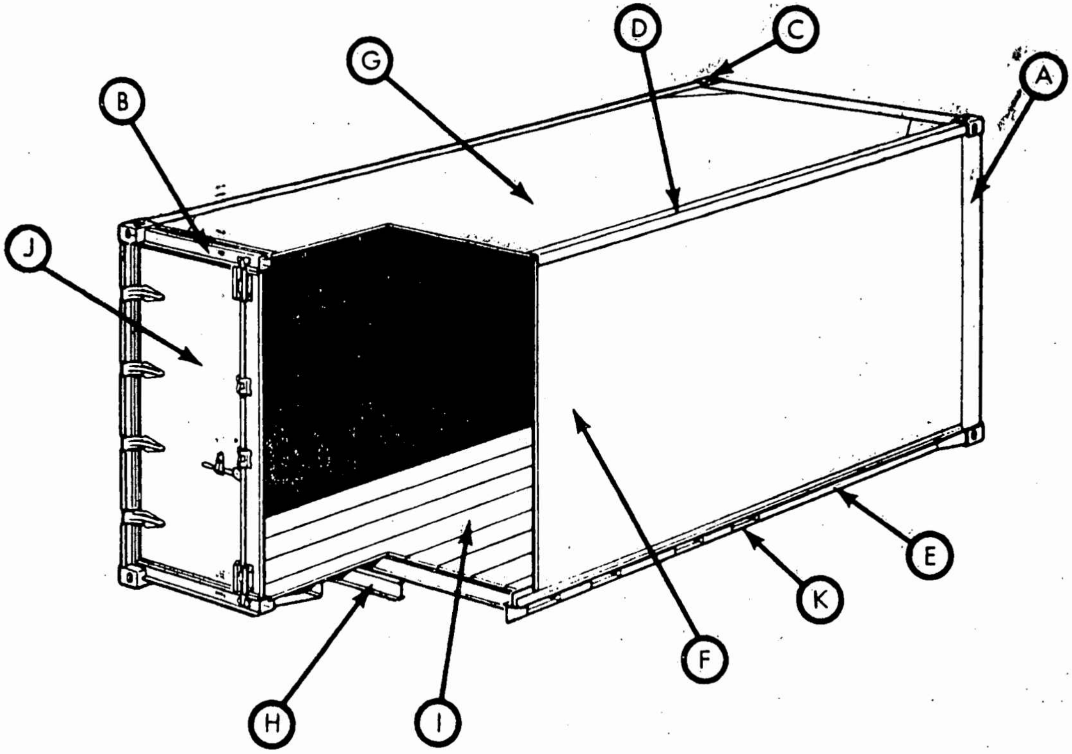
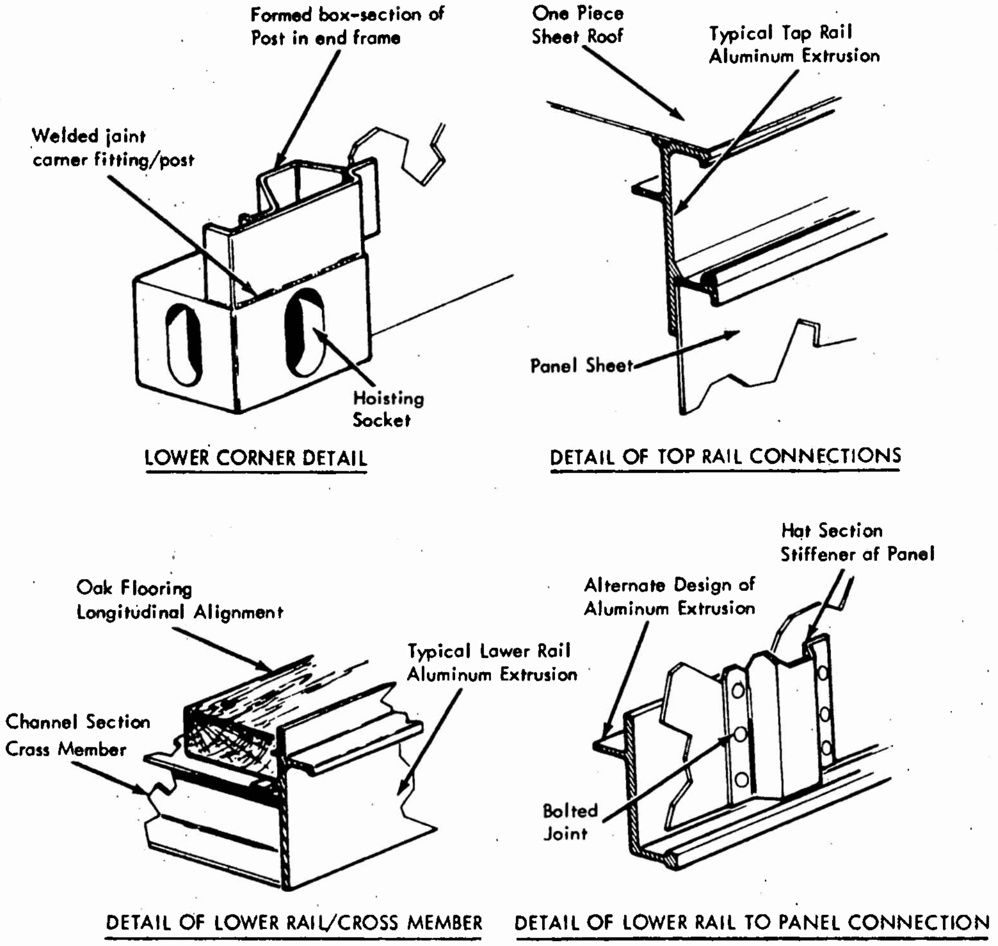


Figure 3-8. Container Structural Features

by bolting. The figure on details (Figure 3-9) also shows a typical section of an extruded aluminum type of rail.

Side Panels. The end frames and rails provide a support for the attachment of panels (F), basically sheet material. In the case of aluminum side panels, sheet-post construction is used, with the posts being of a hat-section type as shown in the details. Posts are spaced, between one and two feet apart, and may be either exterior or interior, depending on where the operator desires to have the flush surface. Sheet material thickness of 0.062 inch is common, with the weight being 0.89 lb./sq.ft. The weight of stiffeners is quite variable, but a value of 0.92 lb./running ft. has been computed for a representative extruded section. With posts spaced two feet apart, the weight of panel material is 1.8 lbs./sq.ft. Aluminum panels are often augmented by a plywood interior liner which may be either half or full-height. With a half-height liner, the average panel weight is approximately 2.2 lbs./sq.ft.

FRP/plywood panels consist of a plywood core with a fiberglass reinforced plastic overlay on each face of the panel. Most often, the fibers are in a woven roving form -- i.e., untwisted in a fabric, within a polyester matrix. Common thickness of plywood stock is 3/4



LOWER CORNER DETAIL

DETAIL OF TOP RAIL CONNECTIONS

DETAIL OF LOWER RAIL/CROSS MEMBER

DETAIL OF LOWER RAIL TO PANEL CONNECTION

Figure 3-9. Some Container Design Details

inch. Total panel thickness is usually in the range of 0.84 to 0.88 inch. The weight of such a sandwich panel is in the range of 3.0 to 3.2 lbs./sq.ft., depending on the proportion of glass fiber in the overlay and the thickness. The panels are joined to the frame by riveting.

Steel panels are also used -- primarily on containers from foreign sources. Steel container sheet material is usually rigidized by corrugation, and separate posts are not added. Welding is used as the joining means. A typical design employs 18-gauge (.049 inch) sheet stock with corrugations of about 1.5 inches depth. Such a panel fabrication weighs about 2.6 lbs./sq.ft.

Roofs. The roof (G) is generally of the same material and construction as the side panels, with only a few exceptions. Roof bows of aluminum units are often joined with adhesives. One-piece sheet material is preferred in order to maximize resistance to water entry from above.

Bottom Structure. The understructure and flooring transfer loads induced by deadweight and inertial reactions of the contents to the side rails. The cross members (H) are formed channels or extruded shapes with a depth on the order of 5 inches and a thickness of about 0.188 inch, if aluminum. Steel is also used for these members, generally when the side rails are of steel. The deck surface (I) is usually of oak or softwood floorboard, shiplap jointed, and between 1-1/8 and 1-3/8 inches thick. Plywood is also used for flooring, in which case an RFP overlay with a silica sand finish may be applied. See the figure on details for typical forms.

Doors. Doors (J) are most frequently of heavy plywood clad with metal faces, referred to as plymetal. The thickness of the composite is in the range of 0.75 to 1.0 inch, with the face material being about 22 gauge (0.031 inch) if steel and .040 inch if aluminum. Sandwich fabrications for doors may also have an aluminum exterior and a steel interior, where the steel is not exposed to a highly corrosive atmosphere and at the same time resists the forces and abrasion of cargo impacting the end wall. Doors are generously proportioned for the further reason that when firmly engaged to the end frame, they significantly contribute to the container's resistance to racking forces. Thus locking bars, either one or two per door half, are securely anchored in keepers on the door and in camming locks on the end frame. In so-called anti-rack hardware these locks restrain the bar end from play in all directions. Hinges complete the assembly.

Handling Provisions. Standardized corner fittings (C) may be seen in Figure 3-8. These fittings have elongated sockets on top to which are engaged connecting fittings of the spreader of a crane or mobile handling unit. It may be noted in the detail in Figure 3-8 that there are protective plates in proximity to the top corner handling fittings to guard against damage when spreader drops on a container top misaligned with the fittings. Similar sockets are on the under surface of the bottom corner fittings to provide restraint when containers are on deck or on a land vehicle. Locking is performed by twisting of the male element either manually or by remote actuation. The container's corner fittings also have openings on their sides to enable hoisting by hooks and slings at both the top and bottom corners. Additionally, forklift pockets (K) are provided to permit handling from the bottom by the tines of lift trucks. This mode of handling is losing favor, and as a consequence pockets in the understructure of containers are becoming relatively rare. Note on Figure 3-8 that four pockets are shown in the typical design. Usually the outer pockets are aligned with the forklift lines of a high capacity lift truck capable of handling a loaded container. The two inner pockets are used by lift trucks capable of handling only an empty container.

3.5 Special Purpose Container Types

The most frequently used container type is the dry, general cargo container as described in the previous section. These comprise over 95% of all containers in use, excluding refrigerator types. There are variations from the design of this type to make containers more suitable to some cargoes, which do not adapt well to the standard van. The alternate types comply generally with standardization requirements on dimensions, handling provisions, and load carrying capability.

Open top containers differ from the standard vans by using a canvas closure over the top to protect the contents from the elements. The advantage of open top containers is that cargoes which are unsuited to loading into the container by forklift can be lowered in by hook from overhead. Long lengths of lumber are an example. Specially designed containers for the transport of automobiles have structural similarities to open top units and are related in function to highway automobile transporters.

Half height containers are inherently open top since they would not have adequate clearance for loading otherwise. Their advantage is that, in the case of very heavy cargoes, for example structural steel shapes, they avoid the loss of cube that would result from the use of full height containers. They fully conform to dimensional standards when two half height units are stacked.

Tank-type containers enable the efficient transport of liquids in small quantities. Typically, 5,000 gallon capacity tanks are mounted within a framework which satisfied the dimensional and load carrying capacity of the standard twenty-foot container. Provisions are included in most designs to enable flamable liquids and various chemicals to be transported safely. Most tank-type containers are suitable for transporting some bulk solids, a typical example being plastic pellets. See Figure 3-10 for an example of the structure used to enframe the tank.

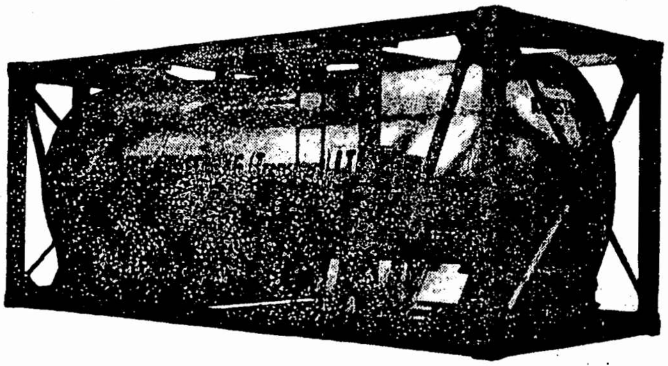


Figure 3-10. Tank-Type Container

SECTION 4

OPERATIONAL UTILIZATION AND ENVIRONMENT

A full appreciation of the problems facing the operators, i.e., the transportation companies, is the necessary first step in a critical examination of the state-of-the-art in containerization. This is not to suggest that the operators have had a completely one-sided influence over container characteristics. The container manufacturers have a traditional approach to design and this has proven to be resistant to any drastic change. However, the operators deal with the container suppliers through specifications and sooner or later these specifications will reflect the attributes of a container which can be expected to provide the operators with a least cost solution.

The transportation analyst charts movements of cargo with deceptive simplicity. While this section takes such charting as a point of departure, it very quickly becomes necessary to recognize the infinite number of variations that can be encountered in attempting to describe utilization and environment that containers will experience in operation. No two steamship lines have identical conditions. There is variation between ships, handling facilities, port operations, weather and seas on the various trade routes, and the cargoes which are stowed in the containers. It would be a task of insurmountable magnitude to collect precise statistics on all aspects of utilization and environment. Nevertheless, through the systematic questionnaire survey of operators -- and their fine cooperation -- it has been possible to obtain the operational descriptions to at least a first approximation.

4.1 Transportation System Functional Description

The functional description of the transportation system identifies the movements and transfers which involve the container. The various interfaces become evident when considering the total system. Despite the overriding importance of the sea transport mode, a general format is developed which includes all surface transport operations.

Network diagrams indicate the possible flows of cargo within container operations. It should be realized when using these diagrams that no particular sequence or mix of operations is implied. Each diagram illustrates the various flow paths which are possible and which are most likely to occur within the total system.

Consider the top-level network diagram of an operating system as shown in Figure 4-1. The diagram consists of a series of <u>links</u> and <u>nodes</u>. The links represent space-time trajectories of the container. The arrows on the links indicate whether the flow is uni- or bi-directional. The nodes represent positions where the container "trajectory" may change in terms of transport mode, direction, and the like. Depending on the level of breakdown of any diagram, a typical node might represent a port terminal or railhead. In the functional diagram illustrated, the main point is the movement of a containerized shipment from a point of origin to a point of destination. This involves two or more nodes and one or more links as shown in the figure, depending on whether any intermediate node points are involved. Note that the links are bi-directional such that the origin can be the destination point and vice versa.

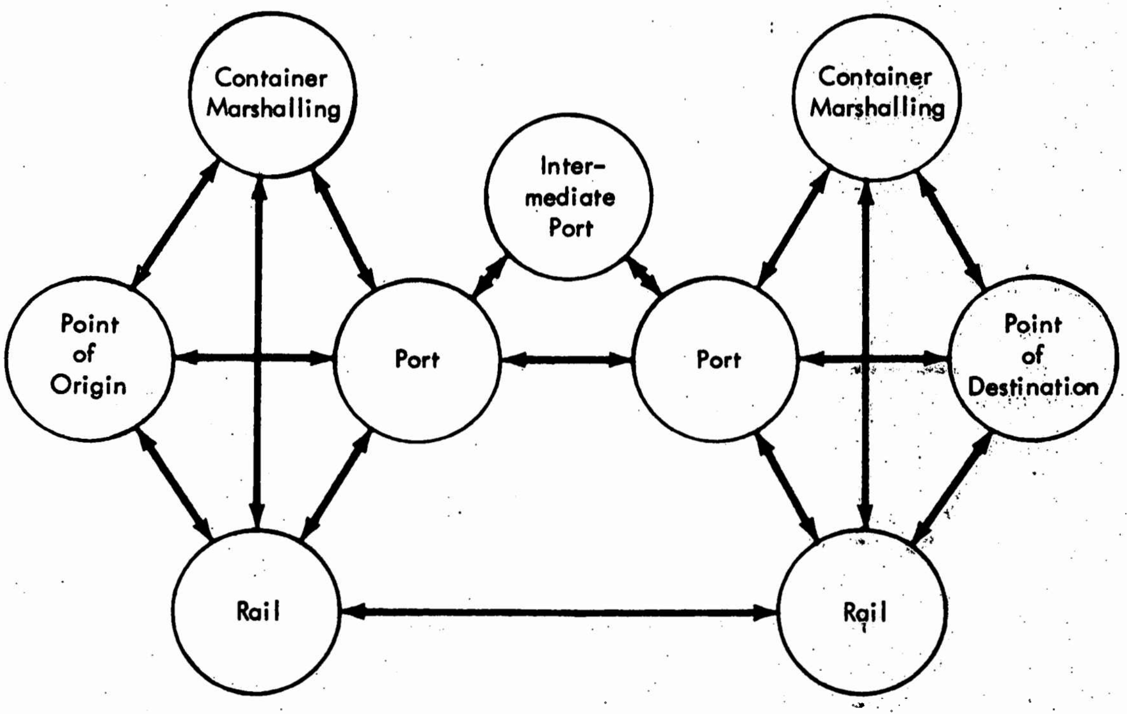


Figure 4-1. Top-Level System Network Diagram

At this first-level view of the system, the nodes represent terminals within the system and the links represent modes of transportation between the terminals. A terminal is any group of facilities, all located within the immediate vicinity of one another, which provide for transfers between transport modes, storage and other related services to the container and its cargo throughout the system. The major modes which connect the terminal are the sea and surface modes.

Several kinds of terminals may be identified. First, there is the port terminal which provides the crucial interface between the sea and surface transport modes. The ship operator is the dominant operator here and usually coordinates the interface activities. A rail terminal is controlled by the railroad operator and is generally independent of a port or other type of terminal (although in past periods many railroads were likely to have operated port terminals). A marshalling yard terminal may be in the system, inland of any port terminal, and is essentially used as a classification and storage yard for the containerized freight. The point of origin and point of destination may be the shipper's loading facility or it may represent a source for the consolidation/breakdown of the cargo in the container. This type of terminal could be controlled by a freight forwarder or shipper who handles large amounts of containerized cargo.

4.1.1 The Cargo Shipment Cycle

The term container cycle is widely used in the transportation field but without a universally acceptable definition. In some trade operations the node-node combination is very simple, for example port to port, and the tendency is to regard a round trip as a cycle. However, this is not the general case. In some other trades the movements are not on well-regulated, repetitive operations and a container may not even return to its point of origin. Therefore, we define a cargo shipment cycle as follows:

> The cycle consists of all transfers (nodes) and space-time movements (links) to transport a shipment of cargo of container lot size from its origin to its destination. The origin and destination are the points where the cargo is stowed in and unloaded from the container.

This definition is obviously oriented to the movement of the container rather than the cargo since a cycle commences when the cargo is stowed into the container. Less than container lots (LCL) of cargo may be moved in various ways to the point where consolidation into container lots takes place.

This definition is of more than passing interest since it serves as a basis for normalizing the utilization data and the maintenance cost findings on containers. However, the shipment cycles have an extreme amount of variability in such important aspects as the elapsed time on rail carriers and at sea, the frequency of handling operations and the type of handling.

In terms of the sea transport mode and its interface with the port and its facilities, the variation in the character of the cargo shipment cycle is a direct function of the individual trade route and its associated characteristics. The trade routes between U.S. North Atlantic ports and ports in the British Isles and Atlantic Europe offer several different types of service. In one case, a service consists of weekly sailings between New York and Rotterdam, characterized by the small number of ports of call on the voyage and a high frequency of Atlantic crossings. Here, the major ports, especially on the European side, are serviced via ship feeder-lines to and from smaller ports. On the other hand, other services on the route consist of calls at several ports on one or both sides of the Atlantic (Baltimore, Philadelphia, New York, Bremen, Hamburg, etc.) with less frequent Atlantic crossings. This difference in the services directly influences all the factors of the cycle.

Another factor influencing the cargo shipment cycle is the trade route location. Trade Route 1 between U.S. Atlantic and South American East Coast ports (New York, Philadelphia, Baltimore, Buenos Aires, Montevideo, Santos, etc.) affects the shipment cycle differently than a North Atlantic service with an equivalent number of port calls and voyage length. The percentage of containerized cargo on the North Atlantic route is high, and is usually transported in new or fully converted containerships specifically designed to transport containers in the most efficient way. In addition, the handling of the containers by mechanized equipment such as ship- or shore-based gantry cranes with automatic spreaders and the like is usually the case.

However, on Trade Route 1, where much less of the cargo is containerized, conventional break-bulk cargo liners with deck stowage of containers, or partially converted ships with one or two converted container holds are used. The container may be handled by the ship's conventional heavy lift gear with ordinary hooks at ports underdeveloped in terms of container operations. The other handling equipment available for transfer of the container to another transportation mode or cargo unloading area is usually barely adequate for the intended use. Additionally, the inexperience of the personnel at such ports leads to rougher handling and more frequent handling.

The interrelation between the cargo shipment cycle and the top-level system network diagram is now apparent. The cycle may be traced through flow paths of transport and terminal operations functionally illustrated in Figure 4-1. Within each operation there are environmental exposures, applied loads on the container due to handling and transport, and interfaces with cargo characteristics and material handling units.

4.1.2 Breakout of Terminal Functions

The terminal nodes of the network diagrams contain the handling operations which must be examined in detail. The terminal is comprised of facilities established to perform specific tasks within the terminal area in the form of equipment, general purpose and specialized structures. A variety of these facilities are shown in Figure 4-2. From the point of view of functional analysis, the terminal (which was considered a node on the top-level diagram) also contains links and nodes.

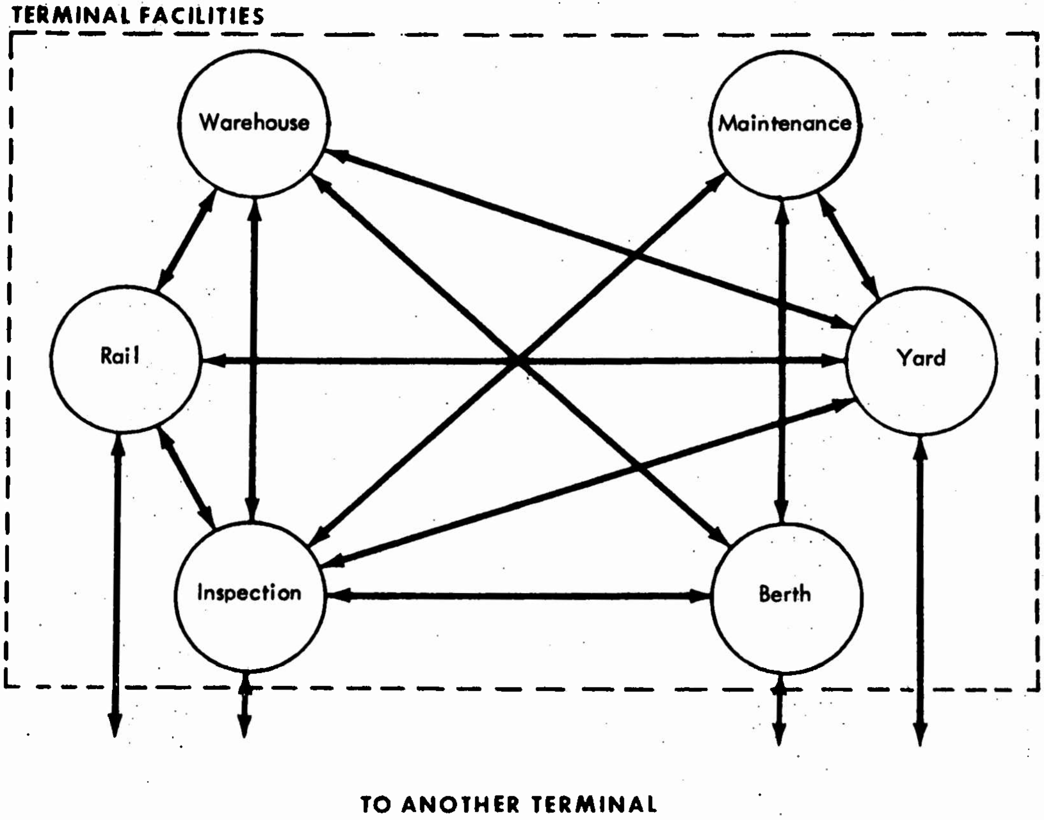


Figure 4-2. Functional Breakout Within a Terminal

The links in Figure 4-2 are of two kinds. Those existing between a facility of one terminal and that of a different terminal are the transport modes identified at the top-level. The other inter-facility links are identified as transfer modes. Transfer is the movement of a container via a material handling equipment within the terminal area. Since all facilities within a terminal area are within the immediate vicinity of one another, any "transport" distances involved will be small in comparison to the inter-terminal distances encountered. The transfer links in Figure 4-2 indicate that the inter-facility transfers are bi-directional and that any node-node combination is possible.

In addition to the transfer function identified above, a second and much more subtle function of the system can be discerned here. Each of the facility types previously listed, especially maintenance and yard, at least implicitly infers some period during which the container is not "moving," but rather is "waiting" (e.g., waiting for cargo at the warehouse, waiting to be repaired at the maintenance facility). Thus, there is a station function of the system on the container whereby the container is not specifically involved in a transfer or transport mode. As will be illustrated shortly, several types of system station modes with respect to the container can be identified.

A third level functional block diagram is presented in Figure 4-3. In addition to the inter-terminal function (transport), it shows "transfer" as both an inter- and intra-facility function, and seven other functions derived from the second-level "station" function. Each of the station functions is further described by the following:

- Stow/Unload Cargo -- the loading and unloading of cargo into and out of the container at some consolidation or breakdown point such as a warehouse;
- Park -- the stationing of a container, empty or loaded, for a period of time in a marshalling or storage yard to wait for transfer, transport, repair, and the like;
- Restrain -- the function of securing the container to some part of the vehicle (e.g., ship deck) which will transport the container;
- Inspect -- the examination of both the container and/or its cargo;
- Weigh -- the determination of both the gross weight or the container and cargo, as well as the distribution of that cargo within the container;
- Repair -- the restoration of the damaged or weakened container to its original state of operability; and
- Maintain -- the preservation of the container in its original state of operability (e.g., repainting, washing).

Note that the transfer function in most cases is intermediate to any two station functions. It represents a key function in the overall operating system. It is therefore important to look at this function in a more detailed manner. The nodes are presented by the following positions of the container: a) in the hold or on the deck of a ship; b) on a railroad flat car; c) on a truck chassis or

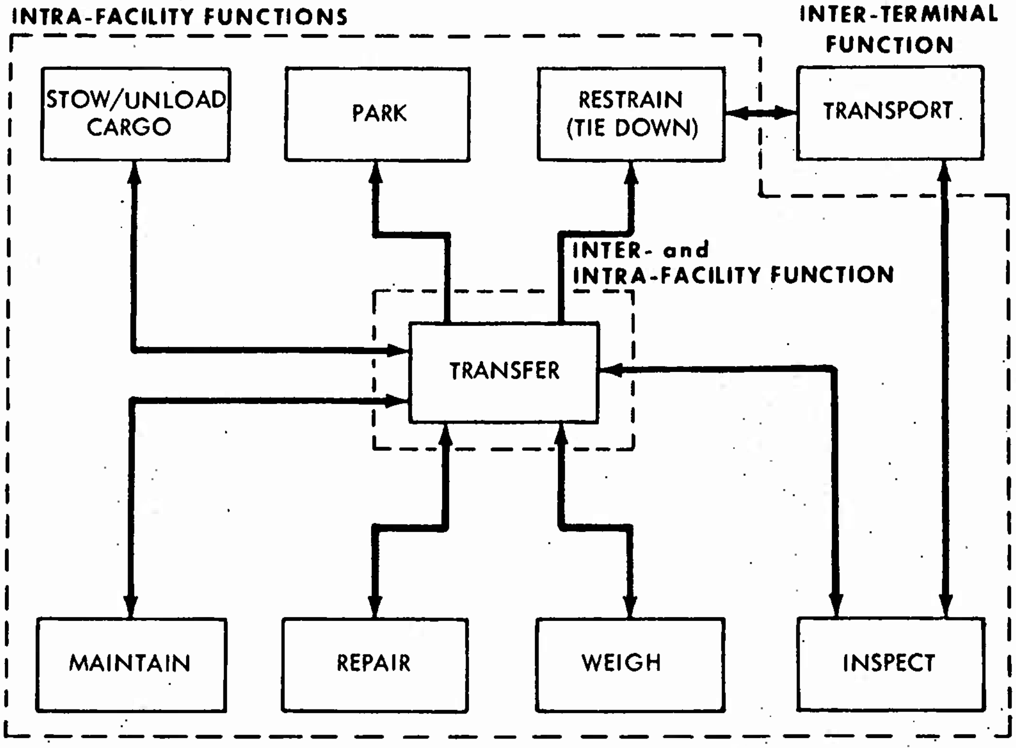


Figure 4-3. Third-Level Functional Diagram: Intra-Facility

bogey; or d) on the ground. The position of one container stacked on another container can occur at all except perhaps position c); therefore, it is considered a special case and is not represented as a distinct node.

The links represent transfer by several different types of handling equipments. These will be discussed in more detail later. Typical transfer equipments would be represented by the gantry crane, fork-lift, straddle carrier and the like.

Handling equipments can also be described in terms of the elemental functions they perform: a) engage the container; b) position to translate; c) translate; d) spot; and e) disengage container. The translate element can be of two types: the displacement of the container from point to point while the transfer equipment is stationary (e.g., ship deck to ground via shore gantry crane); or the displacement of the container from point to point via the mobility of the transfer equipment (e.g., pier to storage yard via forklift truck).

4.1.3 Container Functional Analysis

Thus far, the functional analysis has been used to establish system functions with respect to the container. However, although the container itself represents a completely passive unit without self-motion, specific implicit functions of the container can be identified. Three discernible functions of the container are: a) unitization; b) protection; and c) system interface. In early container operations, cargo unitization was primarily stressed with only a minimum amount of attention given to the other two functions. With the advent of intermodal container operations, the interface function became important, guided by international standards set up by ISO, USASI (now ANSI), and others. It is only recently that operators have become aware of the significance of the protection function -- not only in terms of the cargo, but also the container itself.

These broad functions of a container may be further broken down as illustrated in Figure 4-4. The unitization function consists of aggregating the individual items of a cargo shipment into a unit of sufficient size so that cargo handling economies can be realized. The commodities may be case lot goods; drums, crates or bales; or various odd shape manufactured items which are uncrated, for example, small tractors. Thus the container must provide the space (commonly referred to as cube) and the load carrying capacity to accommodate the cargo. It is from the unitization function that requirements for maximum cube and minimum tare weight -- along with some of the structural requirements -- are derived.

The protection function assures that the cargo survives shipment with minimum damage. Thus the container must resist the natural environment, for example provide a weathertight interior. The container must additionally protect the cargo from damage during handling and transport (the induced environment). It must therefore provide means for restraining the cargo whether this is done by specialized restraint equipment or whether simple dunnage and shoring are applied. Obviously the container must resist all applied loads and maintain its own structural integrity if it is to perform a protection function. Structural requirements of the container are derived from this function.

The interface function is to assure intermodal compatibility. The containers must interface with stowage cells of containerships and with deck fittings. Similar interfacing must be performed with rail cars and highway chassis. Additionally, and equally important, containers must interface with handling equipment. There is a further need to interface containers with each other as required in coupling and stacking. The dimensional standards are derived from the interfacing function.

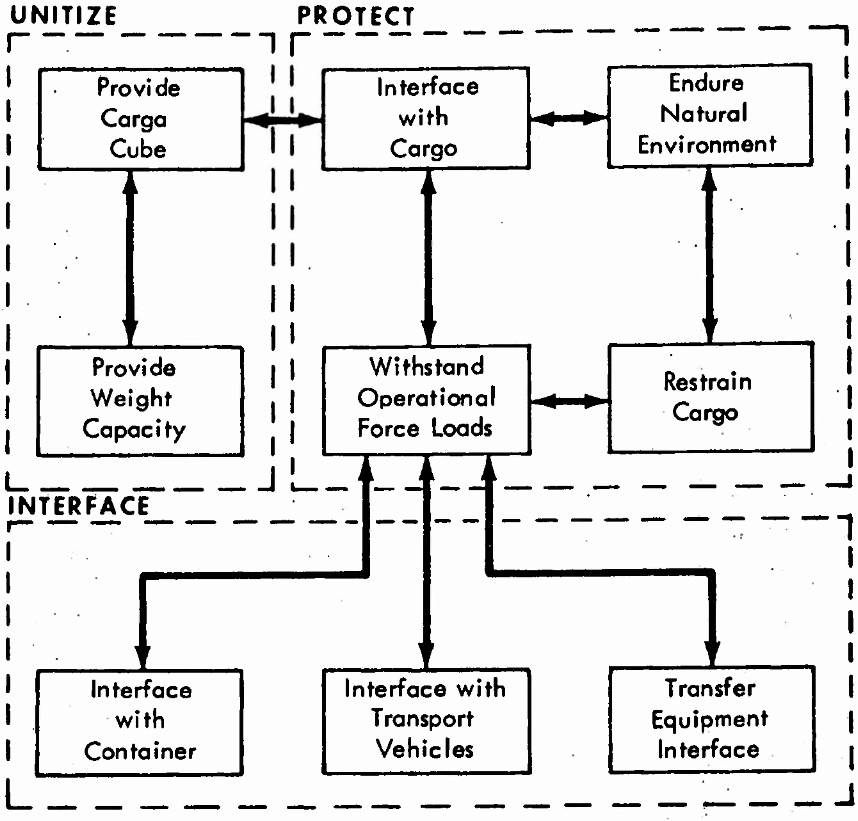


Figure 4-4. Container Functional Diagram

4.2 Service Conditions in Sea Transport

Several types of ships are used in the transport of containerized cargoes. Brief mention was made in Section 3 of some overall characteristics of the ships. At this point the report presents further details on ships, with special reference to the conditions of service which will be imposed on the containers. The sources of this information include the direct communication with steamship operators and the open technical literature (in particular References 4-1, 4-2, and various issues of the trade journals such as Reference 4-3).

4.2.1 Ship Types

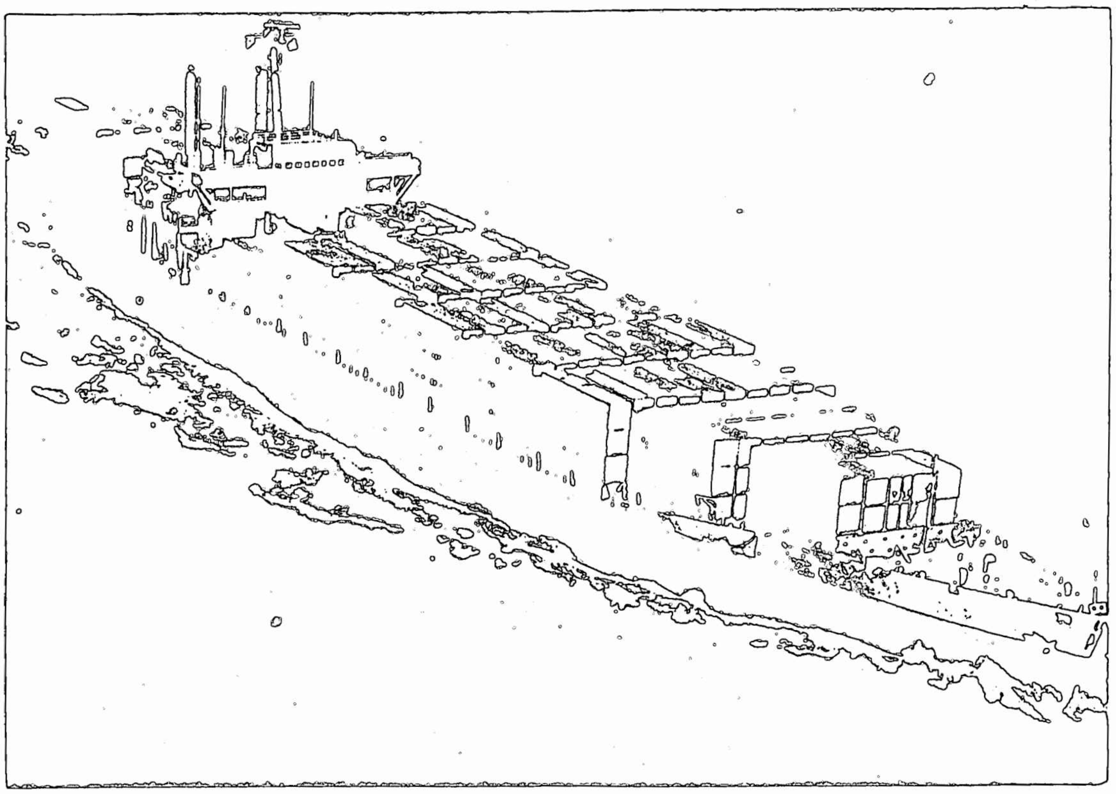
A number of different types of ships are used for the transport of containerized cargoes. The simplest is the conventional break-bulk cargo liner which has not been converted in any way and has no special handling gear or stowage facilities. At the other extreme of the spectrum are a number of specialized designs which may have fully cellularized holds and in fact may be unable to carry anything but containerized cargoes. In Reference 4-1, Henry and Karsch classify container carrying ships into five groups:

- Full container ships, single-purpose, which have special features for handling and stowing of containers;
- Partial container ships in which a portion of the ship's cube is assigned to and designed for containers;
- Convertible container ships in which the container spaces, whether all or part of the ships' holds, can be used for containers or conventional cargoes -- the changeover being on a voyage-to-voyage basis;
- Ships with limited capacity for carrying containers but which do include handling and lashing facilities; and
- Ships without specially designed handling and lashing facilities where the container load, though outsize, is handled similarly to all the other loads taken aboard.

In the next section of this report, on the subject of container damage, there is a presentation of some statistics and a segregation of the damage figures into three categories is made on the basis of the handling facilities. These categories correspond to the first, third, and fifth of the groups above. Figure 4-5 illustrates two containerships of recent design. Note on the Hawaiian Enterprise that the deck load part of the total number of containers carried goes between the two deck houses. The ships structure forward of the containers absorbs the impact of any water coming over the bulwark and provides a protected stowage area for the forward containers. One line whose ships have open forward decks reports that on winter crossings of the North Atlantic the most forward stowage positions are occupied by unserviceable empty containers placed there to absorb the impact of water coming over the deck.

These containerships are some times referred to as non-self-sustaining since they carry no deck gear for cargo handling. They are completely dependent on shoreside cranes for transferring containers on and off the ship. Ships whose trade routes include unequipped port terminals may mount gantry cranes on deck. Such gantries (see Figure 4-6) operate in manner similar to shoreside units with the twist locks of a spreader frame engaging the corner fittings of a container. The particular unit illustrated is a C-frame type which has the attractive feature of being able to handle 40-foot containers by moving two cranes together with their open ends adjoining.

Two ship types are contained within the intermediate category of partial containerships but have special interest to military applications. The Roll-on/Roll-off type was previously introduced



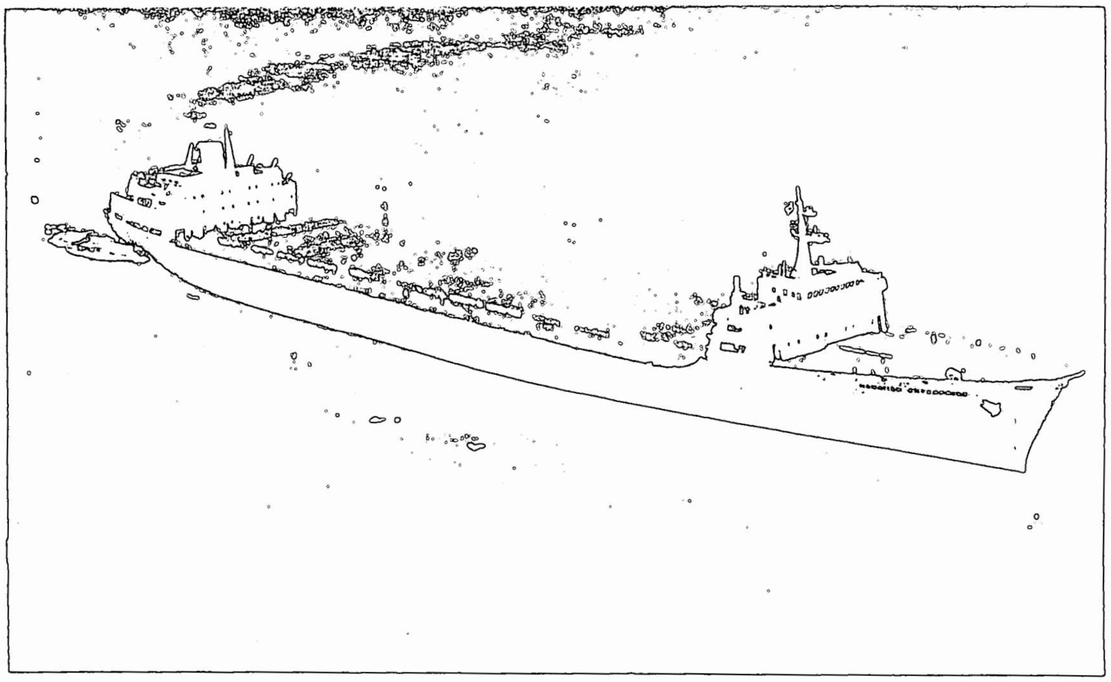


Figure 4-5. Containerships of Current Design

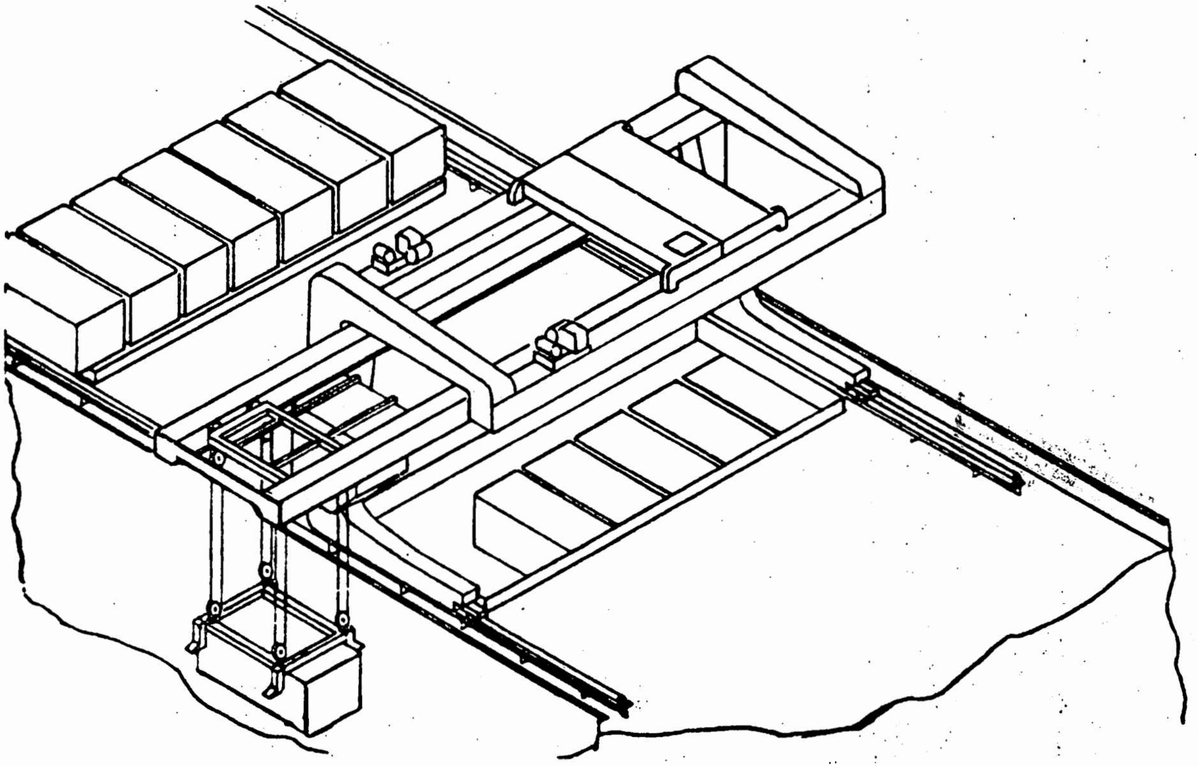


Figure 4-6. Deck Gantry for Container Handling

with the mention of Moore-McCormac's new class. Atlantic Container Lines, a European consortium of the dominant lines in North Atlantic trade, operates a modern class of ships which have the roll-on/roll-off feature. The Military Sealift Command (formerly MSTS) operates the Admiral Callaghan on the North Atlantic and this is generally regarded as the forerunner of a class of ships that could be available to carry Army cargoes to all theaters. This particular ship is equipped with a full complement of cargo handling gear of conventional boom and winch type. The other unique type is the Lighter Aboard Ship, also known as LASH. While this type can carry containerized cargoes in a mix with barges, its main characteristic is that it can handle standardized barges which are in effect super-sized containers. Figure 4-7 illustrates a LASH ship in the process of taking on barges. Note that the barges are being positioned at the stern of the ship where the crane performs the hoisting operation.

The feature of LASH ships that is of interest to the current study centers around their container handling provisions. In addition to the variable mix of containers and barges, containers can be placed in the barges. The consequence of this mode of operation is that barges may be shunted off to exceptionally primitive facilities where the transfer of containers would be subject to harsh handling conditions. Mobile cranes on the dock might be the principal type of

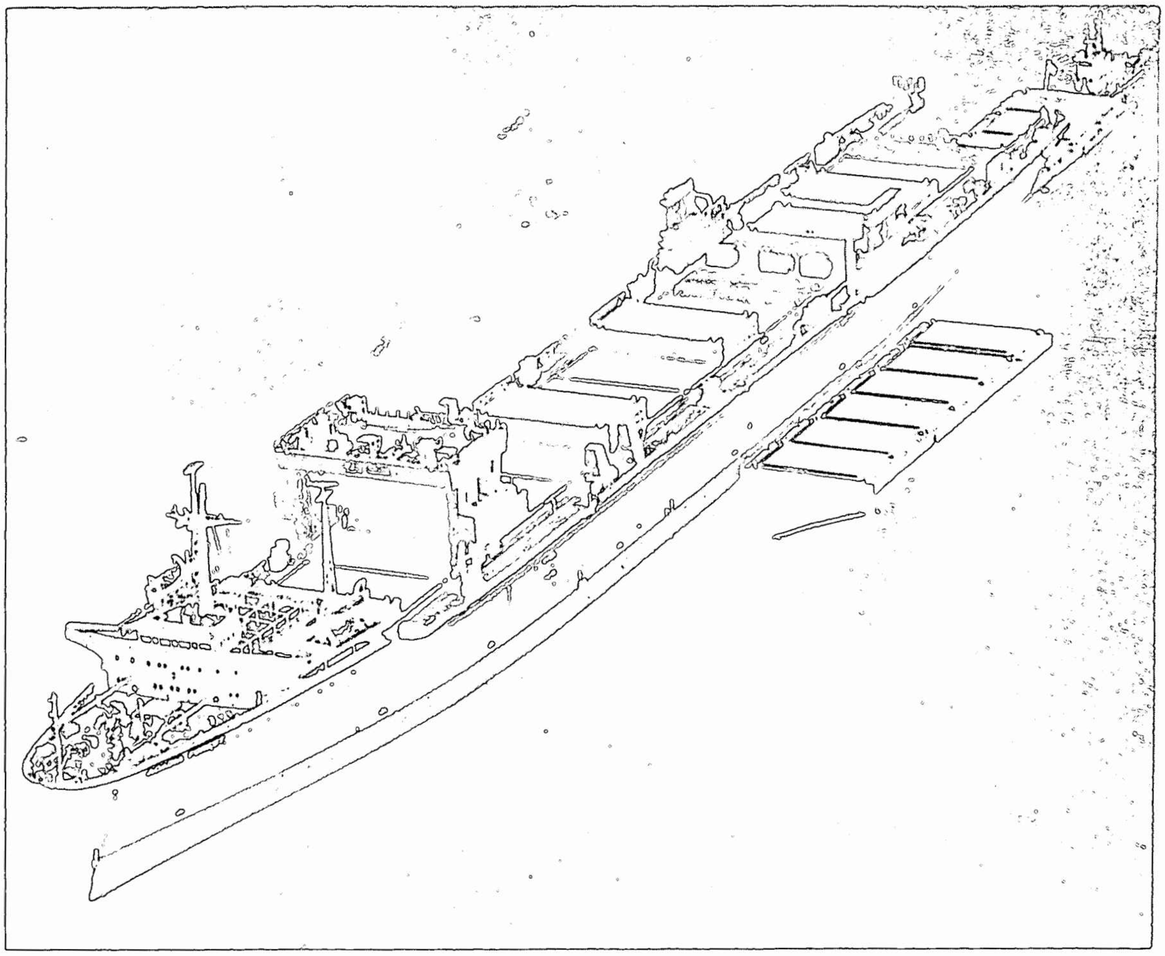


Figure 4-7. LASH Ship with Barges Moving into Loading Position

transfer equipment. The single line operation some times experiences pendulation as the boom is traversed abruptly. Hooks or a spreader frame are not under close control as they lower to engage a load.

Containership Details. Containerships are characterized primarily by their arrangements for transporting containerized cargoes. These ships carry containers in holds with cell guides which restrain the containers from motion and which make rapid loading and unloading possible. With only a few exceptions, the motion of a container is vertical only as it comes over the ship's deck and moves to its stowage. An illustration of a cellular hold is contained in Figure 4-8 which also includes the fittings which pre-center the container and thereby index the container to the cell guides.

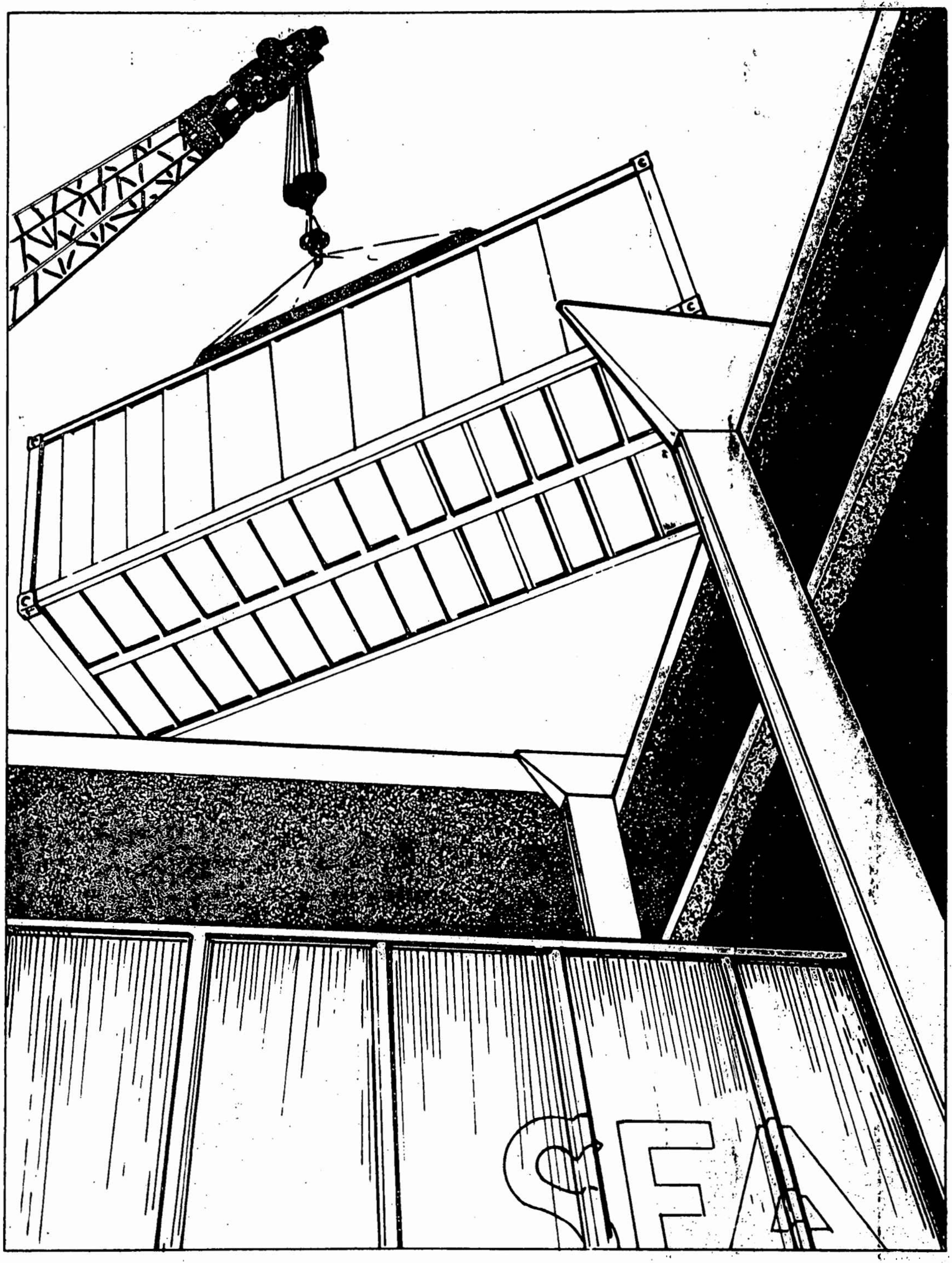


Figure 4-8. Cell Guide Arrangement and Details

4.2.2 Container Stowage

Cell Guides. The role of cell guides is critical. They enable the containers to be lowered to stowage positions when the crane is not precisely centered over the hold or if the ship is listing. In the process of stacking successive containers one over the other, they assure that eccentric loading does not exceed a controlled amount due to misalignment. The most important function performed by the guides is to resist the horizontal loads exerted by the containers under the influence of ship motions. Both analysis and actual experience have shown that the functions are performed best when the guides taper inward toward the bottom. This assures that eccentric loading is at a minimum at the bottom of a stack where the imposed loading is highest.

The standardizing documents on containers contribute to the design of cell guides by specifying tolerances on the envelope dimensions of containers. Thus, with a known variation of plus zero, minus 1/4 inch on the outside container dimensions, it is possible to assign dimensions to guide spacing which will result in a satisfactory interface, or clearance between the container and its guiding rails. A clearance space of 1/2 inch all around has proven to be satisfactory. Excessive clearance permits tilting to take place with the result that binding is possible. If the clearance is too small, then jamming may result.

The general situation on container alignment is that the long dimension is along the longitudinal axis of the ship. Some designs have been proposed in which the containers would go into stowage spaces in the athwartship direction but they are relatively rare and have not been pursued into actual construction. The effect of conventional alignment is that forces due to ship motion, which are greater as a consequence of roll than due to the other motion components, will lead to greater forces on the sides of the container than on the ends.

Variable Dimension Cell Guides. It should be pointed out that the cell guides on each ship are of fixed dimensions so that only a particular length of container can be accommodated by a cell. Matson has designed into its new class of containerships presently coming into service a fully adjustable cell guide structure so that different size containers can be accommodated concurrently. L. A. Harlander reports (in Reference 4-4) some of the details of the design. The key feature is the unobstructed hold length of 150 feet which will accommodate various patterns of container mixes. The transverse framing which mounts the cell guides consumes about 30 feet of hold length, leaving 120 feet free for payload. This can be divided into five bays for the 24-foot special Matson containers or six bays for the standard 20-foot units. The transverse frames can also be positioned for a mix such as two bays of 40-foot units and one each of 24- and 20-foot units. A changeover from one cell geometry to another can be performed during the annual overhaul of the ship. In this design, the transverse members within each 150-foot length are not required as strength members of the ship's hull girder and are essentially floating with only bolted connections.

Lateral Translating Cells (Moose System). A number of containerships are conversions in which the main deck, being a primary strength member of the ship's hull girder, is not cut out for vertical access to each cell. Sea Train Lines is the main proponent of this approach. Containers are lowered through existing hatch openings to form a stack on a skidway at the longitudinal centerline of the ship. After the stacks are loaded, a 50-ton hydraulic power unit (Moose) applies a force to position the stack at its outboard location. Container handling in each hold is remotely actuated and no personnel are required below decks.

Weather Deck Stowage. It is of interest in studying container characteristics to note that substantial numbers of containers are carried on the weather deck of the ship. The use of this space solves a problem for most steamship operators in that ships' holds are generally cube limited. However, the on-deck containers are exposed to sea water over the deck and to the hazards of the weather generally. Additionally, the usual lashing arrangements of the on-deck containers result in much harsher loadings as compared to the loads experienced by containers in cells. An example of a typical lashing on deck is illustrated in Figure 4-9.

The important cases of container strength requirements in racking and restraint at the bottom fittings arise in deck stowage situations. Referring to the figure, it can be seen that a container at the bottom of an on-deck stack will have a horizontal load applied to its top surface as those units above it are forced from side to side due to ship rolling -- if the lashing is something less than perfect in preventing sidewise motion. It should be noted also that racking is a unique kind of loading condition and is not to be confused with torqueing in which a couple would be applied at one end of a box girder and resisted by an opposite couple at the other end.

The height of the stack affects the magnitude of loading experienced by the on-deck containers. With three or four high stacks, the angle from the vertical of the lashing lines must be less than for low stacks. This means that the component of force in the horizontal direction due to a tension condition on the lashing lines is less. Thus, two situations are possible, with gradations in between, in which the lashing lines are tensioned up to the point where the full horizontal restraint is achieved in which case the wire rope is highly stressed. The other extreme is that only a part of the required horizontal restraint is achieved and the end frames and corner

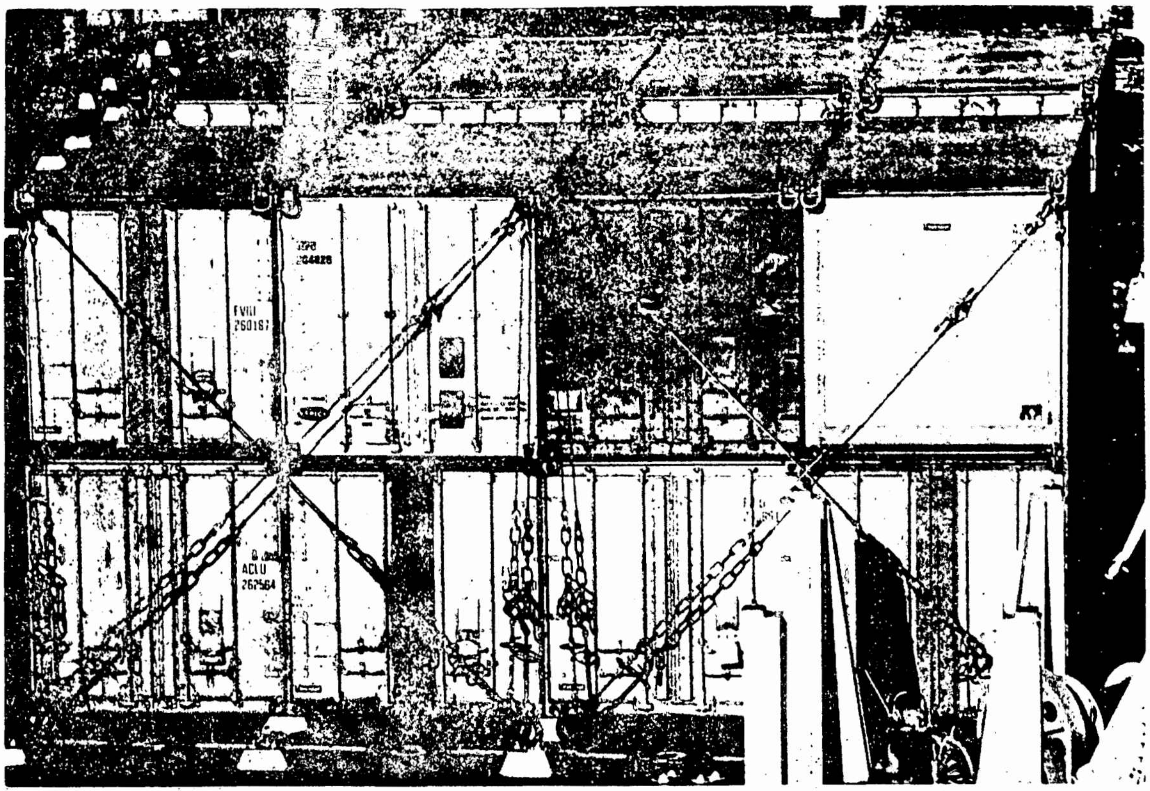


Figure 4-9. An Example of Lashing Containers on Deck

fittings of the container are more highly stressed. In cases where four high stacking is used, the practice in general use is to place only empty units in the top tier. Despite the well known precautions to be taken with deck stowage of containers this remains a real hazard. Remarks of speakers at the September 1970 meeting of the International Underwriters of Marine Insurance covered ship design features tending to reduce the loss hazard of deck stowage. In particular it was noted at the meeting that new designs of containerships have as much as three times the freeboard as early containerships and boarding seas will therefore be less frequent.

The difficulties of lashing down the on-deck containers has forced the naval architects and marine designers to seek alternatives. The Henry and Karsch paper (Reference 4-1) describes a patented buttress system. This approach avoids lashing by employing rigid frames which engage the containers, one tier at a time, and which are supported in turn by buttresses or towers which are mounted on the deck between container groups. These large rectangular frames have fittings which engage the top corner fittings on the successive tiers. Two sections on the framing are required to cover the full dimension of the deck in the athwartship direction.

The referenced paper does not associate the buttress system with any particular ship or line. However, during the field work of this investigation a system which meets the description was observed on Sea-Land ships. The frames were handled by the shore-side gantry cranes. While this operation would seem to slow down the average cargo handling rate, its overall effect seems to be beneficial as it completely dispenses with the time and labor of lashing. Additionally, it can be expected that container and cargo damage will be less with the buttress system as compared to lashing.

An alternative approach is to avoid the problem of deck stowage altogether. Dart Container Lines, another consortium of established steamship operators on the North Atlantic, has developed a new containership design which has all containers below the weather deck. The stacks are nine high in cells as shown in Figure 4-10. It is not known whether the stacks in each cell are supported or partitioned in a way which would reduce the load of stacking on the lower units.

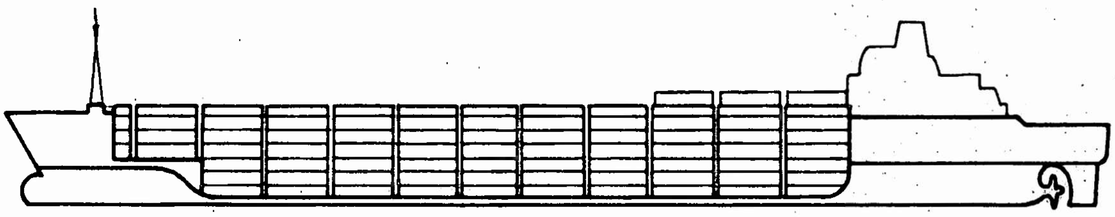


Figure 4-10. Containership Design with Increased Below Deck Stowage Capacity

4.2.3 Ship Motions

A set of ship motion data are implied by the promulgation of load requirements in the standards. These are a maximum roll angle of 30° and a rolling period of 13 seconds. Then if a location at a distance of 45 feet from the ships' center of roll is assumed, the lateral acceleration is 0.6 gravity units. Roll motions also are the origin of racking load requirements. A vertical acceleration of 0.8 gravity units is assigned to the combined effect of pitch and heave by the standards. These values are apparently the result of negotiation and compromise within the standardizing groups. Ship motions can be much more severe. The damage experienced by containers after voyages in heavy weather is partial evidence. There are on record numerous compilations of measurements made on the transportation environment which include ship motions. Most of this work was performed by defense agencies in the period 1950-60 when shipment of guided missiles required precise values for design of protective containers. An adequate treatment of this subject would needlessly burden this report. In any case there should be measurements available from containerships of recent design in the near future (according to a bulletin of the TTMA, Reference 4-5).

4.3 Container Movement by Rail

The dominant approach to intermodal shipments taken by the railroads has been Trailer-on-Flat Car (referred to as TOFC or some times as piggyback). Highway trailers complete with wheels are simply carried on existing flat cars. Several rail lines did not follow the trend primarily because low tunnel clearances could not accommodate the required height above the bed of the rail car. Additionally, some lines improve their capability to expedite intermodal shipments by the use of containers and thus make their service more attractive to shippers. At the present time numerous railroads operate a container fleet.

4.3.1 The Flexi-Van System

This is a proprietary system developed by the New York Central. Special flat cars are equipped with two turntables. The containers are backed up to the rail car, the bogey of the roadable unit is removed and the turntables rotate containers into their travel position. The turntables are hydraulic actuated. The several models of rail car are between 84-88 feet making it possible to carry two 40-foot containers.

4.3.2 Standard Containers on Flat Cars

Flat cars with appropriate securing systems are used to transport containers via rail. The containers are generally lifted on. One type of flat car in wide use is 89 feet long and has raised bolsters that contain locking devices for restraining standard containers. These cars can transport four 20-foot or two 40-foot units. Another type is 107 feet long, of articulated design with two sections of 53-1/2 feet each. Two standard 20-foot containers are carried at each end of a car section leaving a 13-foot clear space between containers. Thus, doors can be opened and loading operations performed without removing the containers from the car.

Existing flat cars have been converted for the transport of containers by the addition of bolsters. Twist-locking devices are used to secure ISO corner fittings. Each tie-down device set consists of two rigid and two adjustable pieces, with the height of the container above the flat car deck about 3-4 inches.

Another type of securing system is manufactured by the MacLean-Fogg Lock Nut Company. Their Series 600 system is normally applied to the 89-foot steel deck flat cars for movement of various length containers. The system incorporates 16 container pedestals with fully automatic locks for engaging, releasing and locking containers in position. The pedestals are fully adjustable and stow flush with the deck of the car, allowing trailers or other freight to be carried when the car is not in a container service.

4.3.3 The Motion Environment of Rail Transportation

The critical item of the rail environment is the humping of rail cars in classification yards. The cars pick up speed as they move down an incline and then are abruptly retarded. The accelerations experienced by the cars depend on both the impact speed and the cushioning provided by the draft gear of the cars. In the case of cars equipped with effective draft gear of modern design, accelerations are at levels which can be resisted by containers of standard design.

However, the field survey indicated that damage occurs when old cars are used for container transport. Operators reported that some times containers leave a major terminal on excellent rolling equipment but may be transferred to old cars with poor cushioning prior to the final arrival at a consignee off of main routes. Once a container is transferred to such a car it is prone to damage. Evidence that this is a serious source of damage is the fact that some operators reinforce the front end of containers with a metal sheet of about twice the thickness of container sheet material.

Measurements of humping accelerations appear in many issues of the proceedings of semi-annual Shock and Vibration Symposia. In one typical set of data from work of the Sandia Corporation, accelerations were measured on the bed of a car which impacted at 10 mph. The "forcing" sprectrum showed a peak acceleration of about 25 gravity units with a duration of 3 milleseconds (corresponding to a forcing pulse frequency of 165 hertz), in the longitudinal direction. The response of a container is a function of the resilience of the restraint. Since the suspension frequency of a container mounted on a rail car appears to be quite low, this forcing acceleration pulse would be attenuated. It is to be hoped that future measurement programs (similar to that noted in Section 4.2.3) will include loaded containers on various types of rail cars subjected to humping impacts.

4.4 Container Movement by Highway Vehicle

Transportation by highway vehicle is an essential part of the movement of a container lot of goods from a shipper to a consignee.

The equipment used is a chassis, bogey, or conventional flatbed trailer. Various designs are in use which attach the container to a skeletal frame chassis. A widely used type mounts bolsters with twist locks at four corners. These locks engage the corner fittings of the container. Another design engages the lower side rails at two locations on each side and at the front and rear sill members of the end frames for a total of six points of engagement.

Coupling chassis are used, with each part mounting a standard 20-foot container, then joined together for hauling double bottoms. Another feature found on some chassis is the adjustment for various lengths of containers. There are also fixed length containers with extra bolsters positioned to accommodate different container dimensions.

Tunnel type containers are used for the purpose of using higher containers while at the same time meeting overhead clearance limits. A depression or tunnel is designed into the bottom structure of a container. A special gooseneck chassis matches the tunnel in the container. A chassis design of the Fruehauf Corporation is multi-purpose. It can accommodate 8-foot 6-inch high containers with tunnel type bottoms as well as standard height containers while maintaining a limit of 12 feet 6 inches on overall height.

Transport over the road does not produce any well defined type of force or acceleration loading on a container which would control design criteria. However, highway transport is nevertheless a source of abuse to containers. A random sample of highway trailers will show that nearly all have some kind of damage to sheet and stiffener members of panels, to rails, and to other structural members. Striking of overhead structures, referred to as low-bridging, while infrequent, does produce severe damage.

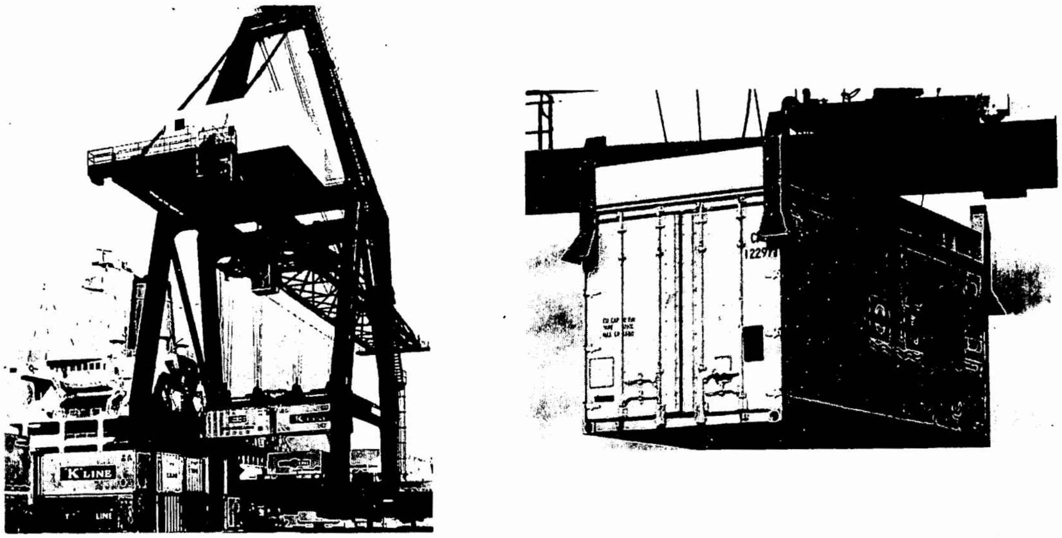
Regulation of highway transportation by the states includes dimensions and weights. In general, highway trailer loads may not exceed 8 feet width, 12 feet 6 inches height, and 40 feet length. Maximum gross weight limits for vehicles are in the range of 68,000 to 80,000 pounds.

4.5 The Handling Equipment

Containers are exposed to numerous hazards during handling. Neither the standards in general use nor the operators have done much to quantify the kinds of loading conditions which are experienced. The number of variable elements in this kind of environment is almost insurmountable and obviously explains the absence of standards. There are variations in the kind of handling gear and within each type there are differences in design and performance in each manufacturer's products. Superimposed on these differences are the variable performance of operators. However, because of the importance of the subject, a brief review of operations and equipment will be provided.

4.5.1 Transfers Between Ship and Dock

This is the most important handling operation in the entire cargo shipment cycle since it must be performed expeditiously so as to minimize the ship's turn-around time in port. The main item of equipment to perform this operation is the shore-side gantry crane as shown in Figure 4-11. The several designs in use throughout the world have essentially similar features. The gantry translates along the dock to align with the ship's hold being worked. Note in the left view of the figure that two standard 20-foot containers are being handled as a unit. The operator's position is elevated and mobile affording him a view of the operation as containers are engaged on the dock and subsequently lowered into cells of the ship's hold. In the right hand view the interesting point to be observed is that guides enable the spreader to be centered over the container and minimize damage. These guides are rotated to an up position as the bottom corner fittings are indexed into position over the cell and cell guides constrain the lowering motion. See Figure 4-12 for a view with spreader guides in the <u>up position</u>. The cantilevered outreaching section of the crane is pivoted to allow ship movements to be free of the obstruction.



(a) Gantry in Position at Ship's Berth

(b) Detail of Spreader Frame

Figure 4-11. Shore-Side Gantry Crane

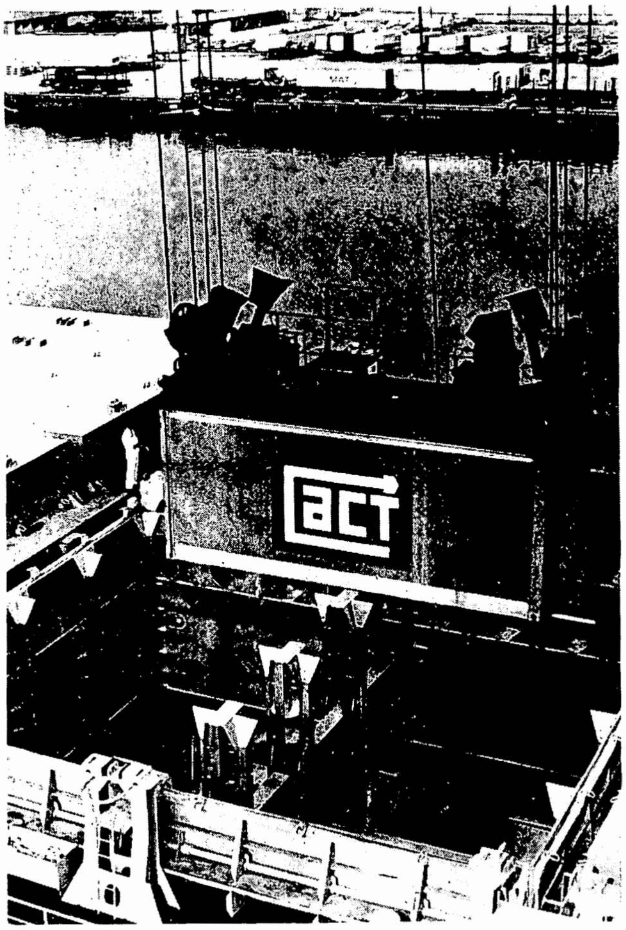


Figure 4-12. Gantry Lowering Container into Cell

The operating rate of these cranes is quoted at various places in brochures and technical journals at approximately 60 transfers per hour. During the field survey, observations were made of such cranes operating at a transfer cycle of 1-1/2 minutes. However, this was effectively a double cycle since one container was engaged, transferred to stowage, released, and then the crane positioned over an athwartship cell (in the same longitudinal position) to engage a second container and transfer it to the dock. Furthermore, the particular operation described was a direct transfer to chassis which involves greater precision than merely depositing the container on the dock.

Deck-mounted gantries were briefly described under ship details (Section 4.2.1). They are similar in function except that the pivoting outreach members extend over the dock. Since they are anchored to the ship there is less difficulty to perform the alignments over the cells under conditions of ship heeling as the balance of its load changes and as the ship surges under the influence of currents and rough water in port.

Ship's conventional deck gear is also used for transfer of containers. The operation is slow when the heavy lift boom must be used. Observations of this kind of operation indicate that 10-12 minute cycles can be sustained under typical port conditions. This is the type of operation that exposes the container and its contents to the greatest hazards. The ship's gear does not have a smooth operation, pendulation may result, and impact with the side of the ship or deckhouse may result.

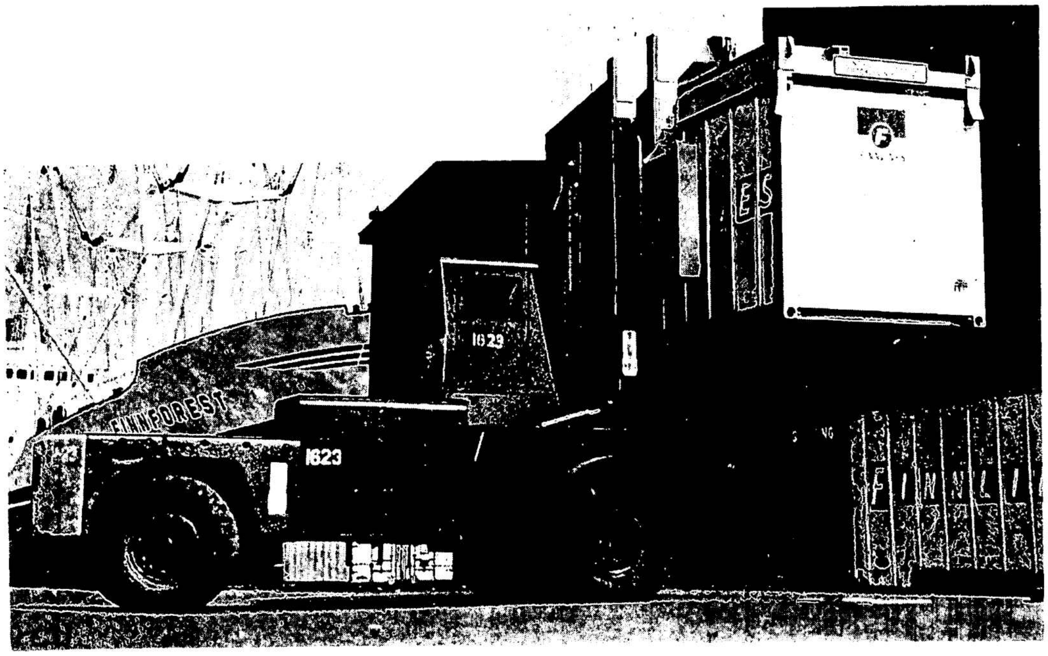
Ships and ports not specifically intended as container facilities may also employ commercial type cranes positioned on the dock to reach over the ship's hold. The speed of a transfer cycle of this kind will better that of ships' heavy lift booms but the hazards are about the same.

4.5.2 Yard Transfers

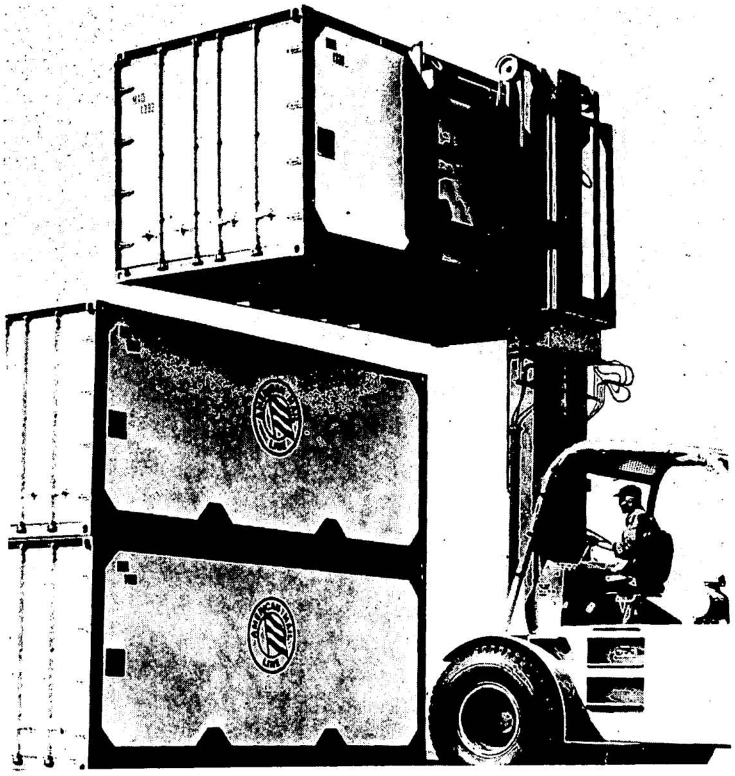
Various transfers of containers must be performed such as: from the apron of the dock to a parking area, stacking in the parking area, transfer to and from chassis and to and from rail cars. The equipments used represent a hazard since they are capable of damaging containers. The most rudimentary type of handling equipment, and the most hazardous, is the forklift truck with conventional lifting tines. Operators of these lift trucks have poor visibility when engaging the tines in container forklift pockets and when moving the containers with the large load immediately to the front. See Figure 4-13 for a typical model. One of the major problems experienced with this type of equipment is the attempt by operators to get under containers not equipped with forklift pockets and in the process to damage lower rails.

Lift trucks with spreader frames overcome some of the limitations of trucks with conventional lifting tines. See the upper view for a current model of this type of handling equipment. Note that the spreader is equipped with guides which facilitate alignment of the spreader with the top corner fittings of the container and limit damage to the top of the container.

Sideloading lift trucks overcome many of the limitations of conventional front-mounted forklifts. See Figure 4-14 for a model of a side loader. This particular model is being produced in the United States by Allis-Chalmers under a license arrangement with its British developers. There are two distinct advantages of this type of equipment as compared to front loading lift trucks. Containers can be moved to and from parking positions where access is by narrow aisles. No



(b) Lift Truck with Top-Engaging Spreader



(a) Stacking with Conventional Tines

Figure 4-13. Lift Trucks in Container Handling Operations

Figure 4-14. Side Loading Container Handling Equipment

turning operations need be performed in the aisles. Additionally, the operator has superior visibility as he transports containers in the sideload position. The low-level forward mounted cab traverses for this purpose. He also has improved visibility as he engages containers with a top spreader. This sideloader is capable of three-high stacking.

Straddle carriers are widely used in container handling operations. They are fundamentally top lifting equipments and have the capability to operate in narrow aisles and confined quarters. See Figure 4-15 for a view of a typical machine of this type. The larger units can straddle rail cars. The Clark Series 521 Van Carrier is an eight-wheel machine having a capacity of 40 tons and a capability to stack 40-foot containers three-high. The lift frame is hydraulically hoisted and stabilized within the carrier frame and has an equalization system which automatically compensates for differences in the longitudinal center-of-gravity of the container. The frame is suspended from a hoist mechanism at four points by one strand of roller chain and has ISO type hydraulically operated twist locks.

The FWD Piggy Packer (Model P70) made by Wagner is similar to a large forklift truck except that it uses a unique type of gripping mechanism. See Figure 4-16 for a view of this type equipment. Its tricycle design gives it a short turning radius, and it can drive up on either side of a rail car. Originally designed to lift wheeled trailers for piggyback operations, it is presently used to also lift containers. It has a capability to handle 40-foot containers. Special side-shifts and extension action of the jaws enable loading and unloading operations with any fastening method. Fork shoes or grapples can be individually shifted either mechanically or manually to allow for variations in trailer or container handling points.

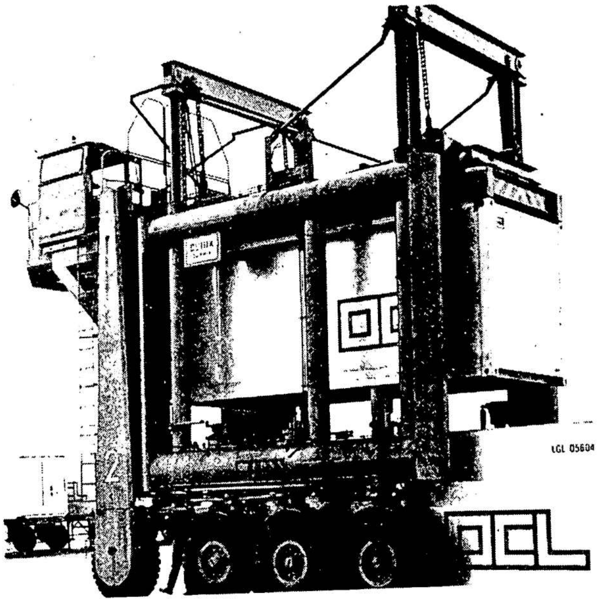


Figure 4-15. Straddle Carrier of 40-Ton Capacity

Figure 4-16. Container Loading on Rail Car by Piggy-Packer Equipment

Among the various equipment items for transfer of containers to rail cars is the Steadman Universal Side-Transfer Unit. It is a trailer with self-contained handling equipment. Operation consists of initially elevating the trailer which transports the container to the rail facility to the same level as the rail car. Then a transfer plate is used to move the container across to the bolsters of the rail car. All operations are hydraulically actuated.

4.6 Container Loading

The loading and unloading of cargo involves numerous problems which the container's design can alleviate, at least partially. Proper stowage involves distribution of the cargo weight as evenly as possible, separation of commodities which might harm each other, best utilization of cube, and dunnaging and restraint of the cargo. Guidelines to be observed during cargo loading operations are published by the National Cargo Bureau (Reference 4-6) and the U.S. Military Traffic Management and Terminal Service (Reference 4-7).

A conference of the Western Area of MTMTS (Reference 4-8) covered some of the problems of container utilization. A paper at the conference concerned cube utilization and graphically portrays loading difficulties. Firm goals are set depending on the type of contractual arrangement with the steamship line. In one case 80% cube was the goal in order that a rate set on each container load would be more advantageous than break-bulk. However, examples were shown where actual cargoes occupied 25-50% of the available cube. The most immediate consequence of the partial load is the difficulty of applying dunnage. In some cases 8 x 8 timbers were applied with an obviously high dunnage cost. The dunnage and chocking problem is complicated by the lack of adequate surfaces for nailing or otherwise taking up restraint forces.

Mechanical handling equipment used in loading containers is a source of damage. Packaged goods and palletized unit loads are usually loaded with a forklift truck. The interior space is confined and when operators must maneuver the lift truck to get cargo into available spaces damage is frequent. The use of plywood interior liners is not a complete solution, since the liners do not prevent damage completely and have a detrimental effect on maintaining containers subjected to small punctures. A frequent report in the industry has been that when patching jobs are performed, the entire liner panel is removed and replaced with a new one.

Restraint systems for containerized cargo are available in the industry but are seldom installed and used. Most of the steamship lines report that there is a loss of cube when the equipment is used and its use by shippers has proven to be ineffective. Additionally the parts of the equipment which are not integrally attached become lost. The overall result to the operator is that the investment that has been made in restraint systems has brought very little return. Exceptions are made in the case of shippers whose freight movements are regular enough to enable specific containers to be assigned for exclusive use. It is also necessary that the shipper's personnel be indoctrinated on the correct use of the equipment.

Typical of the commercially available restraint equipment is the Cargo Control System of the Aeroquip Corporation. Slotted beams in the container wall offer means of multiple decking within the container. Specially bracketed dunnage bars are used to restrain the longitudinal movement of the cargo by connecting to recessed slots in the metal panels in the sidewall.

4.7 The Problems of Military Application

The special problems that might arise with the increasing military application of containerization are not formally within the work plan of the study being reported herein. In any case doctrine for the employment of containerization in logistics operations of field forces is in a fluid state at the present time. Nevertheless, some general requirements may be anticipated. There will be occasions when rapid unloading must be performed. Unloading may be selective when the container serves the purpose of a storage shelter upon its receipt by the consignee.

It appears that provisions for maximum access to the contents of the container would enhance the usefulness of the container adopted for military application. There are designs which have side opening doors. Several railroads use these containers to perform loading operations, with the container on a rail car, at existing rail facilities where the loading dock is conventionally alongside the track. Such doors, in addition to end opening doors, would improve access to stowed cargoes. Another possibility is the installation of openings in the top. There would be a problem in making these openings weather tight but they should greatly improve operational flexibility. For example, with top openings available in containers an alternate mode of loading can be used -- overhead loading cranes. Since mobile cranes are in wide use among field forces this may even prove to be a preferred method of unloading in the field. Additionally, overhead handling gear would make it possible to directly transfer cargo to truck beds alongside containers.

The problem of air transportability of container loads could arise in military operations. Even though containers might not be specifically designed as air cargo containers they may carry cargo which becomes air-eligible in a contingency situation. Any weight burden due to a tare which evolves from design to ground handling requirements would be acceptable in such circumstances. However, an incompatibility between air cargo handling systems and containers would be less acceptable. Figure 4-17 shows the essential features of air cargo accommodations aboard a C-130 (Hercules) aircraft. Note that with the stern ramp down there is roller conveyer surface for moving large items into position for tie down. The conventional container bottom type of structure would not provide a suitable interface for the rollers. A flat bottom would be an improvement.

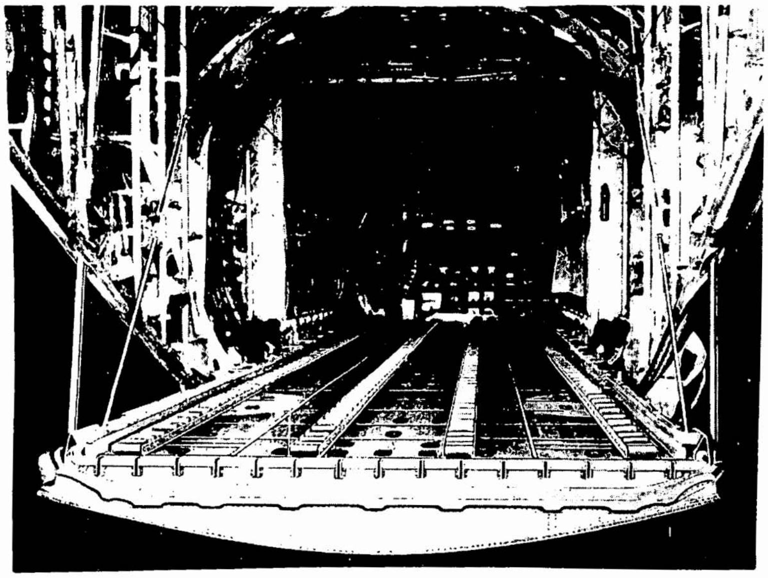


Figure 4-17. Air Cargo Handling Accommodation Aboard C-130 Aircraft

4.8 The Requirements of the Standards

The major question of interest in this investigation has been whether or not the standards in widespread use can be considered adequate design criteria for containers. The standards used in this country are promulgated by the American National Standards Institute (ANSI) and its predecessor organization USASI. The currently effective version of the standards are USASI MH-5.1-1965 Specifications for Cargo Containers (Reference 4-9). The international organization active in this field is the ISO which itself publishes standards. The usual practice is that the member countries of the ISO adopt a recommendation type of document and then each in turn issues its national standards to govern its industry's design and testing of containers. Thus, the national documents take precedence.

4.8.1 Cargo Cube and Weight Relation

By the specification of maximum gross weight (R) and dimensions for standard containers, the standardizing documents are, in effect, anticipating an average value of cargo density. The maximum cargo weight (P) is generally taken to be 40,000 pounds for standard 20-foot containers -- an R value of 44,800 pounds as specified minus a generous allowance for tare weight. If utilization of a container's cube is about 80% and a typical value of cube is 1100 cu.ft. then the usable space would be filled by cargo having a density as shown:

$$\text{Density} = \frac{\text{maximum cargo weight}}{\text{typical cube x fraction utilized}}$$

$$= \frac{40{,}000}{1100 \times 0.80} = 45.5 \text{ lbs/cu.ft.}$$

Data on the actual value of cargo density are published by the Maritime Administration (Reference 4-10, covering the third quarter of 1969 is a typical example). The data show that 21 lbs/cu.ft. is an approximate value for cargoes moving in both directions across the North Atlantic and across the Pacific. Specific values reported are:

North Atlantic	- inbound --	22.2 lbs/cu.ft.
North Atlantic	- outbound --	19.3 lbs/cu.ft.
Pacific	- inbound --	19.3 lbs/cu.ft.
Pacific	- outbound --	23.4 lbs/cu.ft.

Thus it would appear that container loads are, on the average, able to utilize only 46% of the allowable maximum cargo weight. Otherwise stated, loads in standard 20-foot containers tend to be cube limited.

This result was confirmed by operator reports during the field survey. A number of steamship lines having mostly standard 20-foot containers report that their containers are approximately 90% cube limited. Note that with average cargo density, 80% cube utilization, and average tare weight, that an average value of container gross weight load is 11.2 tons.

The situation is altered when standard 40-foot containers are considered. The maximum gross weight allowed by the standards is 30 long tons or 67,200 pounds. With 80% utilization of cube the cargo density that would use the maximum cargo weight is approximately 34 lbs/cu.ft. This is much closer to the actual cargo density than in the case of the standard 20-foot container. Therefore, occurrence of cube limited cargoes should be less than the 90% figure reported above. The non-standard containers in wide use generally alleviate the cube limitation further by using a height of 8 feet 6 inches.

The influence of the cube/maximum cargo weight relation extends to many aspects of container performance. In Section 10, cost analyses show that cube is a much stronger variable than tare weight in a container's revenue producing capability. At this point the question arises on whether -- if container gross weight averages 11.2 tons -- there is an excessive conservatism in the standards. The damage analysis in Section 5 is graphic evidence that this is not the case. It appears that the conservatism due to the low average weight of standard 20-foot containers only partially offsets the lack of conservatism in describing loading conditions which occur in service. Furthermore, based on the altered relationship that exists in 40-foot containers, the conservatism in load resistance due to gross weight being far below the maximum allowable level is partially lost. It is a reasonable expectation that as the proportion of 40-foot containers increases, as is happening in many of the fleets, there will be a rising damage rate.

4.8.2 Structural Load Requirements

A valid and critical review of the structural load requirements of the standards is not possible with the available meager measurements of the transportation and handling environment. The various exposures of this environment were qualitatively noted previously in Sections 4.2 through 4.6. The impression gained by examining the standards is that the loading conditions as described are highly idealized. For example the side wall pressure requirement of 0.6 P, or approximately 24,000 pounds is derived from a ship's rolling motion of a particular amplitude and period which do not cover extreme conditions. Additionally the justification for a uniform distribution of the pressure loading is hardly justified when the forms that cargo might take are observed. The uniform pressure is about 1.14 psi. Impacting of poorly stowed and chocked cargo items could increase this value many times, at least over concentrated loading areas.

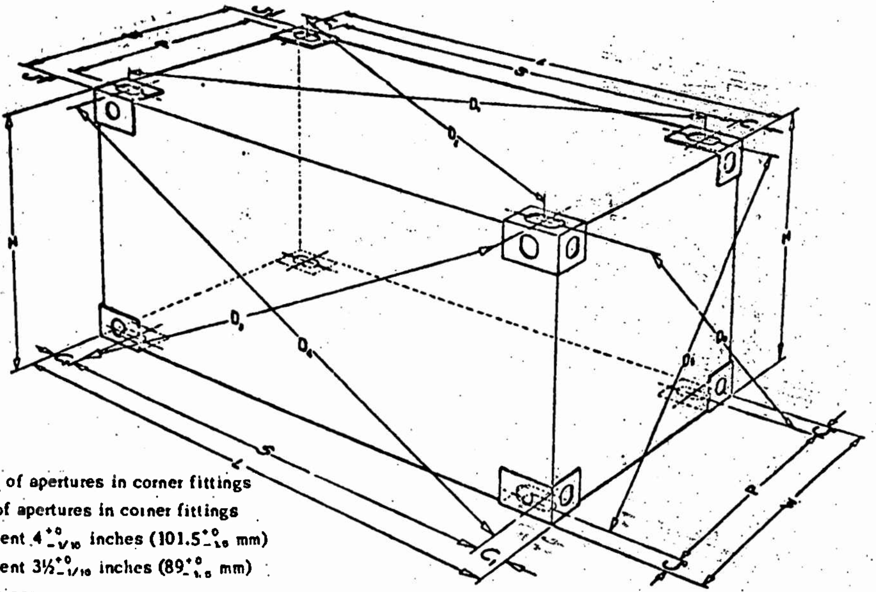
A loading condition which appears to be especially idealized is the acceleration associated with rail humping operations. The values of 1.5 gravity units on longitudinal restraint and 0.4 gravity units on end panels both presuppose that all rail cars are equipped with effective cushioning characteristics built into the draft gear of the rail car. However, the field survey indicates that older rail cars with poor gear are encountered when shipping containers -- most likely when the destination is off the main lines.

An ASME paper by Mr. F. Muller, Jr. (Reference 4-11), discusses some of the accomplishments and unresolved problems of standardization. Note is taken of the lesser requirement of the American standard as compared to the ISO document on bottom corner fittings. Only a vertical application of the load (twice the maximum cargo weight, P, equally distributed to the four corners) is required as compared to the ISO requirement of the same vertical component but a total load acting at 30° from the horizontal.

The load requirements of the standards cannot be judged as a comprehensive description of service loading conditions. An assessment of the amount by which the loads are deficient will need to await further measurements. Nevertheless, progress is being made and there is a mechanism by which the standards are amended. The trend is to more rigorous requirements. The introduction of a racking requirement by the American Bureau of Shipping is an example of recognition of service loads and promulgation of a standardizing requirement to provide adequate strength for resistance. Present damage levels are a further indication of the need for continuing strengthening of load requirements.

4.8.3 Dimensional Standards

The latest issue of standards (designated the Eleventh Draft Document, June 1970) contains the data shown on Figure 4-18. The containers of 24-foot and 35-foot length, which were previously considered to be non-standard, are included in this draft.



S - Length between centers of apertures in corner fittings
P - Width between centers of apertures in corner fittings
C_1 - Corner fitting measurement $4^{+0}_{-1/16}$ inches ($101.5^{+0}_{-1.5}$ mm)
C_2 - Corner fitting measurement $3\frac{1}{2}{}^{+0}_{-1/16}$ inches ($89^{+0}_{-1.5}$ mm)
L - External length of container
W - External width of container
D - Distance between centers of apertures of diagonally opposite corner fittings resulting in 6 measurements, D_1, D_2, D_3, D_4, D_5 and D_6
K_1 - Difference between D_1 and D_2 or between D_3 and D_4; i.e., $K_1 = D_1 - D_2$ or $K_1 = D_2 - D_1$ or $K_1 = D_3 - D_4$ or $K_1 = D_4 - D_3$
K_2 - Difference between D_5 and D_6; i.e., $K_2 = D_5 - D_6$ or $D_6 - D_5$
H - Overall height

*At the present time this size is not included in the air mode. Future revisions may consider this container for such service.

Nominal Length Feet	Length Overall (L)		S		P		K_1 Max.		K_2 Max.	
	mm	Ft-In	mm	Ft - in	mm	Ft - in	mm	in	mm	in
40	12190 $^{+2}_{-8}$	40 0 $^{0}_{-3/8}$	11985	39 3 7/8	2259	7 4 31/32	19	3/4	10	3/8
*35	10668 $^{+0}_{-10}$	35 0 $^{0}_{-3/8}$	10464	34 3 7/8	2259	7 4 31/32	17	11/16	10	3/8
30	9125 $^{+0}_{-10}$	29 11-1/4 $^{+0}_{-3/8}$	8918	29 3 1/8	2259	7 4 31/32	16	5/8	10	3/8
*24	7320 $^{+0}_{-10}$	24 0-3/16 $^{+0}_{-3/8}$	7113	23 4 1/16	2259	7 4 31/32	14	9/16	10	3/8
20	6055 $^{+3}_{-3}$	19 10-1/2 $^{+0}_{-1/4}$	5853	19 2 7/16	2259	7 4 31/32	13	1/2	10	3/8
10	2990 $^{+1}_{-4}$	9 9-3/4 $^{+0}_{-3/16}$	2787	9 1 23/32	2259	7 4 31/32	10	3/8	10	3/8

Width Overall (W): 8 Ft. 0 $^{+0}_{-3/16}$ in., 2435 $^{+3}_{-2}$ mm

Height Overall (H): 8 Ft. 0 $^{+0}_{-3/16}$ in., 2435 $^{+3}_{-2}$ mm or 8 Ft. 6-1/2 $^{+0}_{-3/4}$ in., 2600 $^{+3}_{-16}$ mm

NOTE: Dimensions S and P are reference dimensions only. The tolerances to be applied to S and P are governed by the tolerances shown for the overall length (L) and overall width (W)

Figure 4-18. Assembled Corner Fitting - Diagonal Tolerances

SECTION 5

DAMAGE EXPERIENCE

This section reports on the subject of container damage as experienced in commercial operations. A brief quantitative summary of damage surveyed in the Port of New York area for a representative group of operators is presented. Types and severity of container damage are described, highlighted with illustrative photographs of each example, where possible. Sources of the damage are discussed according to transport mode, handling equipment, natural environment, and other operational influences. Finally, a detailed breakdown of damage data is presented according to container type, sophistication of operating system and severity which lends quantitative evidence that the burden of damage in container operations is significant and should be carefully considered when assessing container design.

5.1 Summary of Damage Occurrence

A survey of container damages* experienced by a representative sample of commercial operators in the New York area reveals that the frequency of damage occurrence is significant. The containers were categorized by type as follows:

a) aluminum with external side posts or stiffeners
b) FRP/plywood
c) steel
d) aluminum with internal side posts

The survey of containers was conducted during both loading and discharging operations of six fully containerized ships, four conversion container ships with deck gantry cranes, and four partial conversions of conventional cargo ships for container purposes. Table 5-1 presents a summary of the number and percentage of damages observed during the on-board surveys. A more detailed breakdown of the data is given in Section 5.2. The total number of containers surveyed was 10,701.

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* Data were prepared by Marine Surveys, Inc. (Staten Island, New York) under subcontract from Control Systems Research, Inc.

TABLE 5-1

SUMMARY OF CONTAINER DAMAGE SURVEY

		Aluminum Exterior	FRP/ Plywood	Steel	Aluminum Interior
All Ship Types	Units Observed	2819	4987	1668	1227
	Units Damaged	499	495	322	233
	% Damaged	17.7	9.9	19.3	19.0
Fully Containerized Ships	Units Observed	872	2792	575	317
	Units Damaged	124	219	88	34
	% Damaged	14.2	7.9	15.3	10.9
Conversion Container Ships Deck Gantry Cranes	Units Observed	1189	1316	767	577
	Units Damaged	213	152	158	113
	% Damaged	17.9	11.6	20.6	19.6
Partially Converted Conventional Ships	Units Observed	758	909	326	333
	Units Damaged	162	124	76	86
	% Damaged	21.4	13.6	23.3	25.8

5.1.1 All Ship Types

The first set of data in Table 5-1 represent the combined total of damages of each container type observed for all of the three ship types mentioned previously. Note that nearly 18% of all aluminum exterior post units were damaged compared to 19% for the aluminum interior post type. The average percentage for all aluminum containers is approximately 18%. Steel containers had the highest percentage of damage incidence at 19.3%, slightly above the aluminum figures. Damage recorded for FRP/plywood was substantially lower at 9.9% when compared to the other units. The overall average occurrence of damage to containers is thus seen to be very substantial. These percentages indicate a container will be damaged, on the average, once in a number of cargo shipments between 5 - 10 (regardless of the type of container). Since the average useage per year is greater than this number of shipments, it is unlikely that any container survives a year of service without damage.

5.1.2 Fully Containerized Ships

The second group in Table 5-1 represents data gathered during loading and discharging operations on fully containerized ships. For the most part, they are operated at fully mechanized terminals where advanced container handling equipment is used. The results for this group are:

a)	aluminum exterior post	14.2%
b)	FRP/plywood	7.9%
c)	steel	15.3%
d)	aluminum interior post	10.9%

For each container type, the percentage of damage observed is less than the combined averages, illustrating the impact of modern container terminals and transfer equipment in reducing damage in commercial operations. Both aluminum unit types showed reductions in the damage rate on the order of 43%, while the FRP and steel containers experienced 20% reductions.

5.1.3 Conversion Container Ships with Deck Gantry Cranes

The converted container ships use deck gantry cranes to handle the units and the operating terminals are somewhat bare in the handling equipment available. The damage incidence of this group from Table 5-1 is:

a)	aluminum exterior post	17.9%
b)	FRP/plywood	11.6%
c)	steel	20.6%
d)	aluminum interior post	19.6%

This represents a significant increase over the results for fully containerized ships. However, these data rates are approximately on the order of the overall averages, each being only a few percentage points above the corresponding values except for the FRP type which is 17% higher.

5.1.4 Partially Converted Conventional Ships

The use of partially converted container ships with conventional cargo handling gear, including a substantial number of forklifts, is the least mechanized of the environments. The results show a further increase in damage frequency over the previous cases. The rates for this group are:

a)	aluminum external post	21.4%
b)	FRP/plywood	13.6%
c)	steel	23.3%
d)	aluminum interior post	25.8%

Each of the rates are significantly higher than that experienced in the system using the fully containerized ships and appropriate handling equipment. The increases for the four types of containers are approximately 100%, 75%, 50% and 135% respectively.

5.1.5 Graphical Presentation of Damage Rates as a Function of Container Operating Systems

An illustration of how damage increases as the operating system becomes less container oriented (i.e., less capable of handling containers) is shown in Figure 5-1. A graph for the four types of containers is shown in the figure. Note that in each instance except that of conventional ships, the order or ranking of damage percentage experienced by the unit type remains the same -- starting with the lower one: a) FRP/plywood, b) aluminum exterior, c) aluminum interior, and d) steel. Also notice that as the operating system becomes less sophisticated, the damage rate gap between FRP/plywood units and the other three types increases significantly.

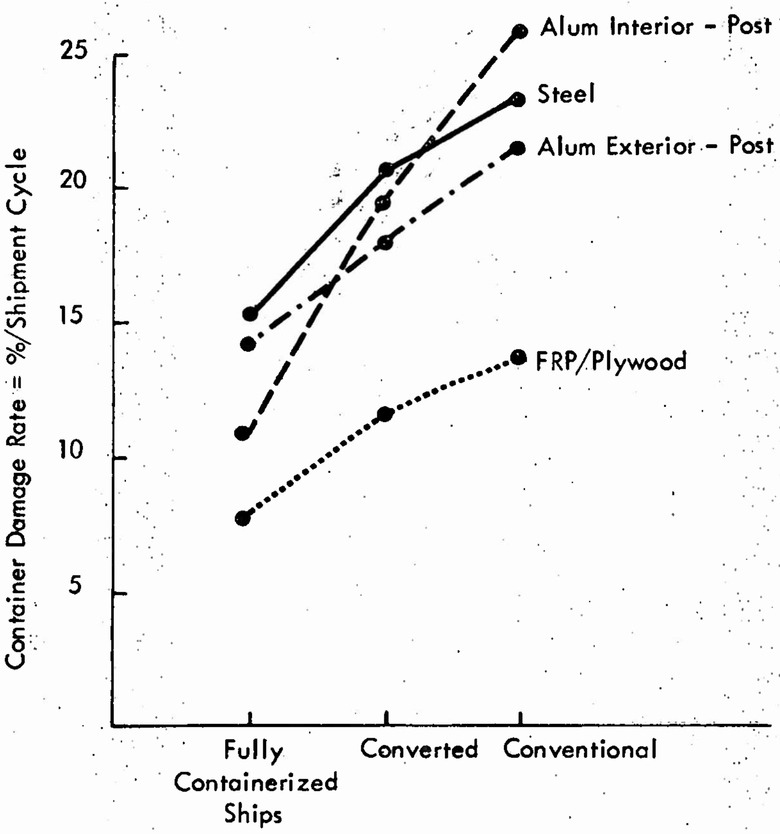


Figure 5-1. Damage Rates as a Function of Container Operating Systems

5.2 Detail of Survey Damage Statistics

The survey of container damages experienced by a sample of ship operators covering 10,701 cargo shipment cycles passing through in the New York port area was presented in summary form at the beginning of Section 5. At this point, the detailed results of the survey are examined. Three categories of damage severity, measured in terms of an estimated average cost of repair are used. A breakdown of the survey damage by container parts for each type of unit is reported with identification of the sources responsible for the damage. Also, damage experience estimates of ship operators obtained during field survey interviews are discussed and compared with the survey result.

5.2.1 Survey Conditions

The observations were made during both loading and discharging operations of six fully containerized ships, four conversion container ships with deck gantry cranes and four partial conversions of conventional cargo ships for container purposes. Each of the three categories of ships were divided into two seasonal classifications with one-half of the survey data covering the winter season during which wind forces of Beaufort Scale 8-11 were experienced on the voyages. The second portion of the survey data represented the summer season with, in most cases, moderate weather and wind forces of not more than Beaufort Force 8.

The fully containerized ships were operated at fully developed terminals with advanced container handling equipment being used for the most part, whereas, the converted container ships and the partially converted container ships with conventional cargo handling gear were operated at terminals which used less sophisticated container handling gear, including for example forklifts.

The total number of containers surveyed was 10,701. This total includes the four types of containers as follows:

Aluminum Containers with External Side Posts	2,819	(26%)
FRP/Plywood Containers	4,987	(47%)
Steel Containers	1,668	(16%)
Aluminum Containers with Internal Side Posts	1,227	(11%)

The cost of repairs to the damages were placed in three categories, referred to by Code numbers as follows:

Code 1: $ 0.00 to $ 50.00
Code 2: $ 50.00 to $200.00
Code 3: $200.00 and up

The repair cost estimates were based on the average being charged by representative repair firms in the New York Port Area with the type of repair being the most practical permanent repair for each given damage, not necessarily the best, easiest, nor least expensive.

No significant difference between winter and summer statistics was observed and for this reason these two categories were joined in the final analysis. A small number of containers were found to be moderately to heavily damaged due to the weather differential on the winter voyages, but no appreciable change in these statistics resulted.

An analysis of cargo outturn and internal damages to the containers would yield more pertinent information in regards to the effects of winter weather conditions in the North Atlantic and North Pacific. The more heavy-weather crossings were not used as a basis of this study, although wind forces of 11 and 12 plus are far from uncommon in the Northern Oceans.

5.2.2 Statistical Results

The statistics resulting from the analysis of the 14 vessels (three ship-type categories) involved in this survey are presented in Tables 5-2 through 5-5. Table 5-2 is a summary of total damage statistics for all the ships, while the latter three tables represent the individual ship-type cases.

It should be noted that the data given below reflect the damages experienced during those cargo shipment cycles where allowances were made for the damages which existed prior to the container's entry upon the trip. A large number of Code 1 type damages, some Code 2 damages, and, even some Code 3 conditions are accepted by container operators as serviceable or are permitted to be sent forward to obviate the necessity of emptying the contents of the damaged unit and stowing into a sound container with the time and expense involved in this operation. However, in such cases where the damage would permit water entry, temporary repairs are usually made to protect the cargo contained therein.

The damage percentages presented in the aforementioned tables are believed to indicate within ten percent the expected door-to-door trip damage for the different container types. If anything, the results are on the low side because of the following reasons. Not all the units were surveyed at the end of the trip, leaving the possibility of further damage occurrence before final unloading of the cargo. Internal damage to the container could not be observed unless it was obvious from the external survey. Both these factors would tend to make the damage data somewhat low.

TABLE 5-2

SUMMARY

ALL SHIPS & CONTAINERS SURVEYED

	ALUMINUM EXTERIOR	FIBERGLASS	STEEL	ALUMINUM INTERIOR	TOTALS
TOTAL CONTAINERS OBSERVED	2819	4987	1668	1227	10,701
CODE 1	366	413	233	185	1,197
CODE 2	127	79	82	45	333
CODE 3	6	3	7	3	19
TOTAL	499	495	322	233	1,549
PERCENT DAMAGED					
CODE 1	13	8	14	15	11
CODE 2	6	2	5	4	3
CODE 3	0	0	0	0	0
TOTAL PERCENT DAMAGED	18	10	19	19	14
PERCENT OF DAMAGES BY CODE					
CODE 1	73	83	72	79	
CODE 2	25	16	25	19	
CODE 3	1	1	3	1	
TOTAL	99	100	100	99	

Balancing this effect to some extent is the possibility of double counting, that is, counting damages from a previous trip. As was mentioned before, efforts were made to exclude from the count all damage which existed prior to the observed cargo shipment cycle. However, some double counting possibly did occur during compilation of the data. Thus, while the data presented is probably low in its assessment, it does represent a good estimate of the quantity of damage experienced during each cargo shipment cycle, that is the door-to-door trip of the container.

Containers Loaded and Discharged. A comparison of damage to the units being loaded and unloaded is contained in Tables 5-3 through 5-5. In all three cases, the frequency of damage among the discharged units was higher than that of the units loaded. Two reasons can be noted to account for the consistent difference. First

TABLE 5-3

FULLY CONTAINERIZED SHIPS

	ALUMINUM EXTERIOR	FIBERGLASS	STEEL	ALUMINUM INTERIOR
TOTAL CONTAINERS DISCHARGED	346	1327	352	137
CONTAINERS DAMAGED DISCHARGED				
CODE 1	37	115	48	13
CODE 2	15	27	9	3
CODE 3	1	1	1	0
TOTAL	53	143	58	16
PERCENT DAMAGED DISCHARGED				
CODE 1	11	9	14	9
CODE 2	4	2	3	2
CODE 3	0	0	0	0
TOTAL PERCENT	15	11	16	12
TOTAL CONTAINERS LOADED	526	1465	223	180
CONTAINERS DAMAGED, LOADED				
CODE 1	54	59	25	16
CODE 2	17	17	4	2
CODE 3	0	0	1	0
TOTAL	71	76	30	18
PERCENT DAMAGED, LOADED				
CODE 1	10	4	11	9
CODE 2	3	1	2	1
CODE 3	0	0	0	0
TOTAL PERCENT	13	5	13	10
TOTAL OBSERVED DISCHARGED & LOADED	872	2792	575	317
TOTAL DAMAGED DISCHARGED & LOADED	124	219	88	34
TOTAL PERCENT DAMAGED	14	8	15	11

of all, the discharged units had already completed the sea transport segment of their trip. Therefore, any sea transport mode damage would be included in their statistics. In addition, they

TABLE 5-4

CONVERSION CONTAINER SHIPS — GANTRY

	ALUMINUM EXTERIOR	FIBERGLASS	STEEL	ALUMINUM INTERIOR
TOTAL CONTAINERS DISCHARGED	598	660	382	328
CONTAINERS DAMAGED, DISCHARGED				
CODE 1	89	77	58	58
CODE 2	28	22	32	14
CODE 3	2	1	2	0
TOTAL	119	100	92	72
PERCENT DAMAGED DISCHARGED				
CODE 1	15	12	15	18
CODE 2	5	3	8	4
CODE 3	0	0	1	0
TOTAL PERCENT	20	15	24	22
TOTAL CONTAINERS LOADED	591	656	385	249
CONTAINERS DAMAGED, LOADED				
CODE 1	71	48	51	31
CODE 2	23	4	14	9
CODE 3	0	0	1	1
TOTAL	94	52	66	41
PERCENT DAMAGED, LOADED				
CODE 1	12	7	13	12
CODE 2	4	1	4	4
CODE 3	0	0	0	0
TOTAL PERCENT	16	8	17	16
TOTAL OBSERVED DISCHARGED & LOADED	1189	1316	767	577
TOTAL DAMAGED DISCHARGED & LOADED	213	152	158	113
TOTAL PERCENT DAMAGED	18	12	21	20

had been transferred both on and off the ship, whereas the other units had experienced the loading transfer only. Finally, the discharged units had originated in foreign countries and ports, which normally are not as developed for smooth handling of containers (other than a

TABLE 5-5

PARTIAL CONVERSIONS OF CONVENTIONAL CARGO SHIPS

	ALUMINUM EXTERIOR	FIBERGLASS	STEEL	ALUMINUM INTERIOR
TOTAL CONTAINERS DISCHARGED	352	401	220	160
CONTAINERS DAMAGED, DISCHARGED				
CODE 1	59	56	37	36
CODE 2	23	6	18	10
CODE 3	2	1	1	1
TOTAL	84	63	56	47
PERCENT DAMAGED DISCHARGED				
CODE 1	17	14	17	23
CODE 2	7	1	8	6
CODE 3	1	0	0	1
TOTAL PERCENT	24	16	25	29
TOTAL CONTAINERS LOADED	406	508	106	173
CONTAINERS DAMAGED, LOADED				
CODE 1	56	58	14	31
CODE 2	21	3	5	7
CODE 3	1	0	1	1
TOTAL	78	61	20	39
PERCENT DAMAGED, LOADED				
CODE 1	14	11	13	18
CODE 2	5	1	5	4
CODE 3	0	0	1	1
TOTAL PERCENT	19	12	19	23
TOTAL OBSERVED DISCHARGED & LOADED	758	909	326	333
TOTAL DAMAGED DISCHARGED & LOADED	162	124	76	86
TOTAL PERCENT DAMAGED	21	14	23	26

few exceptions) as is the New York port area, where the survey was conducted. Thus, it is not unreasonable that the containers damaged-discharged category in the aforementioned tables should show a higher damage frequency rate.

Damage Breakdown by Repair Cost Code. The results are presented in Tables 5-2 through 5-5 in terms of absolute incidents of damage and percent damaged. Table 5-2 which is a summary of the three cases, also gives the percentage of damage by code category, which was defined at the beginning of Section 5. Thus, approximately 70% - 80% of all damage occurs in Code 1 ($0 - $50 per repair), while only 1% - 2% are estimated greater than $200 to repair (Code 3).

Note that for a given code and type of container, the percentage of damage increases as the operating system becomes less mechanized (i.e., from fully containerized to partially converted conventional cargo ships). Thus for FRP/plywood units (discharged), the Code 1 percentage of damage increases from 9% when fully containerized to 14% for partial conversion of conventional cargo ships.

5.2.3 Damage Breakdown by Affected Container Parts

A breakdown of the damages for each type of container was made with the most frequently damaged parts of the containers in each repair Code category listed. Those sources of damage most frequently responsible for same are also reported. Table 5-6 lists the damaged container parts by Repair Code in descending order of damage frequency for the four types of containers.

TABLE 5-6

DAMAGE BREAKDOWN BY AFFECTED CONTAINER PARTS

Repair Cost Code	Aluminum Exterior	FRP/Plywood	Steel	Aluminum Interior
	Container Part	Container Part	Container Part	Container Part
1	Bottom Rails Stiffener/Sheet Roof Floor/Cross Mem.	Panels Roof Bottom Roils	Roof Bottom Rails Panels	Roof Frame Panels
2	Frame Floor/Cross Mem. Stiffener/Sheet Roof	Panels Floor/Cross Mem. Main Frame	Bottom Rails Floor/Cross Mem. Panels	Floor/Cross Mem. Frame Panels
3	Stiffener/Sheet Frame Floor/Cross Mem.	Panels Doors Floor/Cross Mem.	Bottom Rails Panels Floor/Cross Mem.	Frame Roof Doors

Aluminum Containers with External Side Posts: Code 1. By far the greatest number of damages within this container type was found to be in the Main Frame with most of these being damages to the bottom rails. These damages were found to be caused by forklift handling of the containers and by placing of the container upon obstructions or rough surfaces.

Many of the external side post aluminum containers have no fork pockets which increases the frequency of these damages, especially where proper container handling equipment is not available. It should be noted, however, that other container types which do have fork pockets experienced a relatively high frequency of rail damage as will be discussed below.

The second most frequent damage noted with this type of container was found to be damages to the panel posts. This design was intended to reduce or prevent damages to the side panel by having the side posts installed externally. However, operator experience has shown that these posts can be sheared off or otherwise damaged during handling operations. It is noted that this type of damage does not decrease as much with a full container operation as do other categories of damage.

The third in frequency of damages was found to be those to the roof area, these resulting from punctures by twist locks and other handling equipment intended for the lifting of the container from the top corner fittings. The relative ease of puncture of aluminum panel roofs obviously worsens this particular damage record.

Damages to the floor/cross members were found to be fourth in order of frequency. These damages resulted primarily from handling by forklifts and by the dragging of containers into stow position aboard conventional cargo vessels.

Code 2. The order of frequency of damage in Code 2 was found to be to the main frame, floor and cross members, side posts, and roof. These damages similarly were caused as noted above. Note that the relative cost of repairs was the primary reason for the alteration of the order.

Code 3. Within the Code 3 category, the number of damages was not great enough to give especially meaningful indications. However, the most frequent damages were found to be equal between the panel posts and the main frame, with the second in order of occurrence being damage to the floor and cross members.

FRP/Plywood Containers: Code 1. Side and front panel damages more than all others combined were noted with FRP/plywood containers. The greatest portion of these damages were to the external fiberglass layer only. This condition in virtually all cases did not affect the watertight integrity of the container. Most of these damages were caused by sharp objects gouging the panel, such as found on handling equipment.

The damages second in frequency were found to be to the roof area and included both holes and gouges of the exterior layer of fiberglass primarily from handling equipment (twist locks, etc.) and to a lesser extent from improper stacking of containers.

The type of damage third in order of frequency was found to be in the main frame, especially to the bottom side rails. The rails were specifically designed for container handling. Also, dragging of containers into stow position on conventional cargo vessels accounted for some of this type of damage.

Code 2. The order of frequency of damages in the Code 2 category for FRP/plywood containers was found to be panel damages, damages to the floor and cross members, and damages to the main frame. The primary causes were the same as those noted above.

Code 3. The order of damages under Code 3 was found to be to the side and front panels, doors, and floor and cross members. The causes of these damages were similar to those as noted above for the panels and the floor and cross members. The door damages were found to result partially from faulty fasteners incorporated in some of the early produced units, and secondly from a shifting of cargo because of humping in railroad classification yards at such time as the containers were being transported by that mode.

Steel Containers: Code 1. The greatest number of damages to steel containers was found to be in the roof area with causes as noted above. The next in order of frequency was found to be damages to the bottom side rails. It should be noted that a larger percentage of steel containers were equipped with fork pockets; however, side rail damages were still a major factor.

The third cause of damage in order of frequency was found to be damage to the side and front panels. This usually resulted when the panels were struck by handling equipment, or the containers hit other objects during the process of being loaded aboard conventional cargo vessels.

Code 2. The order of damages under Code 2 was found to be to the rails, the floor and cross members, and the side and front panels. The causes for these damages were similar to those as previously described.

Code 3. The frequency of damages to steel containers in the Code 3 category for repair costs was found to be as follows: damages to the main frame or rails; damages to the side and front panels; and damages to the floor boards and cross members.

It should be noted that the design of steel containers is such that when heavy damage occurs at one part of the container, it will be more likely that other parts of the unit will be affected also. This is due to the integral, all-welded character of a steel container. For example, if a side panel is very heavily collapsed, it is likely that there will be damages to the top and bottom rails on that side with a good possibility of distortion of the roof and the overall alignment of the container.

Aluminum Containers with Internal Side Posts: Code 1. Roof damages were found to be the most frequently occurring damage for this type of container. These damages resulted primarily from the relative ease with which the aluminum sheet was penetrated by twist locks, etc., and furthermore, most containers of this type had no protective plate or other feature to prevent punctures in the area of the upper corner fittings. In addition, damage to the roof area occurred during the irregular stacking of containers.

The main frame experienced damage next in order of frequency with the causes of these damages as described above. Third in order of damage frequency was found to be to the side and front panels which were found to be punctured by sharp objects, handling equipment, etc.

Code 2. The comparative frequency of damages in the Code 2 category was found to be damages to the floor and cross members, damages to the main frame, and damages to the side and front panels. Primary causes were as previously noted.

Code 3. Damages to aluminum containers with internal side posts were found to be experienced in the following order of frequency: damage to the main frame, damage to the roof, and damage to the doors.

It should be noted that the door damages were largely contributed to by the design of door hardware in several of the design types encountered. Failure of the hardware was found to result in significant damage to the doors.

5.3 Operator Reported Damage Experience

In addition to the survey data given in the previous section, damage information from individual operators was obtained so that a comparison of the survey and operator data could be made. This section presents both damage frequency data and some operator responses concerning which parts of the container suffer this reported damage. Certain explanations are given relating to the correlation between the survey results and some operator reported damage data.

5.3.1 Operator Reported Damage Frequency

Each operator interviewed was asked a series of questions relating to damage experienced in his operation. The responses resulted in data of different units of measure. These included: 1) average damage per month; 2) a percentage of units down for repair at any one time; and 3) total damages per year. In all instances, no data with respect to damage by type of unit were secured.

All data gathered from the operators were converted to the same unit of measure: damage per unit per year. In some cases, the calculations were straightforward, while in others, supplementary information about the operator's service was used to obtain the desired values. At best, the results are only as good as the operator's original estimates which contained some obvious uncertainty.

Table 5-7 shows the calculated damages per unit per trip reported by seven different operators. These numbers are an average for all types of containers in their respective fleets. Also presented are the percentage of containers damaged per trip.

TABLE 5-7

OPERATOR REPORTED DAMAGE

Operator	Damage Units/Trip	% Damaged Per Trip	Comparable Survey Results (%)	
A	0.0308	3.0	9.0	- 6%
B	0.0448	4.5	17.5	-13
C	0.2194	21.9	19.0	3
D	0.1247	12.5	19.0	- 6.5
E	0.0208	2.1	20.0	- 17.9
F	0.025 - 0.050	2.5 - 5.0	12.5	- 9.
G	0.1303	13.0	15.0	- 2

16

57.4

7.8

The spread in the values for the damage rate is large: a low of 2% for Operator E to a high of 22% for Operator C. This spread is too great to be completely explained by the fact that there is significant variation in each operator's service to account for different damage rates. Rather, the predominant reason for this spread may be explained by the fact that the reported damage data was not consistent between operators. That is, in one instance, the total system damage was reported because the operator had a good reporting system for repairs made throughout his service, including foreign ports. However, in other cases, the damage reported consisted only of repairs made in U.S. ports or even only one major U.S. port, such as New York. This factor thus tends to spread the damage frequency experience reported in Table 5-7.

Also presented in Table 5-7 are the comparable percentages of damage as given in the survey results of Section 5.2. These percentages were selected based on the type of containers, ships and handling equipment used in each particular operator's system. Thus for example, Operator F, who has a mix of steel and aluminum units and uses them in a fully containerized operation, was given a weighted percentage (12.5%) based on survey results for Fully Containerized Facilities, aluminum and steel containers.

The comparison of operator and survey results is good for operators C and G, but poor with respect to the others. This can be explained in part by the reason presented previously in this section, i.e., whether damage for all parts of the operator's system was reported. In addition, a large number of Code 1 type damages, many Code 2 damages, and even some Code 3 conditions are accepted by container operators as serviceable and permit the units to continue in the cargo shipment cycle to obviate the necessity of transferring the contents of the damaged container into a sound unit with the time and expense involved in this operation. However, in such cases where the damage would permit water entry, temporary repairs are usually made to protect the cargo. Thus, a significant amount of damage is never recorded because the repairs are not made promptly on individual work orders, resulting in a lower percentage of damage experience reported.

5.3.2 Damage to Container Parts

Some information regarding which part of the container is damaged most frequently was related by a few operators. Three were ship operators and the fourth was a major repair operator in the New York area. The rankings are presented in Table 5-8 with the most frequently damaged part ranked first.

TABLE 5-8

CONTAINER PART DAMAGE RANKING

Operator B	Operator F	Operator G	Maintenance Contractor
1. Roof 2. Door 3. Bottom Rail 4. Cross Members	1. Floor/Cross Members 2. Side Rails 3. Panels 4. Roof 5. Door	1. Roof 2. Side Rails 3. Door 4. Panels	1. Side Posts 2. Panel Sheets 3. Side Rails 4. Roof 5. Door

Operator B uses both aluminum and FRP/plywood units with the former in the majority. His system is a mixture of all types of routes and ports ranging from fully containerized to partially converted ships and associated handling equipment. The roof damage consists of mainly punctures caused by the spreader frame of straddle carriers. Racking forces were the source of the door damage while the side rail damage was associated with the use of a Piggy Packer in rail transfer operations. The use of forklifts in picking up containers with no fork pockets resulted in the cross member damage reported in the table.

The floor damage of Operator F is an anomoly because whereas most containers have a laminated oak flooring, the units of this operator were constructed of soft wood. This accounts for the high incidence of damage to the floor. This operator's fleet of containers consists of aluminum and steel units in a fully containerized system. The roof damage is lower on the list here because of the use of flippers on the spreaders.

Operator G has a fleet of aluminum and FRP/plywood units which are used on several different trade routes. The roof damage was associated with dropped spreaders during ship loading and unloading operations. Forklifts were mainly responsible for the panel damage.

The ranking given by the repair facility representative must be interpreted in the light of two facts: 1) 95% of the units repaired were aluminum, 5% steel; and 2) most of the repairs represented Code 2 or Code 3 types of damage to the units. This explains how side posts could be the most frequently damaged part. Recall that for aluminum exterior units in the survey, side post damage was ranked third for Code 2 and first for Code 3 damages.

5.4 Description of Container Damage Types

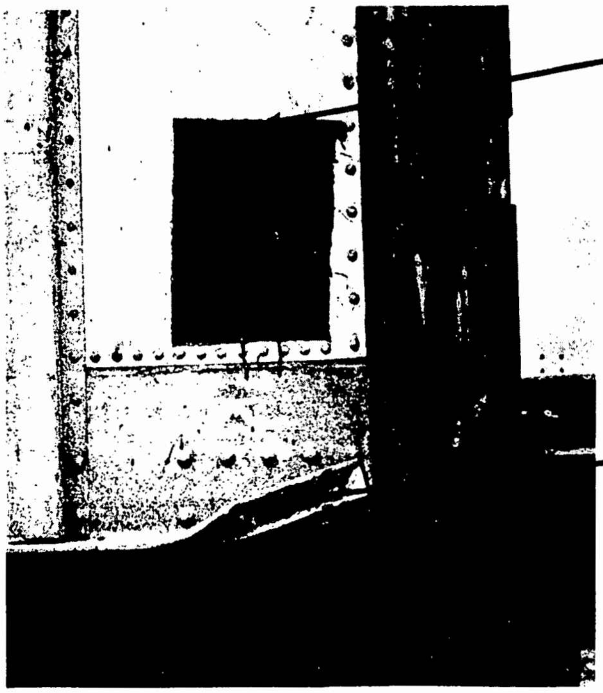
The several types of damage to containers which have been most frequently experienced by the commercial operators will be described here. Many of these damages are further illustrated by photographs of damage incurred during some segment of the operating cycle. Some of the photographs show damage of more than one kind and to more than one member of the container, pointing out the dependence and integral relationship between structural members of an assembled unit.

All parts of the container are susceptible to damage from any of several different sources such as transport vehicles, handling equipment and the natural environment. Damage to the unit's structural members also varies in terms of frequency and severity, and may be a function of container type (e.g., corrosion of steel, pitting of aluminum). The different kinds of damage are described here, categorized according to the structural elements of the container. Sources of damage are discussed in the next section.

5.4.1 Longitudinal Rails

The function of the longitudinal rails is to join the end frames into a unified primary structure while also providing a mount for the side panels, roof, and bottom cross members. The rails transmit loads due to the inertia of the contents acting on the bottom or sides to the ends where the restraining forces resist the loads. Typical cross-sections of both top and bottom rails were previously illustrated in Figure 3-9.

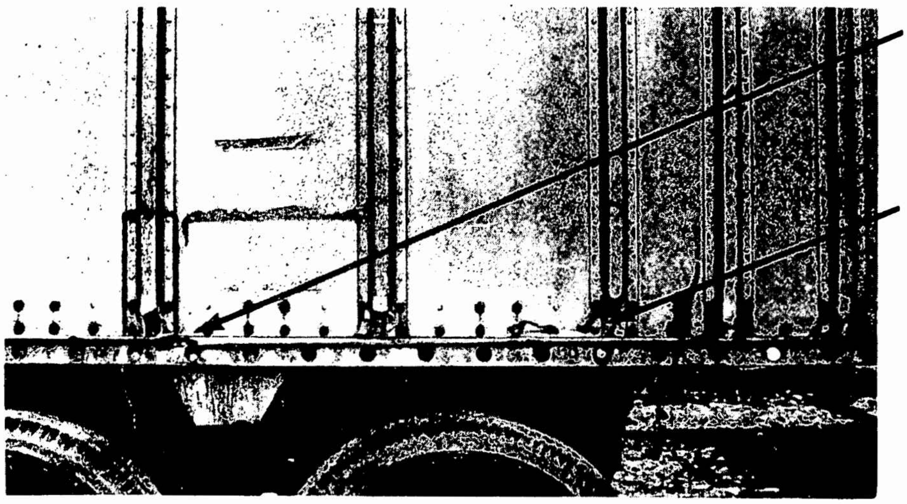
The flange on the bottom rail often protrudes outward and is especially vulnerable. It can be dented, torn, and/or twisted. See Figures 5-2 and 5-3 for typical flange damage. The work of a hard and perhaps sharp body acting on the container is plainly visible.



Existing Patch in Sheet

Protruding Flange of Rail Fractured and Twisted

Figure 5-2. Typical Bottom Rail Damage



Tear in Flange

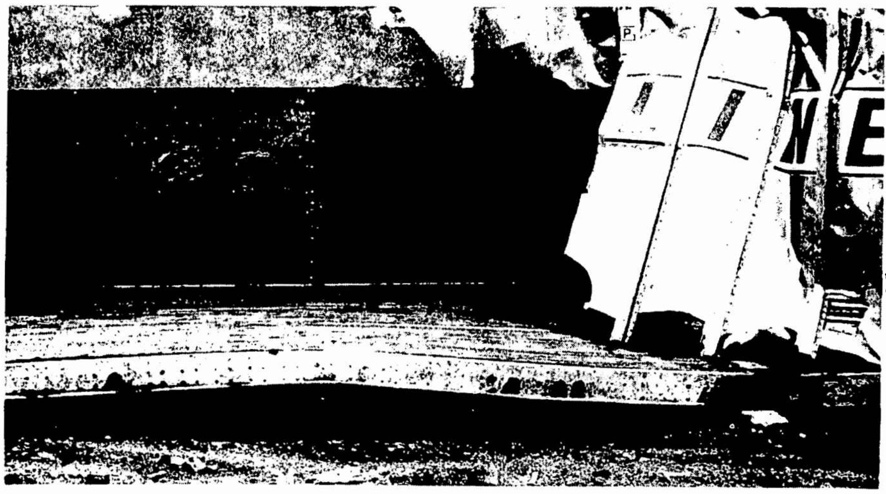
Sheared off Section of Post

Figure 5-3. Typical Bottom Rail Damage

A complete fracture of a lower rail as in Figure 5-4 is a catastrophic failure since there is no alternate load path. Note that the fracture passes through the rivet holds where it undoubtedly originated at a natural stress concentration. The bent rail in Figure 5-5 is a sort that could be caused by a hard landing on an obstruction or uneven ground. In this case, the tearing away of the side indicates that the nature or cause of damage must have been more


Complete Fracture of Rail Through Rivet Holes

Figure 5-4. Typical Bottom Rail Damage


Major Distortion of Bottom Rail

(Associated with Catastrophic Panel Damage)

Figure 5-5. Typical Bottom Rail Damage

complex. It is, however, a fact that the design margins are quite small and overstressing of a rail could be caused by supporting the rail on an obstruction and a consequent concentrated load and excessive bending moment even if the landing was not hard. Aluminum rails have been observed to be especially prone to these several kinds of damage.

Another kind of bottom rail is seen in Figure 5-6. In this case, the rail has been distorted around the forklift pocket. The damage is mild and many more severe dents and deformations can be observed on containers in service which have forklift pockets. Note also that this bottom rail is steel, which is usually the case when a design includes forklift pockets. It is clearly visible in Figure 5-6 that galvanic corrosion has carried away large sections of aluminum as the deterioration propagates outward from the steel fasteners.

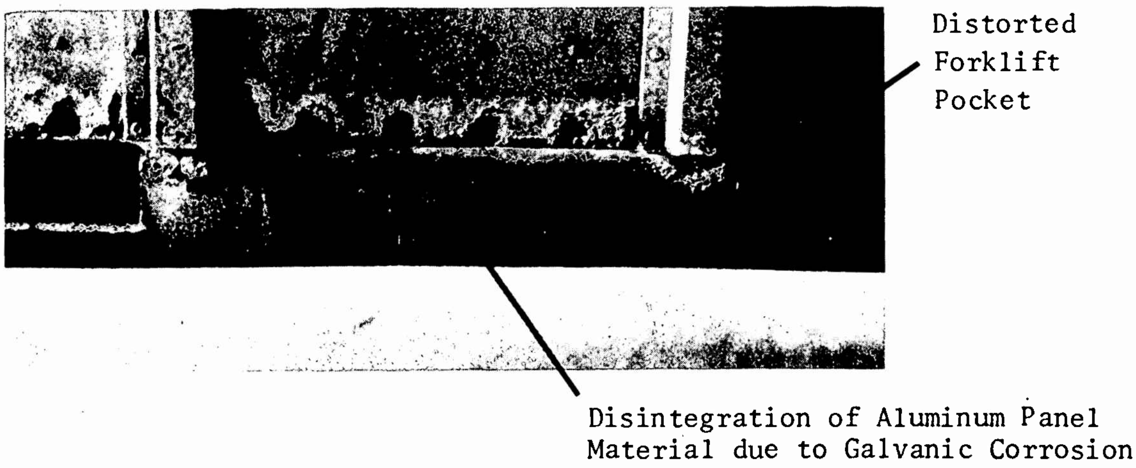


Figure 5-6. Damage to Steel Rail with Forklift Pocket

Top rails are subject to similar kinds of damage as that experienced by bottom rails. The causes of the damage are somewhat different but the deformations are equally large. Whereas bottom damage can occur when a container contacts an uneven surface or is struck by a mobile material handling unit or another container, there are counterparts working against the top. Handling units engaging a container can be misaligned and dent the top rails. Figure 5-7 shows a dented top rail. Further consequences of a catastrophic nature can follow from simple damage to the top rail. When a container is lifted from the top, this member acts as the top chord of a truss and is in direct compression. The failure mode of the top rail during lifting would be by buckling. The dent accelerates the

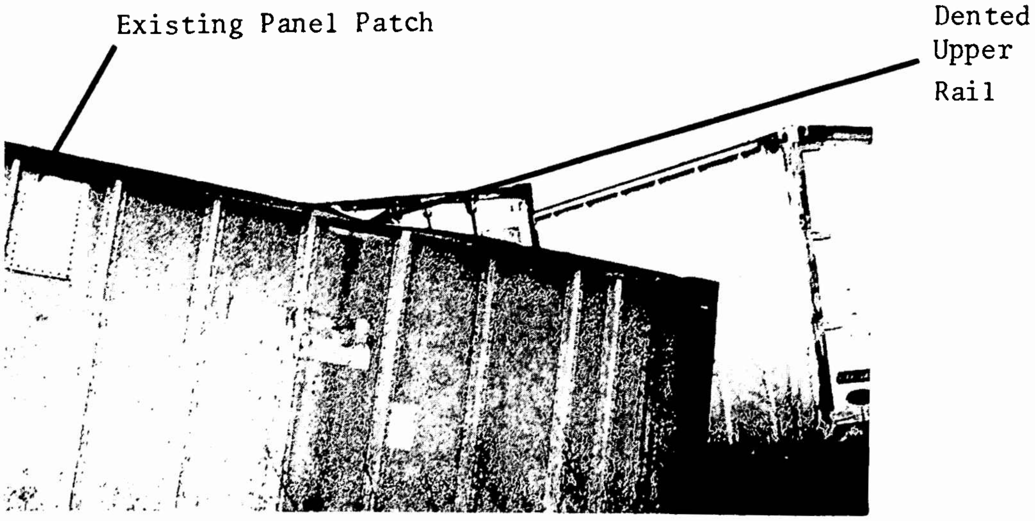


Figure 5-7. Typical Top Rail Damage

the onset of the unstable condition, thereby lowering the compressive load in the rail required to produce a large buckle.

5.4.2 Panels

The front and side panels are susceptible to a considerable amount of all kinds of damage. The range is from nuisance type, which does not interfere with the functioning of the container, to catastrophic failure. Small dents (referred to as "dings") are a frequent occurrence in metal containers. They are especially prevalent in aluminum because of its elongation and ductility. Abrasions in FRP/plywood units occur which gouge or dent the material without actually resulting in a puncture when hit by a glancing blow. Aluminum tends to split (often to a length of about six inches) at a panel puncture. All types of units suffer from panel punctures, initiated from both the outside and inside, which range from very small patchable holes to large penetrations requiring replacement of an entire side panel.

Some typical panel damage is shown in Figures 5-8, 5-9, 5-10 and 5-11. Note in Figure 5-8 a small patchable puncture just above a location where a patch had already been applied. Both these damage items are close to the forklift pockets suggesting that they were caused by the tines of a lift truck. Figure 5-9 is a steel container which was punctured from the inside.

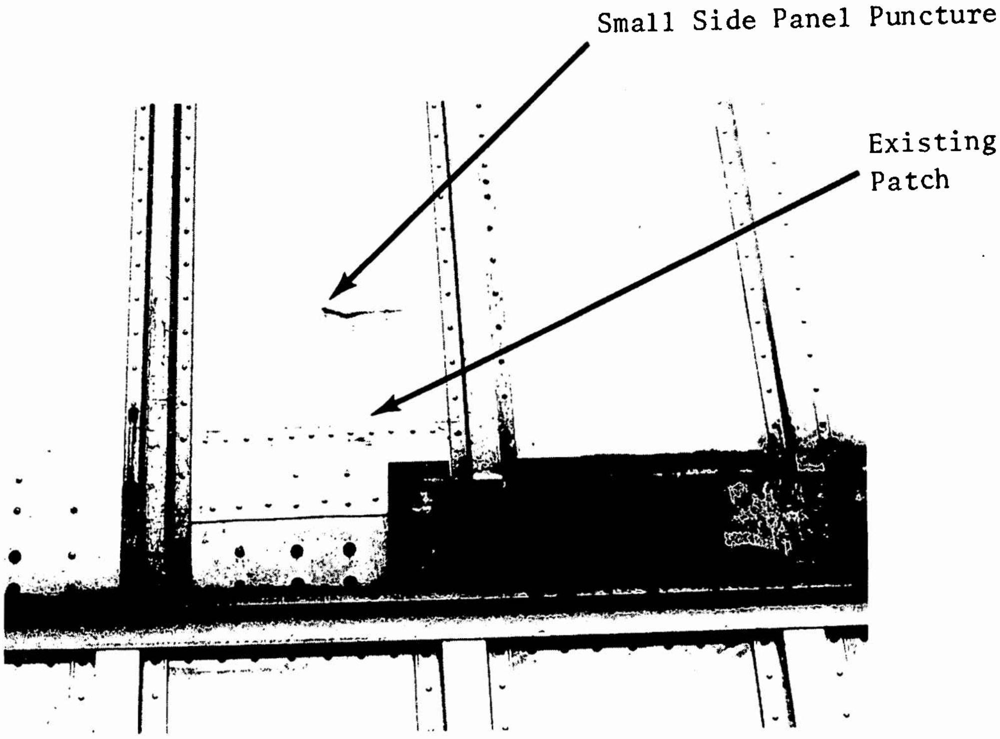
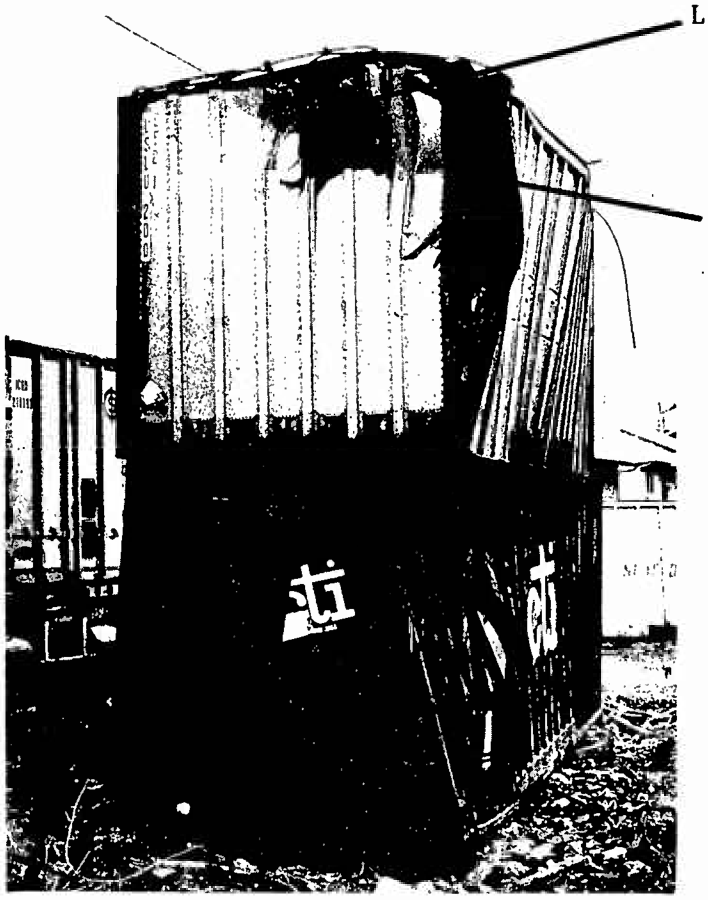


Figure 5-8. Typical Minor Panel Damage

Figure 5-9. Typical Minor Damage in Steel Panel

An example of major panel damage is seen in Figure 5-10 where severe end frame distortion is also present.


Large End Wall Puncture

Associated Frame Damage

Figure 5-10. Typical Major Panel Damage

A case where fracture of the hat section stiffeners are included with sheet tearing and denting is in Figure 5-11 -- whether this damage originated on the outside or inside is not clear. Tearing in steel and aluminum containers is also experienced when side forces act on the panel, see Figure 5-10.

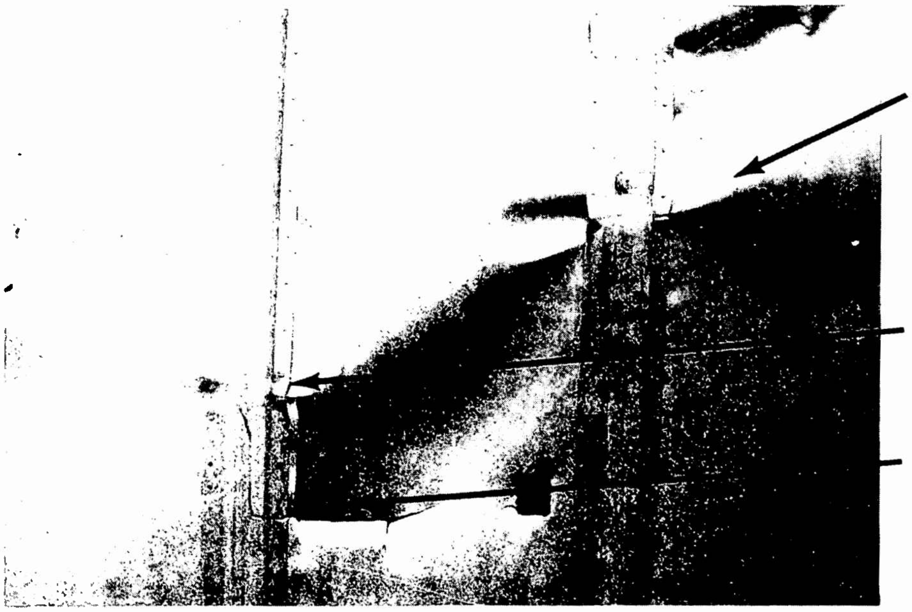


Figure 5-11. Typical Panel Damage to Sheet and Post

Further panel damage is included in Figures 5-12 and 5-13 where a substantial tearing action led to the results of Figure 5-12. Note here that this is an interior post aluminum design and that one of the two posts involved is probably reuseable whereas both would have been in need of replacement had they been exterior. Note also that the end post, when it was forced inward,

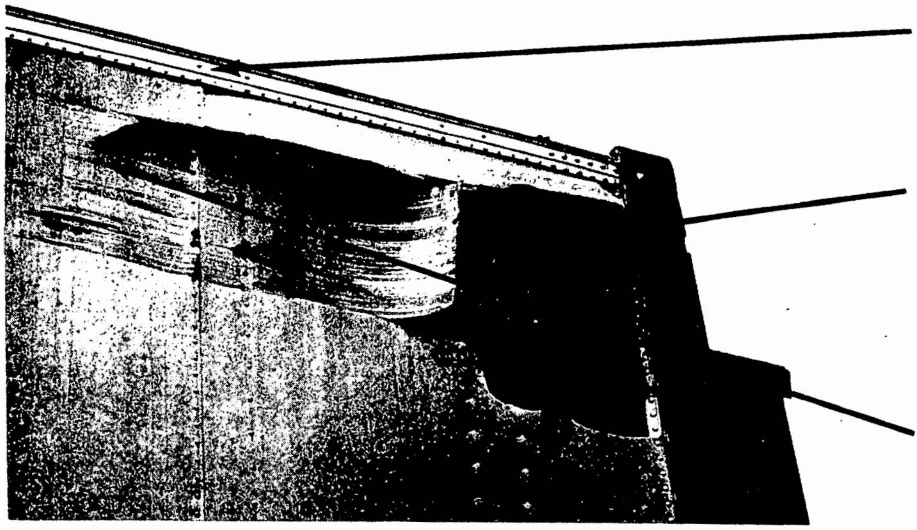


Figure 5-12. Typical Major Panel Damage

pulled a dozen or so rivets through the sheet material. Figure 5-13 shows the action of squeezing forces on the verticals of the front end frame with crumpling of the sheet while the panel stiffeners appear free from distortion.

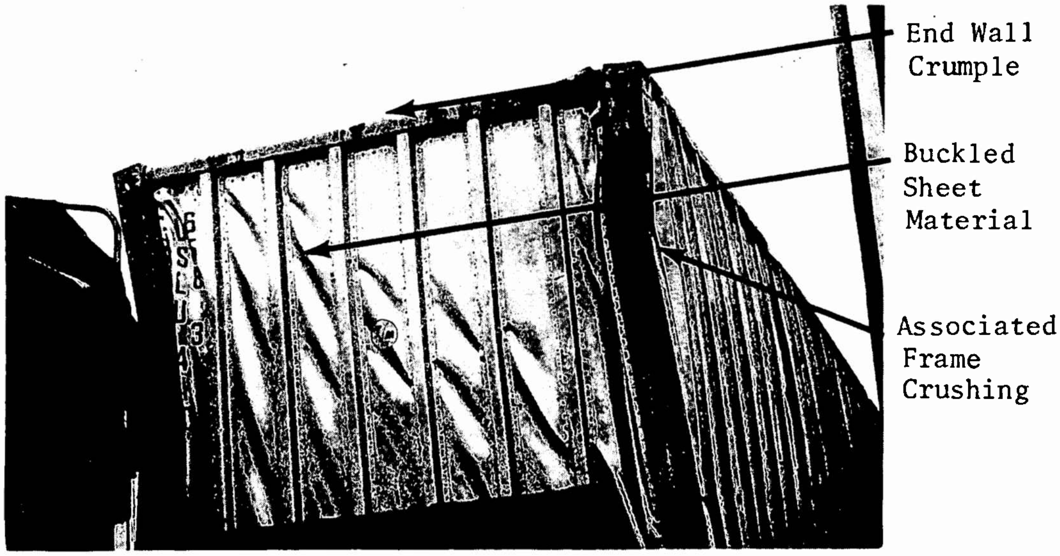


Figure 5-13. Typical Major Panel Damage

5.4.3 Floor/Cross Members

The floor of a container is usually constructed of hardwood (laminated oak). Thus, it is subject to wear and tear damage which results in the eventual splitting and disintegration of the boards. The wooden boards are also subject to contamination from cargo, rendering it useless for other cargo. The cross members which support the flooring are distorted indirectly when other parts of the main frame are damaged and directly when they take direct force blows from fork tines. The cross members can also be damaged due to hard landing on rough surfaces and misaligned contact with skeletal chassis. The result is dents, bending and major distortions. Figures 5-4 and 5-5 indicate that floor and cross member damage exists and will have to be repaired.

5.4.4 Roof

Punctures, especially in aluminum and plywood, represent the most common type of damage to the roof of a container. Most of these occur near the four top corner fittings. Tears in the roof material are also possible although they are infrequent compared to the punctures. The roof shown in Figure 5-14 was caved in when some object was dropped on it or a misaligned container was landed hard on its top. Similar tearing off of the top can be due to low-bridging when on a highway chassis.

Figure 5-14. Major Roof Damage

5.4.5 End Frame

Damage to the end frame consists of many of the same types listed under rail damage (dents, etc.). However, these are less frequent in occurrence by comparison. The type of major end frame damage experienced occurs from racking forces which deform the frame in a lateral direction, as shown in Figure 5-15.

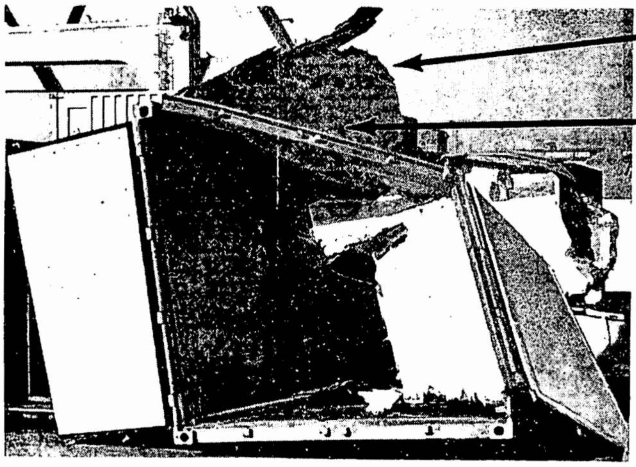


Figure 5-15. Typical Major End Frame Damage

The vertical members of the end frame almost always suffer from abrasion damage as shown in Figure 5-16; however, this does not immediately affect the overall strength of the member frame. This condition does, however, accelerate the rusting of end frames which are usually of steel. It may result in a decreased useful life span for containers as compared to what could be expected if the steel surfaces had benefited from a continuously present protective surface. The previous figures included damage to end frames where the verticals were caved inward (Figure 5-13) and where the vertical was forced out (Figure 5-10).

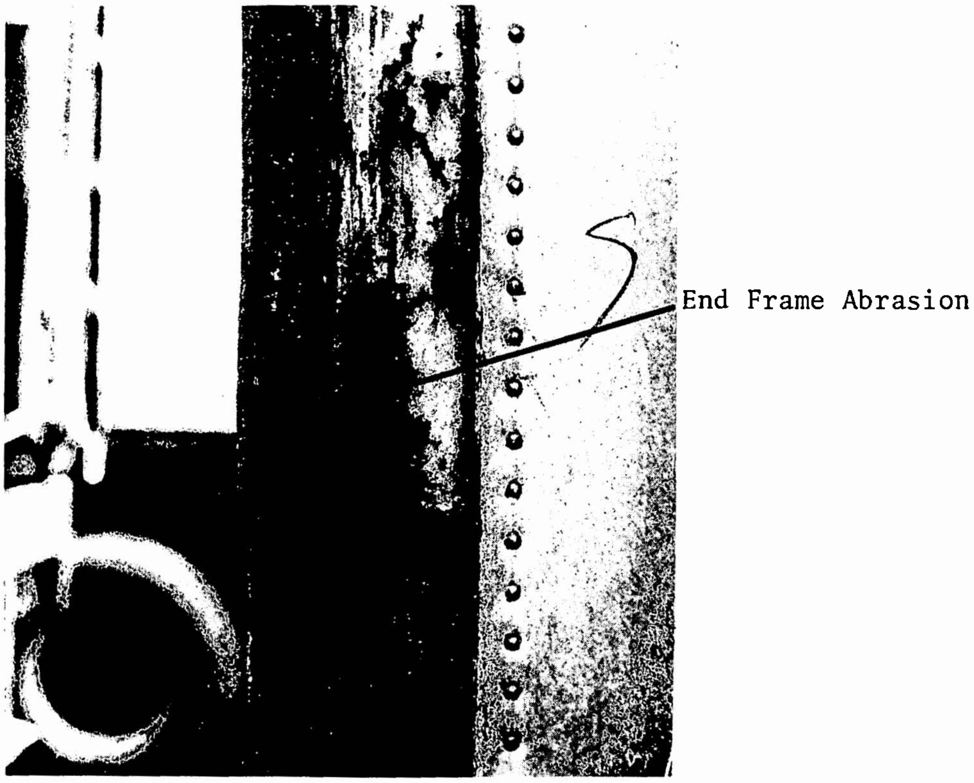


Figure 5-16. Typical Minor End Frame Damage

5.4.6 Doors

A major force applied to the container doors can bend and distort them out of shape. Figures 5-10 and 5-16 are cases of major damage to primary structure of the container which includes severe door damage. Minor damages include sprung hinges, seal impairment, door sill dents, and misalignment of locking bars and hardware. A torn door edge is given as an example of minor damage in Figure 5-17.

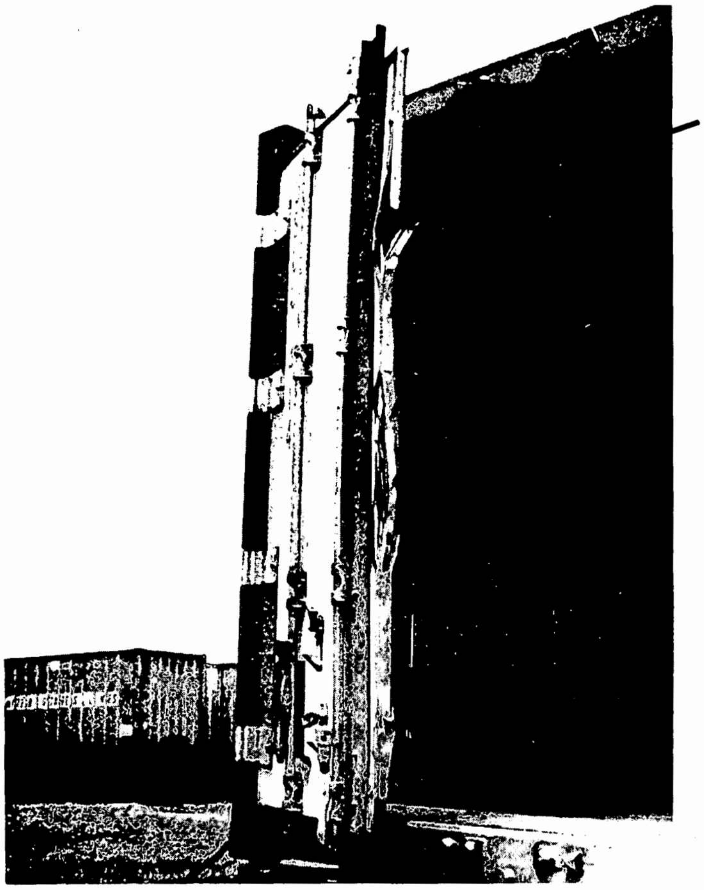

Shattering of Panel Material

Figure 5-17. Typical Door Damage

5.4.7 Corner Castings

The eight corner castings are susceptible to being smashed out of shape when containers are stacked or hit by the spreader bar. Secondly, they can be damaged when the unit is lifted by conventional hooks. Aluminum corner castings in early model containers proved to be especially inadequate. In both cases the fittings become distorted such that coupling, stacking in cells, securement to locking devices and the like becomes difficult if not impossible because the interface between the fittings and connectors becomes incompatible. The corner castings also receive abrasive damage, similar to that encountered by the vertical members of the end frame.

5.4.8 Structural Member Joining

Three primary methods are used to join different structural members of the container to one another: welding, riveting, and bolting. Typical joints include: a) side post - panel, b) corner casting - end frame, c) end frame - side rail, d) side rail - panel, e) floor/cross members - bottom rail, and the like. When one or both of the joining members is damaged, the joint is likely to be damaged as well. Numerous instances of joint failure associated with major damage are immediately apparent in several of the figures. The case of a post pulling out rivets was noted in Figures 5-11 and 5-12. Additionally, there are frequent cases where riveted connections loosen and become unserviceable due to repeated stress cycling. A particularly frequent example of this is the riveted joint of FRP/plywood to upper and lower rails where the rivet holes in the panel enlarge due to service.

5.4.9 Structural Member Corrosion

All steel and aluminum parts of a container are subject to one form of corrosion or another. First, there is ordinary oxidation of a metal or metal alloy such as experienced in certain steel products (Figure 5-16). Even some aluminum alloys are known to exhibit "pitting" action. Secondly, since many containers are constructed such that dissimilar metals are interfaced (e.g., steel rails and aluminum panels), corrosion due to electrolytic action occurs. Figure 5-6 shows this type of damage where the aluminum panels and steel rail or forklift pockets are in contact with each other. It is general practice in container design and fabrication to provide a gasket between or protective coating on mating surfaces of dissimilar materials. However, the metal fastener, whether a bolt or rivet, passes through the gasket and contacts the two metals, thus short-circuiting the protective feature of the design. It was noted in examining the corrosion at Figure 5-6 that the sacrificial action in the aluminum sheet propagated outward from the fasteners. Both types of corrosion processes are accelerated in a salt water environment.

5.5 Sources of Container Damage

The causes of container damage as reported by the transportation operators during the field survey work will be identified at this point. The types of damage to the individual parts of the container originate from several sources. These sources of damage can be related to the transport modes, handling equipments, and natural environment which constitute the total container operating system described in Section 4.

5.5.1 Sea Mode Transport and Transfer Damage

Some damage due to "racking" of the end frame on containers stacked on deck has been reported. End frame deformation causes the buckling of doors, broken hinges and crumpling of the end wall panel. One aluminum end wall panel was observed with diagonal ripples formed across its entire face, requiring its replacement.

Container damage to the panels, doors and other structural members due to cargo broken loose by ship pitch and roll motions has also been experienced. This damage source is discussed in more detail in Section 5.3.5.

External restraint systems used to lash containers on deck have also failed, resulting in damage to both the unit and sometimes its cargo. While the reported frequency of occurrence has not been high, the damage costs can be extremely high. A single loose container in a rough sea can cause havoc among the rest of the lashed units even though they themselves have been properly secured. A study (Reference 5-1) by twelve member carriers of the American Institute of Merchant Shipping reported that of 55 casualty incidents involving container <u>cargo</u> loss or damage:

a) In 47 of the incidents, the containers were stowed on deck;

b) Some 38 of the cases involved <u>more than one</u> container;

c) In 51 incidents, the method of restraint was by wire lashing; and

d) In 26 cases, a contributing factor or secondary cause was the failure of securing devices.

One operator reported damage caused by the tie-down cable for securing deck loaded units. Most of the damage was confined to the upper rails and rain gutters.

It should be noted that no damage due to the vertical force loads incurred under stacking conditions in cells or on deck was reported by the ship operators. However, the result of stacking units on deck contributed to the racking damage mentioned above.

According to findings from the steamship lines, the ship-shore transfer of containers represents an operation where a high frequency of damage to the container occurs. This is due both to equipment operator error and the use of marginally suitable equipment for the transfer, such as a single fall boom with slings. Operator error may be caused by inexperience with new types of handling equipment. Ship operators also report that as experience with the new equipment increases, the occurrence of damage decreases. However, this has not eliminated all damage to the container, even in the most sophisticated of operations. Human carelessness and the pressures of handling to meet a sailing deadline lead to additional incidents of damage.

The most frequent damage to the container during transfer operations occurs when the spreader frame is dropped on the container roof, missing the corner fittings. This action causes roof punctures in the near vicinity of the corner castings. Not much of a force is necessary to accomplish a puncture of this type since the roof panel is one of the weakest of the container components. Since the crane operator does not necessarily have a clear view of all four corners, roof puncture damage is commonplace. Recurring experience of this kind has led to the placement of protective plates at the top corners adjacent to the fittings.

One operator has reported that the use of slings in lifting has damaged the top rails. Another listed a great amount of damage to the external ribs or stiffeners during sling operations. A third operator noted that over a period of repeated use of slings, rivets loosened due to bending of the top rail.

Some damage during the placement or lifting of containers into cells was reported. The most severe cases included the ripping off of side panels. Minor damage consisted of cell guide abrasions to the end frame; however, this abrasion damage does not necessitate the removal of the units from operation for repair. It does not affect the structural strength.

Several operators interviewed expressed the fact that original containers purchased with aluminum corner castings deformed quite readily. The source of the damage apparently cannot be associated with any particular condition, but rather consisted of a series of occurrences which gradually deformed the fittings.

Lifting a container by single fall can also lead to damage. When lifting this way and encountering an eccentric center of gravity, a shifting of the cargo can damage the side panels. The tilting of the container or sway due to wind can cause it to hit the ship's deckhouse bulkheads. In addition, the use of a single fall can lead to a dropped container -- a force which the unit is not designed to withstand. In fact, no standard drop test for containers at even small heights exists at present.

5.5.2 Rail Mode Transport and Transfer Damage

The severe deceleration forces experienced by containers on rail cars in classification yards (rail humping) is the primary cause of damage for the rail transport mode. The transient motion on the rail car platform causes the loosely stowed cargo to shift against the end wall panel or doors resulting in damage ranging from minor to major in nature. Most operators interviewed acknowledged that some amount of rail humping damage was always experienced when transporting their units by rail.

One of the variables influencing the degree of damage suffered by containers on rail cars is the effectiveness of the car's draft gear and suspension resilience. There is a distinct difference in the environment provided by recently manufactured cars with well designed cushioning devices as compared to older cars without such devices. The problem experienced by a number of operators is the inability to assure the better rail cars would be available for through shipment of their containers. One operator reports that cushioned cars were available for movement of containers from the port city, but that containers were being transferred to unsatisfactory cars for the final leg of the shipment to remote locations. The consequence is that an extra handling operation is introduced into the cargo shipment cycle and that the harsh environment of humping and rail car motions are difficult if not impossible to avoid. Thus, damage of all sorts continues to accumulate during rail transport.

Operators who report that both container-on-flat-car and trailer-on-flat-car (including a container coupled to its chassis) modes are used find damage to be less in the latter case. Both modes suffer some damage from continued humping, but the suspension of the chassis cushions the loads as they are transmitted from the deck of the flat car to the frame of the container.

The use of gantry cranes in rail transfer operations can cause damage depending on the manner of lift employed. A top-lift device with spreader is responsible for roof puncture as noted in the previous section. In addition, if a bottom-lift attachment with grapplers is used, bottom rail damage is possible. One of the contributing factors for this damage is the lack of specified standard lift points on the various sizes of containers. Similarly, many units are not fitted with lifting hard points which would protect the rails.

The <u>Piggy Packer</u>, designed to transfer highway trailers, which include an integral chassis built into the vans, must be used very carefully when handling containers. The nutcracker jaws of the lifting mechanism easily damage container bottom rails. Operators report a singificant amount of bottom rail bending due to

Piggy Packer use on containers. Damage associated with side-transfer equipment was not documented because the operators interviewed did not use these in their operational systems.

5.5.3 Road Transport and Yard Transfer Damage

Reports from the transportation operators -- primarily steamship lines -- have been varied and uncertain on the subject of damage sustained when containers move over-the-road. The problem is due to the transfer of responsibility for the shipment to the highway common carrier when he moves the container/chassis unit out of the port terminal, with his own truck-tractor. The highway carrier is responsible to deliver the container/chassis back to the terminal in the same condition in which it left, and all claims for cargo damage sustained after leaving the terminal go against him. Thus, records on repairs of highway damage are necessarily incomplete.

The type of damage sustained on-the-road ranges from minor to catastrophic. In the first category, there are many light collisions with obstructions in which side panels tear, posts crumple, and rails are lightly bent. Major damage includes such accidents as low-bridging a container which may put the frame into such a condition that it is not repairable. In less severe cases, the top rails may be torn and bent and the roof taken off completely. Rolling over of a container/chassis unit is another possibility. The frequency of occurrence of major damage is relatively rare but the value of individual losses is high.

The marshalling yard is ranked by most operators as the place where damage to the container most frequently occurs. Handling operations are frequent as specific containers are moved to ships or on to inland destinations. Generally, maneuver space for handling equipment is limited. Forklifts and straddle carriers constitute the major handling equipment types used in yard operations. They transport the units from the yard to piers or rail sidings, lift them on and off of chassis, and maneuver them around the yard, as required.

Operators have reported a significant number of forklift puncture damage to the container, especially to the bottom rail and side panels. This damage usually occurs when the forklift operator tries to pick up off the ground a container which does not have fork pockets. However, even units with fork pockets experience frequent damage because the operator often misses the pockets with the fork tines. Cross member damage can also occur when lifting a container that does not have fork pockets. When larger units (35-40 foot) are lifted by a forklift, a bow in the bottom rail can result which could prevent the unit from seating properly in a ship cell, on a chassis, or on rail car bolsters.

Straddle carriers were introduced into transfer operations to help reduce forklift damage. However, some ship operators report that they have not experienced any significant change. Carriers with top-lift devices still produce punctures when hard contact is made with the roof. When stopping quickly, straddle carriers allow the container frame to rock and possibly to bend. External panel stiffeners are often ripped off when an improperly aligned straddle carrier approaches a unit. Also, when a straddle carrier employs a bottom-lifting device (grappler), bottom rail damage due to the squeezing action can result, as previously mentioned.

Damage usually associated with chassis operations in the yard occurs to the bottom rail, side panel and side posts when one container on a chassis hits another which is parked. One reason for this is the lack of chassis standards (especially a height standard) which results in several sizes of chassis being used for one standard container. If, in addition, yard space is insufficient, the parking of the units next to one another can result in damage to both the container and the chassis.

5.5.4 Natural Environment

The natural environment includes elements which are damaging due to cumulative effects over a long period of time, or which strike abruptly as in the case of a storm at sea. The question of whether large amplitude ship motions are natural environment or induced environment is a moot point and does not warrant any lengthy discussion. One point is clear -- the forces applied to containers on ships passing through storms can exceed standard design loads which do not cover the worst of worst ship motions.

The hostile environmental conditions which deteriorate containers to the point where damage can be identified are the atmosphere with its moisture and salt content, seawater over the deck, and temperature extremes. The first two act as a catalyst for corrosion and can deteriorate metal parts to the point of failure. The previous illustrations of disintegration of the aluminum panels at their joints to the bottom rail are a case in point. The panels shown could not resist the standard side loads.

Under extreme cold conditions, the freezing of water with its related expansive properties in forming ice, can spring the door hinges on containers. This is especially true of North Atlantic winter conditions where the sea spray hitting the deck-stowed units freezes on contact. Extreme cold has also been reported to make some of the sealants used in the construction of the container brittle, such that the sealant breaks away rendering the unit subject to leaking.

Under severe thermal excursions (especially due to the high temperatures of the tropics), containers constructed of dissimilar metals with different coefficients of expansion experience thermal stresses leading to loosening of rivets and joints. The reports obtained on the loosening of mechanical joints assumed that stress cycling was the primary source of the effect, but there is no reason to neglect the contribution of thermal cycling.

Rain and salt water both represent secondary sources of damage to the container. They both are involved as agents in the corrosion processes which result in container damage. A detailed discussion of the types of corrosion and their effect on the types of container materials is presented in Chapter 6.

Heavy seas, especially in the North Atlantic during winter months and the Pacific during typhoon season, are a source of severe if infrequent damage to deck-stowed containers. Indirectly, the energy of a heavy sea is translated into extreme ship pitch and roll motions, which result in racking damage to units on the bottom of the pile. Deck-stowed containers are also exposed to boarding seas. The tremendous power of a wave hitting the exposed units results in severe, if not total damage, to one or more of them. This point is evident in Figures 5-14 and 5-15, showing the kind of results that can be caused by wave action.

5.5.5 Cargo

Container damage can be attributed to the cargo for two reasons: improper weight distribution, and improper dunnaging. The weight of the cargo should be distributed evenly throughout the unit. The center of gravity of the load should be within two feet of the center of the container in the fore and aft direction, and within one foot in the transverse direction. If the load is concentrated in a small area, the unit could deform upon lifting or even break in half, depending on the weight distribution.

Both minor and major damage to the container can result if the blocking and bracing of cargo is insufficient or improperly applied. The omni-directional forces experienced during intramodal transport and handling are much more severe than those encountered in ordinary rail and highway transport. If the cargo has not been braced tightly, shifting of the cargo results, which can lead to the cargo breaking loose. This loose cargo can then damage the container walls, and possibly even break through containers. Figure 5-11 shows the results of internal damage due to shifting or loose cargo.

SECTION 6

MATERIALS OF CONSTRUCTION

Selection of the most suitable materials is a matter which dominates much of the current technical activity in the field of containerization. There is more controversy surrounding the material preferences of manufacturers and users than is attached to any structural arrangement or even to the general levels of strength and durability. As a consequence, this critical examination of the state-of-the-art in containerization dwells on the various properties of materials at great length. An attempt has been made to avoid encyclopedic completeness, while presenting and discussing those properties which must be considered in evaluating the several competing materials.

The state-of-the-art, for purposes of examining suitable materials, is very inclusive. There is no restriction that a material must be in use on commercially supplied containers. Thus, any material that is found in related structural applications is included. However, materials which are generally regarded as exotic, and have a high cost that would clearly show up in overall economic comparisons, are omitted regardless of their outstanding strength-to-weight ratio or other performance parameter.

The boundary between what constitutes a property of material and a property of design is not clear. Composite materials dispose the constituent materials so that each is used efficiently. This leads to good performance, as for example when sandwich-type composites are subjected to bending. By comparison, isotropic materials do not show up as well under specific loading applications until the material is put into a configuration which is appropriate to the load. This section concentrates on the inherent properties of the materials; all considerations of design efficiency are reserved for Section 7.

6.1 Properties of Aluminum

Among structural metals, aluminum is now second only to steel in the quantity produced throughout the world. It is abundantly available from commercial bauxite ores. Unlike most other common metals, aluminum cannot be separated from the ore by inexpensive smelting operations. The ore must first be treated chemically, then reduced electrolytically to yield an aluminum of commercial grade ranging from 99.0% to 99.5% purity (iron and silicon being the principal impurities).

Aluminum has many useful properties. In commercially pure form, it is highly resistant to atmospheric corrosion and to many chemicals, and it has very high electrical and thermal conductivity. This grade has such low strength as to be of little practical use as a material of construction. However, the addition of various alloying elements produces a vast improvement in structural qualities. The alloys also have less resistance to corrosion, an increase in specific gravity (modified by the lowering tendency of silicon and magnesium), and a decrease in conductivity.

Further advantages are found to a greater or lesser degree in alloys of aluminum. Their strength can be improved by strain hardening due to cold work. Improvement can also be achieved by suitable heat treatment. The effect of either cold work or heat treatment can be removed by annealing. (Depending on the alloy and temper, this requires raising the temperature to about 700°F.) Certain of the heat treatable alloys exhibit a phenomenon called age hardening within a few days after quenching. They must be kept at very low temperature (0°F) or their workability will be lost. Where workability is of no concern, the additional strength due to age hardening can be established quickly by heat treatment to 300°F, known as precipitation hardening.

6.1.1 Classification of Alloys

Aluminum alloys are designated by four-digit numbers in groups 1000 through 8000. The first digit describes the major alloying material. A summary of the characteristics of each group is contained in Table 6-1. In the 1000 series, the main applications exploit the high corrosion and the high electrical conductivity of almost pure aluminum. The relatively high percentage of copper (2% to 6%) in the 2000 series results in diminished resistance to corrosion, and in certain applications intergranular corrosion may occur. The 3000 series, with its good workability and moderate strength, has a general purpose character. In the 4000 series, silicon in quantities of 5% to 12% lowers the melting point of the alloy without embrittling the metal. The result is a metal especially suitable for welding and brazing wire. The alloying element magnesium, in the 5000 series, brings the corrosion resistance of this group to the point where its applications include marine service. In the 6000 series, the major alloying elements are magnesium and silicon added in the proportions necessary to form magnesium silicide. These elements provide the series with its heat treatability. The 7000 series has superior strength due to the alloying element zinc, but its corrosion resistance is not up to that of the 5000 and 6000 series. Thus, its utility in marine applications is reduced. An overall view of the characteristics of each group and their applications is contained in Table 6-1.

TABLE 6-1

SUMMARY OF ALUMINUM ALLOY CLASSIFICATIONS

Alloy Number	Major Alloying Element	Characteristics	Important Uses
1000	None	Practically pure aluminum very soft, low strength, high corrosion resistance	Chemical industry Bus duct
2000	Copper	Low corrosion resistance, high strength	Structural shapes aircraft engines forgings
3000	Manganese	Moderate strength, good workability	Cooking utensils, hardware, sheet metal work
4000	*Silicon	Lowered melting point	Welding & brazing wire
5000	Magnesium	Good corrosion resistance in marine environment, good weldability, good workability, good strength	Welded structures pressure vessels marine service
6000	Magnesium & silicon	Good corrosion resistance in marine environment, good weldability, workability and strength, heat treatable, good fatigue life.	Extrusions structures
7000	Zinc	High strength, low corrosion resistance, poor workability	Aircraft and other highly stressed structures
8000	Other Elements		

6.1.2 Temper of Alloys

In addition to the various alloys, a wide variety of mechanical characteristics, or tempers, is made available through combinations of cold work (strain hardening) and heat treatment. The temper should be so specified that the characteristics at that temper plus the characteristics added during fabrication will be the desired characteristics of the finished product. Table 6-2 lists tempers for both strain-hardenable alloys and heat treatable alloys.

TABLE 6-2

TYPICAL TEMPER DESIGNATIONS

Nonheat treatable alloys		Heat treatable alloys	
Temper designation	Definition	Temper designation	Definition
-0	Annealed recrystallized (wrought products only) applies to softest temper of wrought products.	-0	Annealed recrystallized (wrought products only); applies to softest temper of wrought products.
-H14	Strain-hardened half-hard temper.	-T2	Annealed (castings only).
-H18	Strain-hardened full-hard temper.	-T3	Solution heat-treated and cold-worked by the flattening or straightening operation.
-H24	Strain-hardened and partially annealed to half-hard temper.	-T4	Solution heat-treated.
-H28	Strain-hardened and partially annealed to full-hard temper.	-T5	Articicially aged only (castings only).
-H32	Strain-hardened and then stabilized. Final temper is one-quarter hard.	-T6	Solution heat-treated and artificially aged.
-H34	Strain-hardened and then stabilized. Final temper is one-half hard.	-T351, -T451, -T3510, T3511, -T4510, -T4511.	Solution heat-treated and stress relieved by stretching to produce a permanent set of 1 to 3 percent, depending on the product.
-H36	Strain-hardened and then stabilized. Final temper is three-quarters hard.	-T81	Solution heat-treated, cold-worked by the flattening or straightening operation, and then artificially aged.
-H38	Strain-hardened and then stabilized. Final temper is full-hard.	-F	For wrought alloys; as fabricated. No mechanical properties limits. For cast alloys; as cast.
-H112	As fabricated; with specified mechanical property limits.		
-F	For wrought alloys; as fabricated No mechanical properties limits. For casts alloys; as cast.		

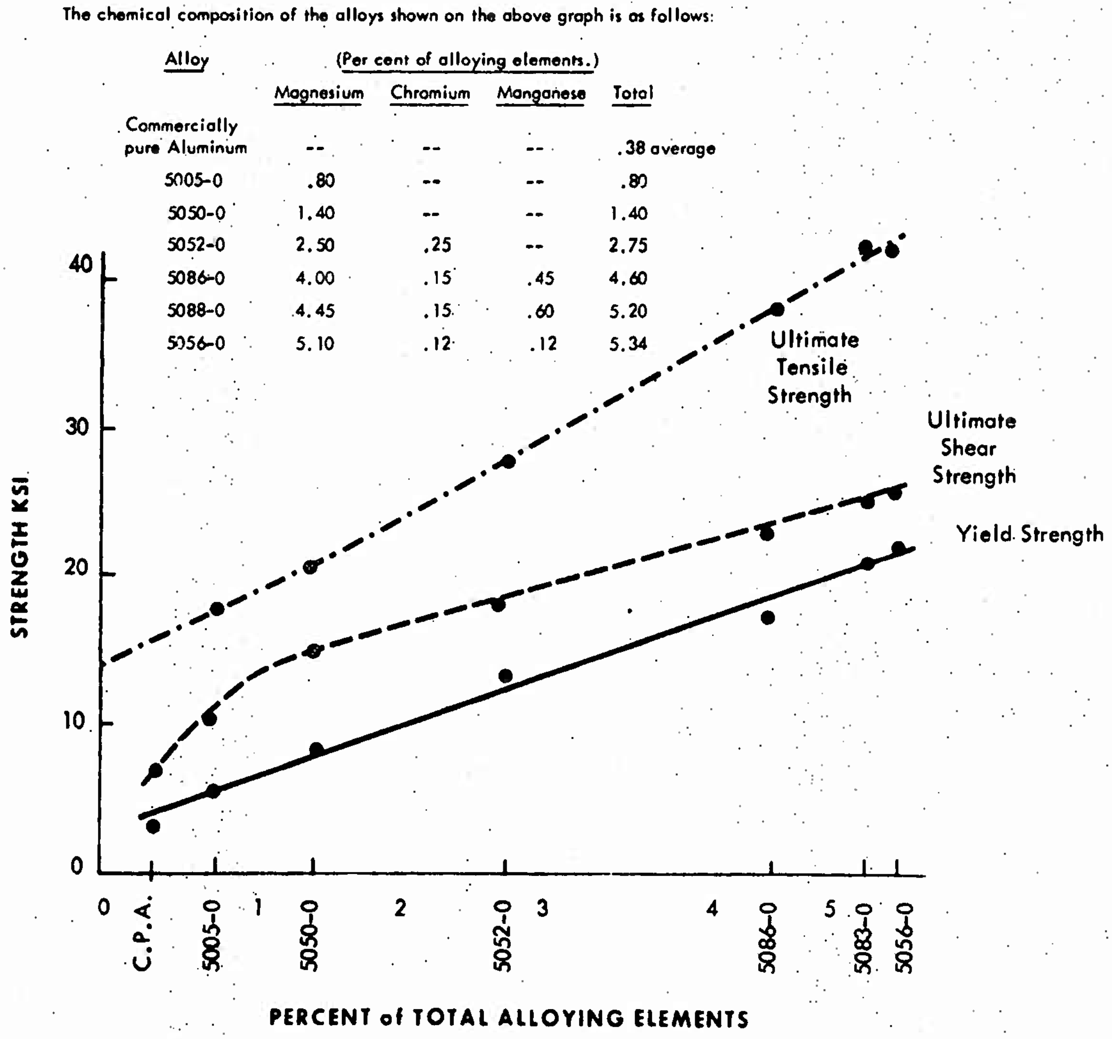
6.1.3 Mechanical Properties

Ultimate Tensile Strength (UTS). It is apparent that, with the several series of alloys and the many temper variations, the strength of aluminum alloys cannot be stated in simple terms. The ultimate tensile strength, or stress level in tension, that can be expected to produce a failure is influenced by alloy elements and by temper, as the few figures below show.

Alloy	Temper	UTS
1060	H18	19,000
2014	T6	70,000
2218	T72	48,000
3004	H38	41,000
4032	T6	55,000

Alloy	Temper	UTS
5052	H32	33,000
6061	T6	42,000
6261	T9	58,000
7001	T6	98,000
7075	T6	83,000

The apparent scatter in UTS can be rationalized. In general, the UTS (in the soft condition) will increase as the percentage of alloying elements increases. Figure 6-1 illustrates the 5000 series of alloys, for which the relationship of UTS to the total percentage of alloying elements is nearly linear.



The chemical composition of the alloys shown on the above graph is as follows:

Alloy	(Per cent of alloying elements.)			
	Magnesium	Chromium	Manganese	Total
Commercially pure Aluminum	--	--	--	.38 average
5005-0	.80	--	--	.80
5050-0	1.40	--	--	1.40
5052-0	2.50	.25	--	2.75
5086-0	4.00	.15	.45	4.60
5088-0	4.45	.15	.60	5.20
5056-0	5.10	.12	.12	5.34

Figure 6-1. Variation of UTS with Alloy Content

The figure provides some useful insights into the properties of aluminum alloys. Commercially pure aluminum is included on the plot, but it falls sufficiently below the line for the 5000 series of alloys to indicate that a given percentage of randomly occurring natural elements does not produce the improvement in properties that can be had with scientifically selected alloying elements. Strength versus total percent of alloying elements is very close to being a linear. (Strength versus percent of magnesium fits a straight line almost as well.) The UTS more than doubles (233%) in passing from 5005-0 to 5056-0: it goes from 18,000 to 42,000 psi. Commercially, this means going from a non-structural to a structural material. The Yield Strength (YS), going from 6,000 to 22,000 psi, goes through an even greater increase (366%). The ratio of UTS to YS goes from 3 to 1.9. This ratio will improve considerably with tempering, so that the designer may select from a wide range of material specifications.

The UTS of strain-hardening alloys is also dependent upon the amount of cold working applied to the part. Figure 6-2 illustrates the improvement in alloy 5052 in going from 5052-0 (soft) to 5052-H38 (full-hard). To take advantage of the maximum UTS of this alloy, a specification must required at least 5052-H36 (3/4 hard).

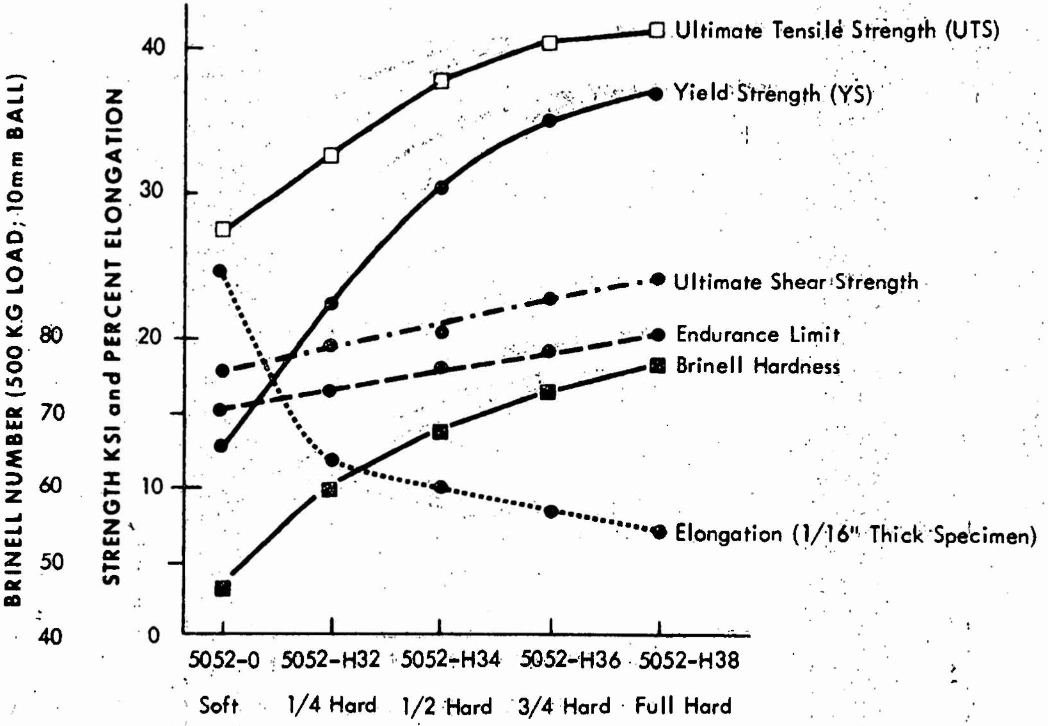


Figure 6-2. Variation of Mechanical Properties with Temper Alloy

The changes in mechanical properties as the alloy hardens are noteworthy. UTS increases from 28,000 psi -- a 50% gain. At the same time, the yield point shows a much greater change (about threefold) as it goes from the ductile alloy (25% elongation) to a somewhat brittle alloy (8 1/2% elongation). Surprisingly, the endurance limit (stress level below which the number of strain cycles that can be resisted is immeasurably large) increases very little. The flatness of this curve is due to the significance of stress risers (nicks, inclusions, imperfections) as the alloy becomes more brittle with increasing hardness.

Yield Strength (YS). Aluminum alloys, in common with most metals, exhibit a proportionality between applied stress and the resulting strain, in accordance with Hooke's Law. The behavior of a typical alloy is shown in Figure 6-3. For some ductile materials, the departure of the stress-strain relationship from linearity is abrupt, and the yield point is the proportional limit. For aluminum alloys, a permanent set of 0.002 inch per inch (0.2%) is defined to be the yield strength, with the values for tension and compression being approximately equal. Note that after yielding, the new stress-strain curve is A-B-C.

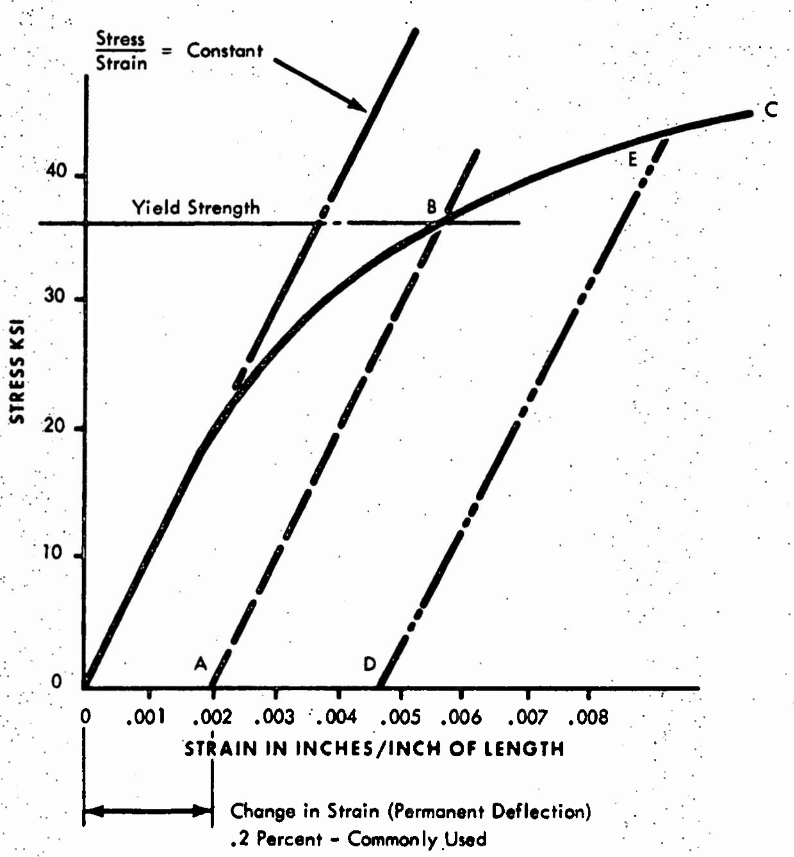


Figure 6-3. Stress-Strain Curve

The YS also depends on the amount of alloying elements and the amount of cold working (see Figures 6-1 and 6-2), and it generally follows the UTS. The above figure indicates one of the mechanisms at work in increasing the YS. As cold working increases from zero strain in an alloy in the soft condition to an amount equal to 0-D, the line conforming to Hooke's Law moves to the right to D-E. Point E now becomes the YS, and D-E-C becomes the stress-strain curve. The further to the right this line moves, the more brittle the alloy becomes. Figure 6-3 emphasizes this feature. Even though the UTS increases, the YS increases from 50% to 88% of the UTS, and the elongation decreases correspondingly. The modulus of elasticity for aluminum alloys, 10 x 10^6 psi, may be observed as the slope of the stress-strain curve in the linear region.

Elongation. The percentage of change in the length in a 2-inch long sample stressed to fracture in tension is defined to be the elongation -- it is an inverse measure of brittleness. In Figure 6-2, it may be seen that elongation is reduced as the hardness (cold working) increases. This is generally true for heat-treated alloys as well. The "overstraining" (Line A-D on Figure 6-3) is now a part of the length of the sample before stressing. The soft alloys are the good-ductility, high-elongation materials.

Temperature-Strength Relationship. The strength of aluminum alloys drops quite rapidly as temperature increases, so that at approximately 400°F it may have only 50% of the alloy's room temperature strength. At low temperatures, strength increases, so that at -300°F there is approximately a 50% increase. As would be expected, elongation increases as the temperature increases; however, elongation increases as temperature decreases also. The least elongation occurs at room temperature. With increasing strength and increasing elongation, aluminum becomes a very tough material at low temperatures.

In Figure 6-4, a typical curve based on alloy 5052-H38 graphically describes the above phenomenon. The curve shows the extent to which a strain-hardened alloy loses strength under varying temperature conditions. The useable range of this alloy is significant and appears on Figure 6-4. This alloy is very popular and among the strongest aluminum alloys readily available, but beyond 250°F, its use is severely limited.

Hardness. Brinell hardness is determined by forcing a very hard sphere (very often a carbide), under a known load into the surface of the material being tested and determining the indentation diameter. The hardness number is the load divided by the surface area of the indentation. The load generally used for aluminum alloys is 500 kilograms; the sphere diameter is usually 10 millimeters.

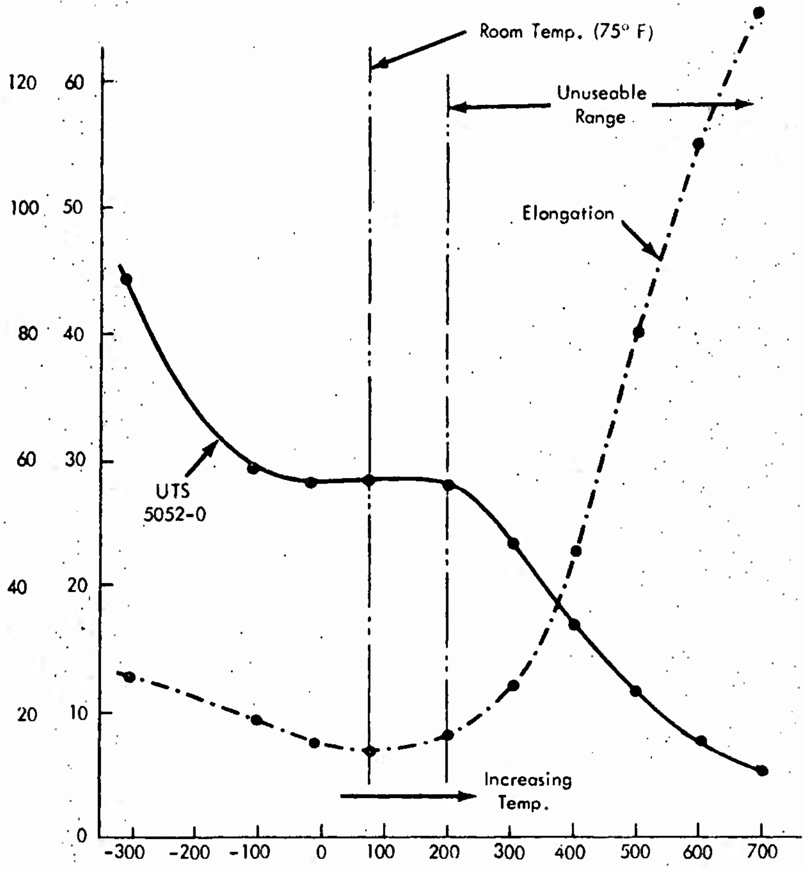


Figure 6-4. Temperature-Strength Relationship

In Figure 6-2, the Brinell number rises from 47 to 77 (an increase of 166%) and follows the curve of UTS very closely.

Aluminum is generally poor in resisting abrasion. However, the harder alloys may develop surface hardnesses satisfactory for use in mild abrasive environments.

Ultimate Shear Strength (USS). The USS is the maximum stress in shear exhibited by a part prior to complete failure. The USS is dependent on the same characteristics as the UTS; namely, the amount of alloying elements plus the degree of cold working (or heat treatment). Figure 6-2 shows the relationship of USS for soft alloys with increasing percentages of alloying elements. The USS increases quite rapidly from 8,000 to 15,000 psi with the addition of only a small amount of alloying element. It then increases slowly, so that the overall increase through this range of alloys is from 8,000 to 26,000 psi, or an increase of 325%. The USS increase due to cold working is from 18,000 to 24,000 psi, or only 33-1/3%.

Endurance Limit. Metal structures or parts subjected to repeated loads may fail at a stress level considerably below the specified strength of the material. This is designated as a fatigue failure -- a frequent form of field failure. The endurance limit is that stress value below which the structure or part can tolerate an immeasurably large number of strain cycles without failure. Thus, a noticeable flattening out of an S-N (stress level for varying numbers of stress cycles to produce a failure) indicates the endurance limit. The endurance limit for aluminum is not well defined on an S-N curve (see, for example, the data contained in MIL-HDBK-5, Reference 6-1). At one million cycles, a frequently used reference point for materials without a well-defined endurance limit, failures of alloy 6061-T6 products (free from notches and stress risers) will occur in the range of 18,000 to 26,000 psi.

Strength-to-Weight Ratios. A commonly used parameter for evaluating structural qualities of various materials is the strength-to-weight ratio. The ratio is especially useful in designing those structures wherein weight saving is an important design criteria. The following table shows commonly used container construction materials and their strength-to-weight ratios, based on both UTS, YS, and alloy. Specific gravity is listed in descending order.

TABLE 6-3

STRENGTH-TO-WEIGHT RATIOS OF SELECTED ALLOYS

Alloy	Density lbs./cu. in.	Spec. Gr.	UTS ksi	S/W	YS ksi	S/W
7075-T6	.101	2.80	86	30.6	73	26.1
X5090-H38	.095	2.60	69	26.6	53	20.4
2014-T6	.101	2.80	70	25.0	60	21.4
5052-H38	.097	2.68	42	15.6	37	13.8
6061-T6	.098	2.70	45	16.7	40	14.8
3003-H14	.099	2.73	22	8.1	21	7.7
ALCLAD						
7075-T6	.101	2.80	76	27.1	67	23.9
6061-T6	.098	2.70	42	15.6	37	13.7

Table 6-3 shows a large range of values for the s/w ratio of aluminum alloys. The commonly used structural materials for containers are about midway through the range (19.4 and 16.7) for alloys 5052 and 6061 respectively. A large increase of over 50% in strength can be achieved at no increase in weight by moving up to alloys 7075 and X5090 (30.6 and 26.6). The question of what is the best overall compromise arises, since alloy 7075 has previously been observed to be in a group of alloys which have less corrosion resistance. The alloy X5090 is a recent development which offers substantially higher strength at only a slight increase in cost (as compared to alloy 5052) while maintaining the attractive qualities inherent in the 5000 series.

It is interesting to note the range in weight of the various alloys, going from .095 to .101 lbs/cu.in., a difference of 6%. If X5090 were to be substituted for 5052, not only would there be an increase in strength, but also the specific gravity contribution to s/w ratio would be improved. Alcladding (see Corrosion, Section 6.1.4) reduces the strength of the alloys 7% to 11% depending on the thickness of the material used for cladding. The s/w ratio decreases a corresponding amount.

Analysis of the s/w ratio of various materials and combinations of materials leads to the most efficient materials to be used in structures where weight is a significant criteria. Re-examining the s/w ratios in light of their costs in a subsequent section leads to the most economical structures.

6.1.4 Corrosion of Aluminum Alloys

Pure aluminum is highly resistant to weathering, to marine atmospheres and to industrial atmospheres which often corrode other metals. A simple mechanism leads to this property. When aluminum is exposed to the atmosphere, a thin, invisible, self-healing oxide skin forms practically immediately. This oxide skin is highly resistant to corrosion and it protects the aluminum below it unless the film is ruptured or removed mechanically or by the action of the few substances which attack the skin, e.g., alkalis and some acids.

Unfortunately, the addition of alloying elements to aluminum decreases its corrosion resistance (and the ability to withstand stress corrosion), especially elements such as copper, zinc, and to a lesser degree, magnesium and silicon. The Aluminum Association, in order to rank the corrosion resistance of the various alloys and to make recommendations for specific conditions, has set up standardized tests for measuring surface attack. The results of these laboratory tests have been related to field experience so that by now the laboratory tests have a high degree of reliability.

The results of the laboratory tests are divided into ratings A through E in decreasing order of merit, based on exposures to sodium chloride solution of about 4% by intermittent spraying or immersion. Alloys with A or B ratings can be used in industrial and seacoast atmospheres without protection. Alloys rated C, D, or E should be protected, especially on faying surfaces.

Stress corrosion cracking ratings are based on the same test using the immersion technique. The ratings:

A - No known instance of failure in service or laboratory tests.

B - No known instance of failure in service; limited laboratory failures of short transverse specimen.

C - Service failures with sustained tension stress acting in short transverse direction relative to grain structure; limited failures in laboratory of long transverse specimen.

D - Limited service failures with sustained longitudinal or transverse stress.

The ratings are applied to a group of typical alloys in Table 6-4. Room temperature conditions should be associated with

TABLE 6-4

CORROSION RESISTANCE RATINGS

Alloy	Temper	Resistance to Corrosion	
		Gen.	Stress Corrosion Cracking
1060	All	A	A
2014	T3-T6	D	C
2024	T3-T4	D	C
	T6	D	B
	T8	D	A
3004	All	A	A
5005	All	A	A
5052	All	A	A
5056	H-11-H34	A	B
	H18, H38	A	C
	H192, 392	B	D
6061	0	B	A
	T4	B	B
	T6	B	A
6063	All	A	A
7075	T6	C	C
	T7	C	A

the ratings -- resistance to corrosion can be expected to decrease at elevated temperatures. It may be noted that the higher strength alloys are the ones with the poorest resistance ratings -- which gives rise to the need for protective surfaces on aluminum alloys in some applications.

Anodizing. The process of anodic oxidation is used to apply a thicker and tougher oxide coating to the aluminum surface than would form naturally. Resistance to corrosion is increased in proportion to the coating thickness. Such coatings are extremely adherent and do not delaminate during the usual fabricating processes. Additionally, anodizing can include the application of a dye color.

Alcladding. The corrosion resistance of an alloy may be improved to equal that of pure aluminum by "sandwiching" the alloy between thin skins of pure aluminum or highly corrosion resistant alloys. In addition to physically protecting the alloy, the skins will be anodic to the core material, hence protect it electrolytically at the same time. This coating is introduced early in the metal processing stage so that it intimately adheres to the core by being passed through the rolling mill together. The cladding thickness and alloy have been standardized (see Table 6-5), however, other thickness and materials are available to special order.

TABLE 6 - 5

TYPICAL ALCLAD COMPOSITIONS

Core	Cladding	Composite Thickness	Nominal Cladding Thickness % of Composite Thickness
2014	6003	to .024	10%
		.025 - .039	7-1/2
		.040 - .099	5
		.100 and over	2-1/2
2024	1230	.188 and over	1-1/2
6061	7072	All	5
7075	7072	to .062	4
		.063 - .187	2-1/2
		.188 and over	1-1/2

Needless to say, cladding increases the cost while decreasing the overall strength-to-weight ratio of the material since the skins generally add little to the strength. However, some specialized properties are sometimes produced this way. Easily brazed alloys can be clad to a non-brazeable core to allow the composite to be assembled by brazing.

Painting. Container experience in marine environments indicated that considerable surface pitting on panel sheets could be expected. Furthermore, appearance of containers is a factor most operators are concerned about. Thus, almost all aluminum sheets for use on containers are prepainted at the mill with wash and prime coats on both surfaces and an additional finish coat (generally acrylic) on the outside. In addition to arresting corrosion, painting of aluminum alloy sheets also simplifies cleaning of the end product.

Corrosion - Dissimilar Metals. Dissimilar metals, coupled together and exposed to an electrolyte, form a short-circuited galvanic cell which accelerates corrosion of one metal in the couple. The corrosion takes place in the more anodic of the metals, i.e., the metal with the highest negative potential, and its extent depends on the conductivity of the electrolyte and the potential difference between the metals. When containers are constructed of a combination of aluminum and steel, the conditions for accelerated corrosion are present: dissimilar metals with a large potential difference, and abundant sea water constituting an electrolyte of high conductivity. Of the pair, aluminum is the sacrificial material.

Protective measures can be taken. By coating the steel with zinc (more anodic than aluminum) the sacrificial element is in the coating. Additionally, the potential difference is smaller thereby reducing the rate of corrosion. There are design features which can be incorporated to further inhibit corrosion and they are used in the container manufacturing industry. Various coatings, bituminous and otherwise, have been recommended but most coatings fail in that if they are in the joint -- the joint loosens and relative motion accelerates the removal of the coating and corrosion eventually gets a foothold. A more recent preventive measure is an inert film such as polyethylene, cut so that it extends 1/4 to 1/2 inch beyond the joint, plus coating of the aluminum with zinc chromate primer. This has proven to be an effective joint protection in service experience to the present time. Just as important as the protection of the faying surfaces, is the protection of dissimilar metal fasteners. This is extremely difficult to accomplish, so much so that some container users insist on using fasteners and members of only a single material.

Of less importance, but nevertheless to be considered, is dissimilar metal protection between the various aluminum alloys. Adequate protection is generally obtained by covering both faying surfaces with a zinc chromate primer.

6.1.5 Weldability

The weldability of aluminum presents a mixed picture. On the one hand, there are a number of alloys which have good welding characteristics and structures of welded fabrication offer some advantages over those based on other joining means. Conversely, when welding is performed in a purely manual way, the skill level required is quite high. The high thermal conductivity of aluminum (as compared to steel) requires high heat inputs for fusion welding and more precise control of the welding variables. Additionally, the tenacious oxide film on aluminum alloys must be removed or broken up during fusion welding to permit coalescence of the base and filler material. However, with mechanical and automatic equipment for aluminum welding, the required skill level is forced down, cost benefits can be achieved, and a changeover to welding is reaching more acceptance in many industries. A typical hand-held welding machine is capable of producing seams at the rate of 10 feet/minute. A carriage-mounted machine is shown in Figure 6-5 (reproduced from Reference 6-2).

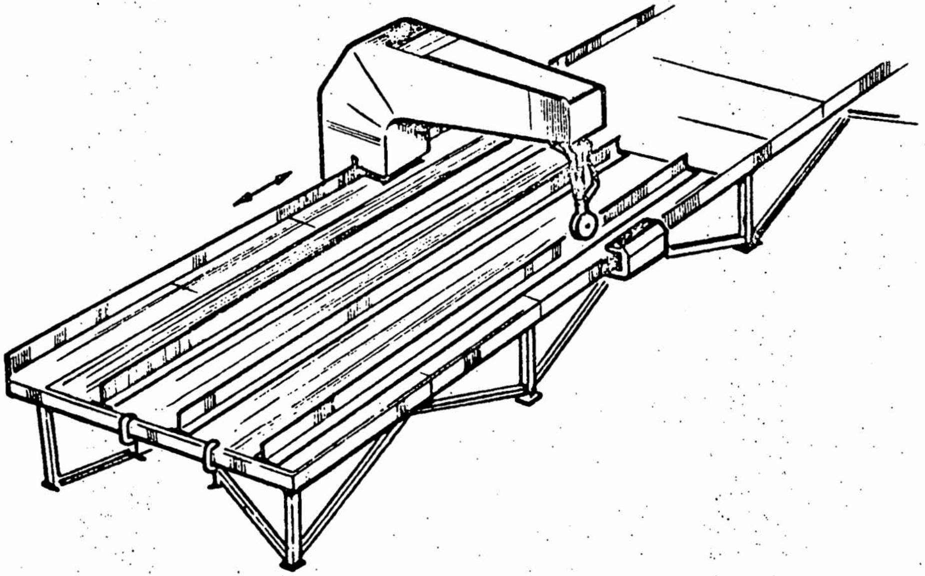


Figure 6-5. Typical Carriage-Mounted Welding Machine

A rating system for aluminum alloys and their various tempers, developed by the Aluminum Association, follows:

A = Generally weldable by all commercial procedures and methods.
B = Weldable with special techniques or for specific applications which justify preliminary trials or testing to develop welding procedure and weld performance.

C = Limited Weldability because of crack sensitivity or loss in resistance to corrosion and mechanical properties.

D = No commonly used welding methods have been developed.

The alloys of importance to the container industry rate well on the scale. For example, alloys 5052 and 6061, which are widely used for sheet stock and extrusions respectively, are rated "A" in all tempers for both gas and arc welding. However, the highest strength alloys are very difficult if not impossible to weld. Alloy 7075, for example, has a "D" rating for gas welding and a "C" rating for arc welding.

The application of welding requires attention be placed to the location of joints during design. When alloys of H temper (cold worked) are welded, the heat affected zone becomes changed to effectively an O condition (annealed). Similarly, when T temper alloys are welded, the heat affected zone is also changed to an O condition.

Full details on welding techniques used to produce satisfactory fabrications for many diverse uses are described in Reference 6-3.

The point to be observed in regard to the subject of weldability of aluminum is that feasibility is fully established. The alloys which have appropriate properties for application in container construction are fully weldable. The techniques of fabrication are fully developed and in continuous application in related industries. There are advantages in weight-saving due to elimination of large overlaps found in riveting and in the weight of rivets; and in the avoidance of stress concentrations in joints. Labor saving advantages have also been realized. The performance of maintenance by welding is no detriment to the application of the technique since many items in the Army inventory are of welded aluminum construction -- including vehicles such as armored personnel carriers.

6.1.6 Aluminum Castings

Techniques used for casting aluminum are principally sand mold, permanent mold, and die casting. Casting alloys follow wrought alloys in that there are two general types, non-heat treatable and heat treatable. The non-heat treatable are generally used in the as-cast condition (F) but may be annealed to relieve casting stresses or to limit distortion while machining. Heat treatable alloys are treated to take advantage of the higher strengths after heat treatment.

The choice among the alloys depends upon service requirements and in some cases the ability to cast the desired part. The various alloying elements give the casting similar corrosion and high temperature properties as those listed under wrought alloys, with the following difference. The addition of silicon gives excellent casting qualities and is required for complex castings.

Sand castings are used when the quantities required are small, when a smooth surface is not required (or can economically be secured through machining) and when close tolerances on as-cast dimensions are not required. Permanent mold castings are smoother, require less machining, can be cast to closer tolerances, and for the same alloy have higher mechanical properties (tensile strengths improve 10% - 30%). Die castings, used to a lesser degree, can be held to much closer tolerances, have a smooth surface, and high degree of uniformity. However, tooling costs are high and there is a limit to the alloys that can be used. The following table lists some of the commonly used alloys, type of casting, and typical uses:

TABLE 6-6

TYPICAL CASTING ALLOYS

ASTM Designation	Hardness Bhn	Type of Casting	Typical Uses and General Data
CS72A	70	Sand and Permanent Mold	General purpose alloy with fair strength and resistance to corrosion; often used for oil pans, crankcases, camshaft housings, and other parts not highly stressed.
CG100A	--	Sand and Permanent Mold	Primarily a piston alloy, but also used for aircooled cylinder heads and valve tappet guides.
S5B	40	Sand and Permanent Mold	Used for intricate castings having thin sections; good resistance to corrosion; fair strength but good ductility.
C4A	60	Sand	General structural castings requiring high strength and shock resistance.
CN42A	--	Sand and Permanent Mold	Used primarily for aircooled cylinder heads, but also used for pistons in high performance gasoline engines.
ZG61A	--	Sand	General purpose structural castings developing strengths equivlent to SAE 38 without requiring heat treatment.
ZG32A	65	Sand and Permanent Mold	High strength, general purpose alloy; excellent machinability and dimensional stability; very good corrosion resistance; can be anodized.
ZG61B	75	Sand	High strength, general purpose alloy; excellent machinability; easily polished; very good corrosion resistance; can be anodized.
ZC81A	75	Sand and Permanent Mold	High strength, general purpose alloy; excellent machinability; easily polished; very good corrosion resistance; can be anodized.
G4A	50	Sand	Moderate strength; high resistance to corrosion.
SN122A	--	Permanent Mold	Pistons, low expansion.
SC51A	65	Sand and Permanent Mold	General use where high strength and pressure tightness is required, such as pump bodies and liquid-cooled cylinder heads.

6.1.7 Forgings

Forging is a metal working operation which forces metal into useful form by plastic flow. The alloys commonly forged are shown in Table 6-7 below. The most noteworthy example of aluminum forging of interest in container design is that of the corner fittings being forged by one American manufacturer to be able to supply an all aluminum, light weight container. These fittings are expected to overcome the deficiencies experienced with cast corner fittings in previous all aluminum designs. The alloy used is a 7000 series, high-strength, weldable alloy. This alloy will be weldable to heavy gauge extruded corner posts. Forgings lend themselves to fittings, where their high strength, good surface and relatively low cost allow them to compete with steel in a highly stressed application.

TABLE 6 - 7

TYPICAL FORGING ALLOYS

Alloy	Temper	Tensile Strength	Yield Strength (Offset 0.2%), Min, psi	Elongation in 2 in., Min, %	Brinell Hardness 500-kg Load 10-mm Ball, Min
1100	-H112	11,000	4,000	25	20
2014	-T6	65,000	55,000	8	125
2218	-T72	38,000	29,000	8	85
2219	-T6	58,000	38,000	10	100
3003	-H112	14,000	5,000	25	25
4032	-T6	52,000	42,000	5	115
5083	-H111	42,000	22,000	14	—
6061	-T6	38,000	35,000	10	80
6151	-T6	44,000	37,000	14	90
7075	-T6	75,000	65,000	10	135

6.1.8 Workability

Since the alloys of special interest to the container industry are supplied and processed in the hardened state, their workability will be noted. This general property of an engineering material describes its ability to be formed, cut, and handled by the usual press shop tools. The high strength alloys do not rate high in overall workability. On an arbitrary scale used by the Aluminum Association using rankings from A - D, they are in either the fair or poor category, as the few data below show. Note also that the limitations on bend radii for a 90° cold bend limit the forming that could be performed during a corrugation process and thereby influence the industry use of rivet-on stiffeners:

Alloy	Workability Rating (indicative of Machinability)	Cold Bend Radius Limit (multiple of thickness)
2014-T6	D	4 x
3004-H38	C	2 1/2 x
5052-H38	C	2 1/2 x
6061-T6	C	1 1/2 x
7075-T6	D	5 x

The alloys listed are generally similar, but the two having superior strength, alloys 2014 and 7075, are extremely difficult to work. They are avoided in applications requiring any forming at all. The limiting cold bend radius noted above (as a multiple of the material thickness) is applicable to gauge of material as currently used in container sheet parts. For thicker material, the multiple increases.

6.1.9 Cost of Aluminum Alloys

Aluminum is generally sold by the pound, the ingot price (prior to being processed into useable forms) in the current market being $0.29/lb. The quoted prices are frequently discounted by an amount which varies with market conditions and the importance to the supplier of any particular order.

The pricing and procedures of Table 6-8 are taken from the Alcoa price data sheets dated principally 14 April 1970. Due to the special nature of sheets for trailers and containers, the industry has established a special commodity price for this material.

When the prices of aluminum are introduced into the material comparisons of Section 6-5, the regular pricing schedule for flat sheets of alloy 5052 is used. This is done to keep the materials evaluation as objective as possible. The price fluctuations due to market conditions are a substantial but unpredictable quantity which similarly are not taken into account. It may be noted that the higher strength alloys, 7075 and 2014 (tempered) are notably higher in cost. Their suitability for many applications is probably missed when selection decisions are based on cost only rather than on a more rational criteria as developed in Section 6-5.

TABLE 6 - 8

PRICING SCHEDULE FOR ALUMINUM SHEET
in Alloy 3004 and 5052 - Sheets - 30,000 Lbs.

	Reg. Pricg. Flatsheet	Trailer Stock Coiled Sheet		QUANTITY EXTRAS/LB.	
Thickness	30 - 36 in. W/ 72 - 180 in. L	24 - 50 in. W	50 - 60 W	30,000 lbs. and over	Base Price
A = .126 - .096	$ .463	$ .401	$ .411	29,999 - 20,000	.010
B = .096 - .076	.465	.402	.412	19,999 - 10,000	.020
C = .076 - .060	.467	.403	.413	9,999 - 8,000	.050
D = .060 - .047	.469	.405	.415	7,999 - 4,000	.070
E = .047 - .037	.480	.435	.445		
F = .037 - .030	.511	.435	.465		

	PRICE VARIATION PER ALLOY									
Thickness	1100 3003	5005	3004 5052	5050	5657 5557 5457 5257	6061-0	6061-T	2024-0	2024-T3	2014-T 7075-T
A	.441	.463	.463	.451	.542	.483	.502	.504	.533	.549
B	.443	.453	.465	.453	.540	.487	.506	.513	.547	.566
C	.445	.445	.467	.457	.534	.492	.513	.519	.560	.586
D	.447	.447	.469	.459	.540	.501	.524	.536	.584	.620
E	.459	.449	.480	.474	.545	.510	.533	.547	.612	.659
F	.464	.464	.511	.480	.550	.540	.567	.573	.653	.718

6.2 Properties of Steel

Steel is the structural material in widest use and provides the base line against which the proponents of most other materials claim some advantage. While the main constituent of steel, the chemical iron, has little commercial application in its pure form, the addition of alloying elements produces radically improved properties. Additionally, the hot and cold working operations during production have profound effects on the properties of the final product.

The production of steel commences with smelting of ore in blast furnaces. The underlying chemical reaction is straightforward. The ore, being an oxide of iron, is reduced to iron plus carbon dioxide by the reducing agent carbon. The combustion of the carbon provides the necessary heat. The impurities are fused with limestone and removed as slag. The product of the blast furnace is pig iron, the raw material for processing into useful iron and steel compositions. Pig iron, scrap, plus a flux then yield steel in an open-hearth furnace process. Other steel making methods -- Bessemer converters, electric furnaces, and basic oxygen process -- treat the materials in a roughly similar way. Molten steel is then cast into ingots which are hot rolled into billets (less than six inches in diameter), blooms (over six inches in diameter), or wide section slabs. Billets and blooms are subsequently hot rolled into bars or structural shapes and slabs are hot rolled into plate or sheet. Further hot work produces tube and rod stock, and forgings. Subsequent cold working includes cold rolling of sheet stock, stamping, and wire drawing.

6.2.1 Classification of Steels

Standards for the designation of steels on the basis of chemical composition and physical test properties have been established by the American Iron and Steel Institute (AISI). Such steels are referred to as standard. The Society of Automotive Engineers (SAE) has similarly developed a classification system using chemical composition. The two organizations now closely coordinate their designations to avoid any conflict.

The four digit system is used. The first digit indicates the type, as for example: "1" for carbon steel, "2" a nickel steel, "3" a nickel chromium steel. See Table 6-9 for a summary of the use of the designations. Frequently all the types, other than carbon steel, are lumped as alloy steels.

The carbon steels are the high volume, general use materials. It may be noted in Table 6-9 that various elements are included in addition to carbon, even in the 10XX series. Additional detail on the chemical composition of some common carbon steels are as follows, where the right hand two digits of an AISI designation are indicative of the carbon content of the steel:

AISI No.	% C	% Mn	% P (max)	% S (max)
1010	.08 - .13	.3 - .6	.04	.05
1020	.18 - .23	.3 - .6	.04	.05
1030	.28 - .34	.6 - .9	.04	.05
1040	.37 - .44	.6 - .9	.04	.05

The purpose of these elements is to improve machineability, surface quality and to augment the ability of carbon to increase strength and hardness of the metal. However, the primary determinant of the properties of carbon steel remains the amount of carbon. Sheet stock and structural forms are the items of interest in container design and the carbon content, in the range of 0.05 to 0.35 percent, may be seen in the listing of suitable applications (Table 6-10).

TABLE 6-9

BASIC NUMBERING SYSTEM FOR STEELS

Numerals and Digits	Type of Steel and Average Chemical Contents, %
	CARBON STEELS
10XX	Plain Carbon
11XX	Free Cutting, S 0.12, 0.20 and 0.29
12LXX	Leaded, S 0.30 — Free Cutting
	MANGANESE STEELS
13XX	Mn 1.75
	NICKEL STEELS
23XX	Ni 3.50
25XX	Ni 5.00
	NICKEL-CHROMIUM STEELS
31XX	Ni 1.25, Cr 0.65 and 0.80
32XX	Ni 1.75, Cr 1.07
33XX	Ni 3.50, Cr 1.50 and 1.57
34XX	Ni 3.00, Cr 0.77
	MOLYBDENUM STEELS
40XX	Mo 0.20 and 0.25
44XX	Mo 0.40 and 0.52
	CHROMIUM-MOLYBDENUM STEELS
41XX	Cr 0.50, 0.80 and 0.95, Mo 0.12, 0.20, 0.25 and 0.30
	NICKEL-CHROMIUM-MOLYBDENUM STEELS
43XX	Ni 1.82, Cr 0.50 and 0.80, Mo 0.25
43BVXX	Ni 1.82, Cr 0.50, Mo 0.12 and 0.25, V 0.02 minimum
47XX	Ni 1.05, Cr 0.45, Mo 0.20 and 0.35
81XX	Ni 0.30, Cr 0.40, Mo 0.12
86XX	Ni 0.55, Cr 0.50, Mo 0.20
87XX	Ni 0.55, Cr 0.50, Mo 0.25
88XX	Ni 0.55, Cr 0.50, Ma 0.35
93XX	Ni 0.25, Cr 1.20, Mo 0.12
94XX	Ni 0.45, Cr 0.40, Mo 0.12
97XX	Ni 0.55, Cr 0.20, Mo 0.20
98XX	Ni 1.00, Cr 0.80, Mo 0.25
	NICKEL-MOLYBDENUM STEELS
46XX	Ni 0.85 and 1.82, Ma 0.20 and 0.25
48XX	Ni 3.50, Mo 0.25
	CHROMIUM STEELS
50XX	Cr 0.27, 0.40, 0.50 and 0.65
51XX	Cr 0.80, 0.87, 0.92, 0.95, 1.00 und 1.05
501XX	Cr 0.50
511XX	Cr 1.02
521XX	Cr 1.45
	CHROMIUM VANADIUM STEELS
61XX	Cr 0.60, 0.80 and 0.95, V 0.10 and 0.15 minimum
	TUNGSTEN CHROMIUM STEELS
71XXX	W 13.50 and 16.50, Cr 3.50
72XX	W 1.75, Cr 0.75
	SILICON MANGANESE STEELS
92XX	Si 1.40 and 2.00, Mn 0.65, 0.82 and 0.85, Cr 0.00 and 0.65
	LOW ALLOY HIGH TENSILE STEELS
9XX	Various
	STAINLESS STEELS
	(Chromium-Manganese-Nickel)
302XX	CR 17.00 and 18.00, Mn 6.50 and 8.75, Ni 4.50 and 5.00
	(Chromium-Nickel)
303XX	Cr 8.50, 15.50, 17.00, 18.00, 19.00 20.00, 20.50, 23.00, 25.00 Ni 7.00, 9.00, 10.00, 10.50, 11.00, 11.50, 12.00, 13.00, 13.50, 20.50, 21.00, 35.00
	(Chromium)
514XX	Cr 11.12, 12.25, 12.50, 13.00, 16.00 17.00, 20.50 and 25.00
515XX	CR 5.00
	BORON INTENSIFIED STEELS
	B denotes Boron Steel
	LEADED STEELS
XXLXX	L denotes Leaded Steel

TABLE 6-10

APPLICATIONS OF CARBON STEELS

Percent C	Uses
0.05 - 0.10	Sheet, strip, tubing, wire nails
0.10 - 0.20	Rivets, screws, parts to be case-hardened
0.20 - 0.35	Structural steel, plate, forgings such as camshafts
0.35 - 0.45	Machinery steel — shafts, axles, connecting rods, etc.
0.45 - 0.55	Large forgings — crankshafts, heavy-duty gears, etc.
0.60 - 0.70	Bolt-heading and drop-forging dies, rails, setscrews
0.70 - 0.80	Shear blades, cold chisels, hammers, pickaxes, band saws
0.80 - 0.90	Cutting and blanking punches and dies, rack drills, hand chisels
0.90 - 1.00	Springs, reamers, broaches, small punches, dies
1.00 - 1.10	Small springs and lathe, planer, shaper, and slatter tools
1.10 - 1.20	Twist drills, small taps, threading dies, cutlery, small lathe tools
1.20 - 1.30	Files, ball races, mandrels, drawing dies, razors

6.2.2 Temper and Heat Treatment

Alloys of steel respond in a number of ways to cold working and heat treatment, depending primarily on their alloying elements. The strength of mild steel can be doubled by cold rolling to a full hard condition where it then becomes difficult to work. The workability and elongation of cold rolled steel in various tempers is summarized in Table 6-11.

TABLE 6-11

EFFECT OF TEMPER ON MECHANICAL PROPERTIES OF COLD ROLLED STRIP STEEL

Temper	Tensile strength, psi	Elongation in 2 in. for 0.50 in. thickness of strip, percent	Remarks
No. 1 (hard)	90,000 ± 10,000	3 ± 2	Intended for flat blanking only.
No. 2 (half hard)	65,000 ± 10,000	10 ± 6	Intended for bending up to 90 deg. across the rolling direction. (No bending along the rolling direction.)
No. 3 (quarter hard)	55,000 ± 10,000	20 ± 7	For shallow drawing and stamping. Bends 180 deg across the rolling direction. Bends up to 90 deg along the rolling direction.
No. 4 (skin-rolled)	48,000 ± 6,000	32 ± 8	For fairly deep drawing where no surface strain or fluting is permissible. Bends 180 deg in any direction.
No. 5 (dead soft)	44,000 ± 6,000	39 ± 6	For deep drawing where stretcher strains or fluting are permissible. Also for drifting erroneously called "extrusion." Bends 180 deg in any direction.

Heat treatments are performed on various steels for the purpose of improving their strength and hardness. When the temperature of the metal is raised beyond its critical range, the existing crystal structure of the aggregate of ferrite (pure iron) and cementite (iron carbide) progressively changes to a homogeneous solid solution. That grain size which is reached during heating to the maximum temperature can be retained during cooling back to the normal temperature range. The essential reaction during heating is ferrite plus cementite to austenite which is reversible on cooling. The reaction, however, requires time. Thus, by quenching the reaction velocity does not develop and the austenite does not become significant. The austenite is restrained in the steel at normal temperatures. A more complete coverage of the theory and processes of steel heat treatment is not warranted in this examination of materials. It will simply be noted here that Brinell's original work, published in 1901 in the Journal of The Iron and Steel Institute, still provides a comprehensive view of the benefits of heat treatment (see Figure 6-6). Note on the curves that the lowest line corresponds to AISI 1010 grade (including all the elements other than carbon) and that by quenching from 850°C (1560°F) the tensile strength can be raised to 85,000 psi, roughly a doubling of the unheat-treated strength.

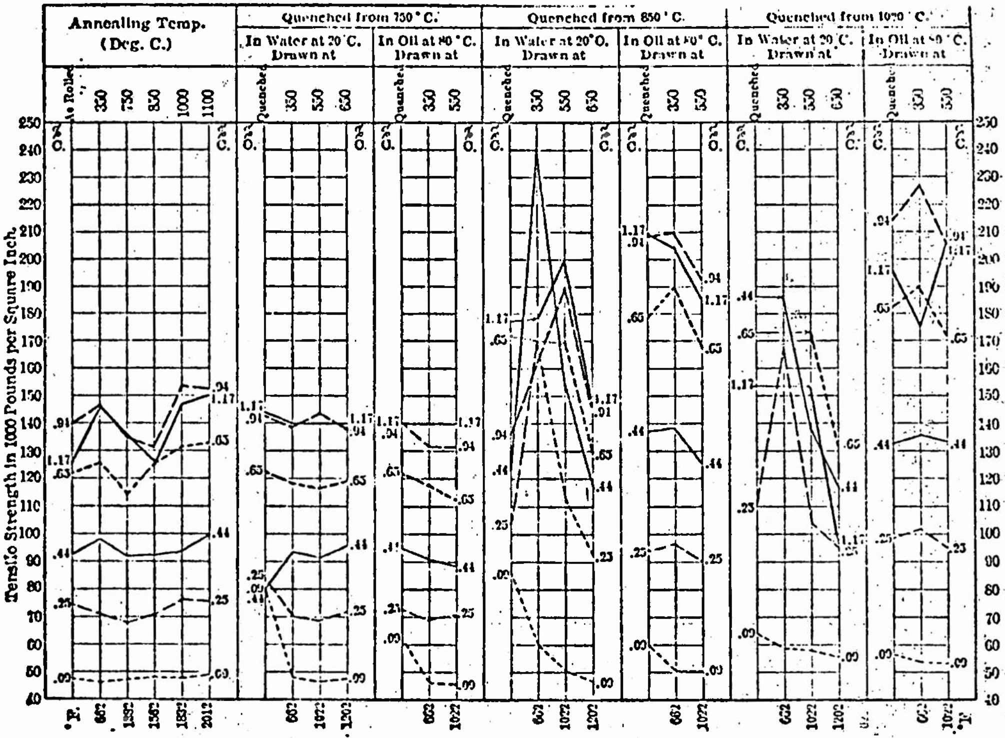


Figure 6-6. The Effect of Heat Treatment on Tensile Strength of Steel (Data from Brinell's Original Experiments)

The unfavorable effect of extreme hardness and minimum ductility, which are associated with peaking of tensile strength, was noted in Table 6-11. Modification of the results of heat treatment is, therefore, usually accomplished by temperature or drawing. This consists of reheating the hardened steel to a temperature below the critical range and cooling as desired. Note the effects of drawing in the curves of Figure 6-6.

6.2.3 Mechanical Properties

Ultimate Tensile Strength (UTS). Carbon steels exhibit an UTS (sometimes referred to simply as tensile strength) almost directly in proportion to the carbon content up to about 0.8%

carbon, after which it remains fairly level (see Figure 6-7). These figures are based on hot-rolled steels and UTS is available from approximately 50,000 psi at 0.1% carbon up to 130,000 psi at 0.8% carbon. Beyond this point there is little increase in strength but a significant decrease in elongation, hence these carbon steels are specified for special situations.

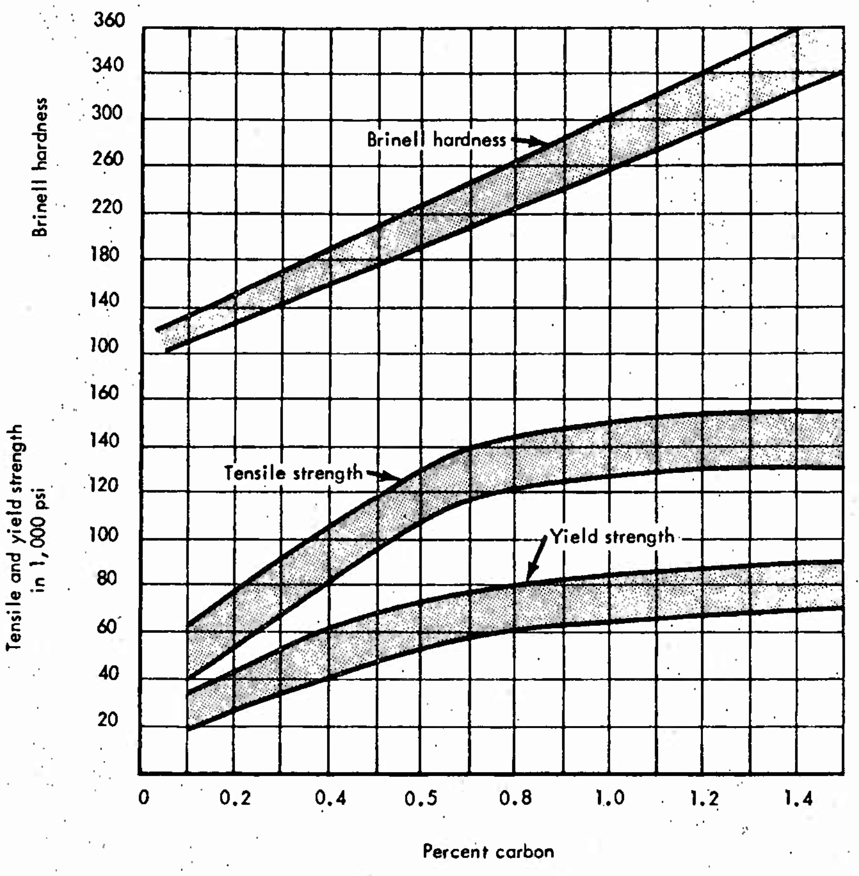


Figure 6-7. Tensile Strength, Yield Strength Brinell Hardness

A special group of low-alloy high-strength (LAHS) steels has been developed to meet a need for superior properties at only slightly greater cost. In particular, the transportation industries -- reuseable freight containers being a typical example -- place emphasis on strength-to-weight ratios and improved UTS makes a direct contribution. While it would appear that the desired improvement in UTS could be obtained by a simple increase in carbon content or by heat treatment, there are some associated disadvantages. The LAHS steel category provides UTS at the 70,000 psi level in the untreated state while specific qualities of weldability, notch resistance, machineability, and corrosion resistance are available in specific proprietary alloys. One member of the LAHS group stands out as being of particular interest in the container application -- COR-TEN* -- by virtue of its superior corrosion resistance. It will be covered in detail subsequently.

Extreme values of UTS -- approaching the 300,000 psi level -- are available through the recent development which produces a fully martensitic structure on quenching. A specific advantage of the development is in the self-tempering action during quench so that normally no further tempering is required and the brittleness experienced with higher carbon steels is avoided. In a report on the development work at Inland Steel Company (Reference 6-4) UTS values between 140,000 and 210,000 psi were obtained, with carbon content in the range of 0.04% - 0.12%.

Yield Strength. The yield strength of steel is a more clearly defined point (on a stress-strain curve) than it is for many other materials. Note on Figure 6-8 (reproduced from Reference 6-1) that the behavior of steel closely follows the ideal linearity of Hooke's Law. The proportional limit is the point of departure from a linear stress-strain relationship. As the stress in the material

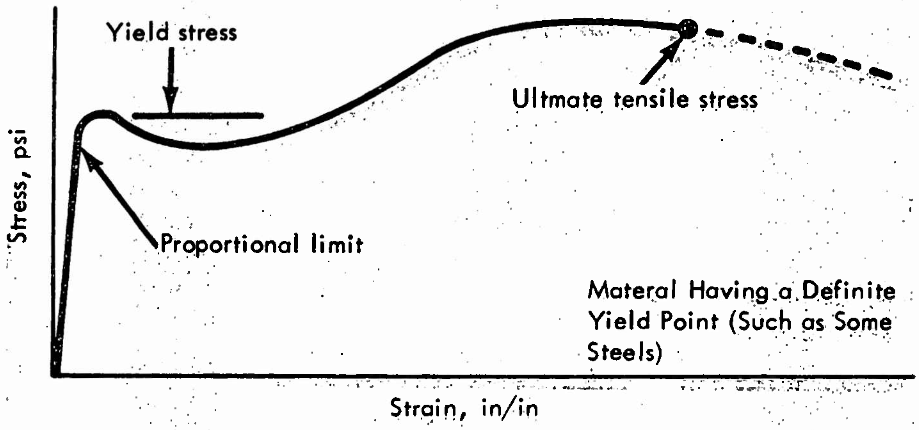


Figure 6-8. Stress-Strain Curve Showing Well-Defined Yield Point

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* Registered Trademark of U.S. Steel Corporation

is raised beyond that point, a condition is reached where elongation (permanent deformation) occurs without an additional stress increase. This is the yield point and marks the entry of the material into the plastic region of deformation -- as opposed to the elastic region. The variation of yield point with carbon content of steel may be seen in Figure 6-7 where it is apparent that yield point and tensile strength are not in constant proportionality. Note also that beyond the region 0.8% - 1.0% carbon there is only a slight gain in yield point.

The stress-strain curve in Figure 6-8 provides a graphic view of the modulus of elasticity for steel. The slope of the curve up to the proportional limit is the modulus (in psi per in./in.). In many applications, the relatively high modulus of steel contributes to rigid structures. For example, for a member in direct stress at a level of 40,000 psi, the deflection is 0.13% of the length whereas for aluminum, the corresponding deflection would be 0.40% and for FRP it would be in the range 1% - 2% depending on the amount and disposition of fiberglass in the matrix.

Hardness. The subject of hardness of steel is closely related to UTS and, in fact, was mentioned in several connections during the previous discussion. Brinell hardness was plotted on Figure 6-7 against carbon content. Up to about 1% carbon, the increase in hardness parallels the increase in UTS. An approximate relationship is the Brinell Hardness Number times 500 equals the UTS. However, beyond 1% carbon, hardness continues to increase without a comparable benefit in UTS.

Ultimate Shear Strength (USS). Since shear failures arise in practice, this is an essential property of a material. Many standard reference sources on properties of materials show that values of USS are approximately 75% of UTS. However, there are design activities which prefer to use a lower value of USS, down to 50% of UTS, in order to have a conservative stress analysis under the uncertainties in USS and shear stress calculations. The shear modulus for steel is approximately 12,000,000 psi.

Resistance to Elevated Temperatures. Short-time tensile tests of structural materials usually show that there is a loss of strength with increasing temperature. However, this is not a serious problem for low carbon steels, since the lowered strength is experienced at temperatures above 800°F. In fact, low carbon steel has a superior strength in the range of 400° - 600°F than it does at normal temperatures.

Long time periods of stress and elevated temperature combine to produce a phenomenon known as creep. This is an increased deformation above what would be produced by a given stress level at normal temperatures. The magnitude of the effect may be observed in Figure 6-9. Note on the figure that a fairly severe condition might be a case where the temperature is 1000°F, the applied stress is 4,000 psi, and the deformation rate is 0.001 in./in. per 1000 hours. The amount of accumulated deformation in 1000 hours corresponds to the deformation that would be due to 30,000 psi of stress when the applied stress is only 5,000 psi. However, with the high temperature extremes due to environmental conditions normally encountered, even on a world-wide basis, creep is not a design problem.

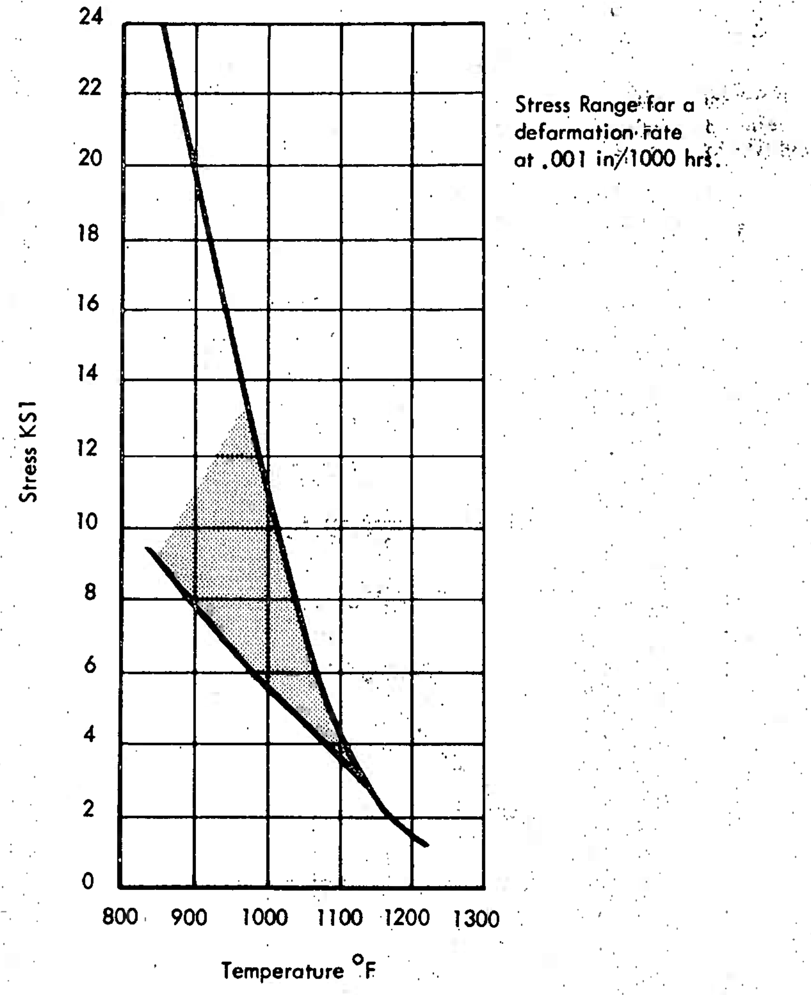


Figure 6-9. Typical Creep Rate for Low Carbon Steels

Endurance Limit. Vibratory stresses, when applied to a very large number or cycles, will produce failures at a stress level that is some value below the UTS as determined in static testing.

The failure mode is a fatigue type. A distribution of failures in accordance with the number of stress cycles and the level of the peak stress is shown in Figure 6-10. This type of diagram is referred to as the S - N curve for the material, where S is the peak stress in the stress cycle and N is the number of cycles.

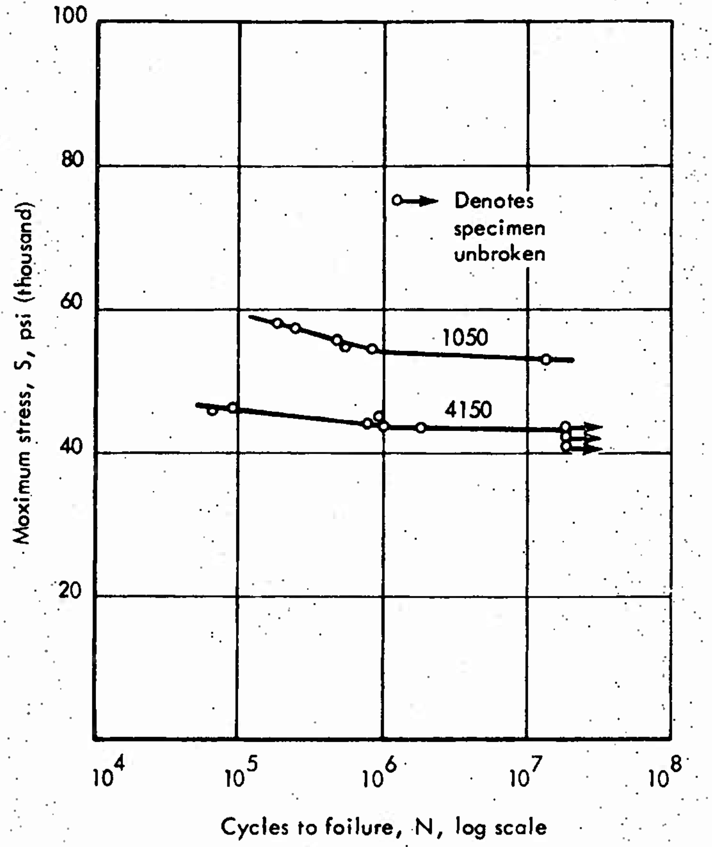
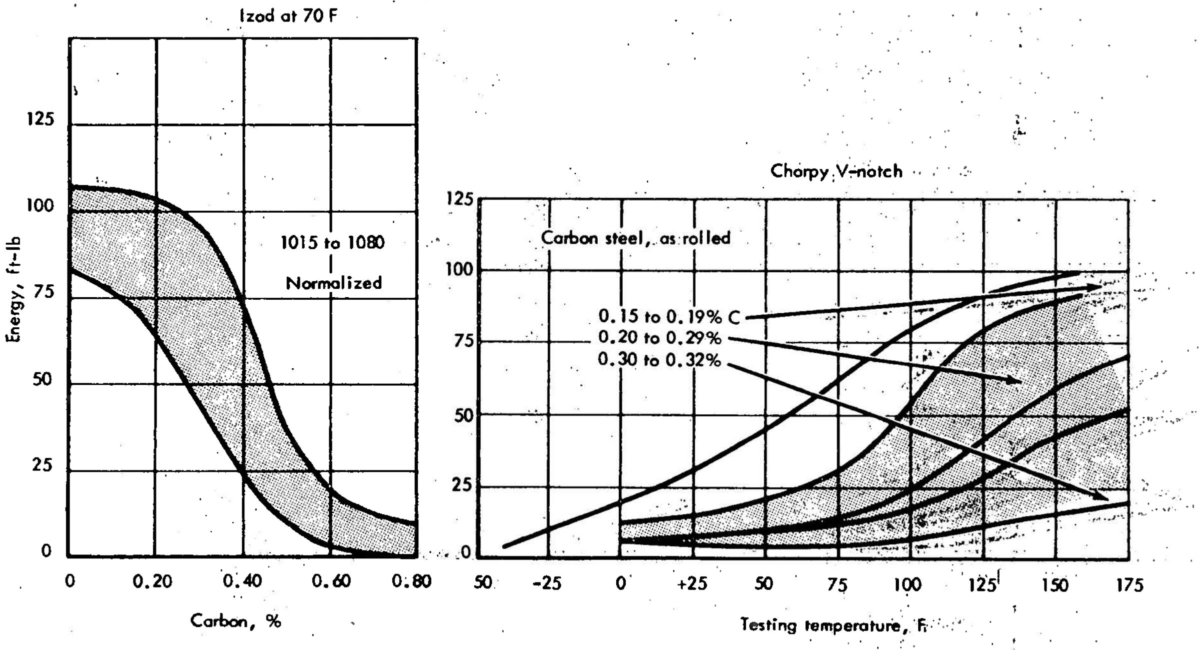


Figure 6-10. Typical S-N Curve for Low Carbon Steel

Two points are noteworthy on an S-N curve for steel. When the number of cycles is above one million, the curve becomes relatively flat. The stress level at which the flattening out occurs is referred to as the endurance limit. If a structural member subject to vibratory stress is proportioned so that stress levels are maintained below this value of stress, there should be no fatigue failures over the entire life span of the structure or product. The second point to be noted on the curve is that the endurance limit stress is approximately one-half the single cycle or static UTS. Most other structural metals do not have the clearly defined endurance limit of steel.

Impact Resistance. Structures are able to resist impact load by a combination of their design features, such as stiffness and mass distribution, and by the properties of the structural materials. It is thus difficult to assign single values or even simple functions to a material's impact resistance. Nevertheless, there are measures of impact resistance in widespread use which are derived from the well recognized Charpy and Izod tests. The tests involve impact of strikers against standardized, notched specimens. The results of tests on plain carbon steel specimens are shown in Figure 6-11. Note in the left hand curves that the specimens with lowest carbon content -- thus also lowest strength and lowest hardness -- have the best resistance to impact. The significance of the right hand curves is that whereas many properties of materials are degraded at elevated temperatures, the impact resistance is poorest at low temperatures and within the limits of temperature frequently encountered. Impact resistance may come very close to zero at -25°F. The absolute values of impact energy are meaningful only when the standard specimens are considered.



A. THE EFFECT OF CARBON CONTENT

B. THE EFFECT OF TEMPERATURE VARIATION

Figure 6-11. Impact Resistance of Plain Carbon Steel

6.2.4 Corrosion Resistance of Steel

Steel corrodes severely under the environmental conditions encountered by containers in their normal service. Paint and other protective coatings alleviate the problem. Section 9.2.2 covers the subject of protective coatings. At this point, the inherent corrosion resistance of steel will be examined.

Vast quantities of test results accumulated at test stations throughout the world are in the technical literature. Correlation of these data is difficult because of variables in test conditions, surface protection, and composition of the test articles. For example, some workers in the field quote a rate at which metal is lost from corroding steel surfaces as 3 mils per year in fresh water and 6 mils per year in sea water. Atmospheric corrosion rates range over observed values of 1 - 8 mils per year for various specimens. The Inland Steel Co. has performed a series of tests for the purpose of rating COR-TEN corrosion resistance against that of carbon steel under controlled comparisons. The results are shown in Figure 6-12 for normal atmospheres and in Figure 6-13 for the marine atmosphere. It may be noted that the first year corrosion rates are highest as the formation of the initial oxide layer takes place.

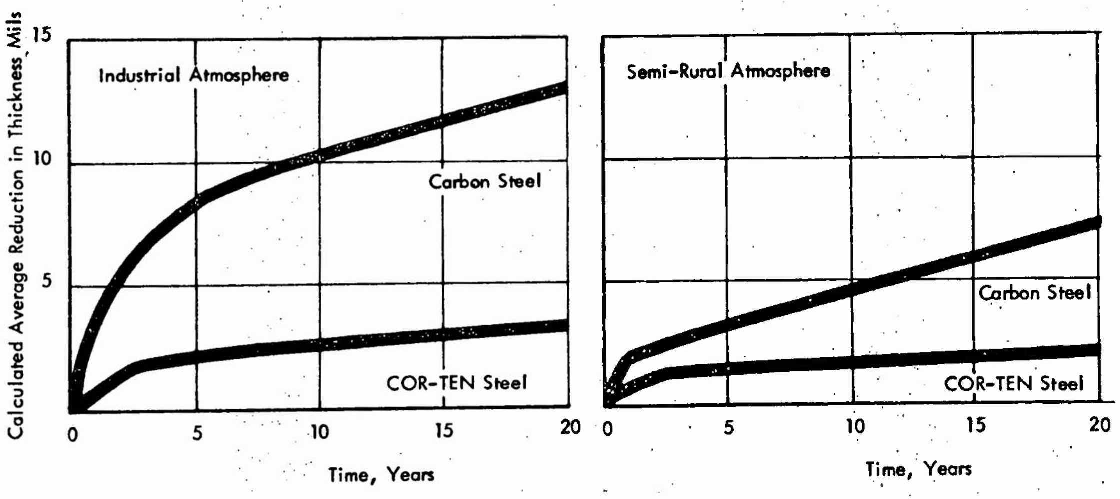


Figure 6-12. Resistance of Steels to Atmospheric Corrosion

<u>COR-TEN Steel</u>. This particular alloy was introduced previously in mentioning the low alloy high strength group. However, it is of particular interest in this investigation in connection with its corrosion resistance characteristics. The material is

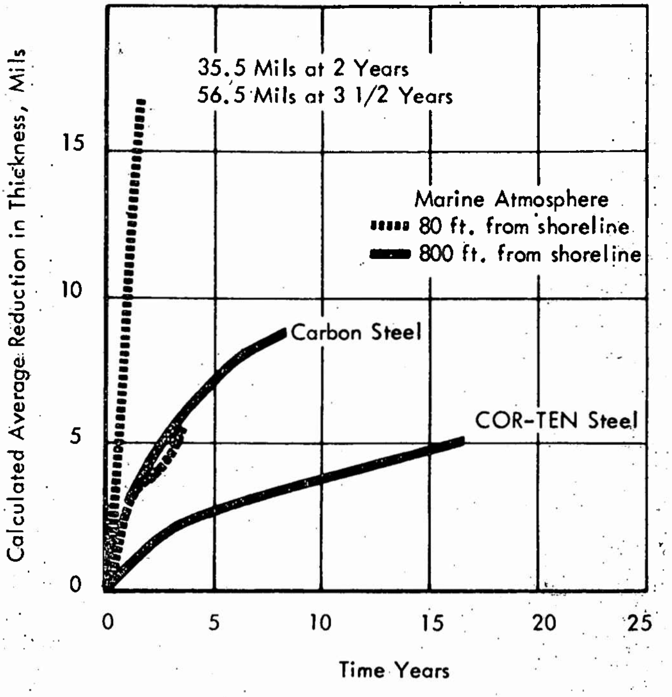


Figure 6-13. Corrosion Resistance of Steels to Marine Atmosphere

is supplied in three grades with suffixes A, B, and C. The A grade has its corrosion resistance rated at 5 to 8 times superior to plain carbon steel, while the other two grades are rated at only 4 times. The C grade has superior strength by approximately 14% while the B grade has the best weldability. Some of the mechanical properties of the material are:

Yield point, minimum, psi	50,000
UTS, minimum, psi	70,000
Elongation, %	19
Bend radius, minimum	1 x Thickness
Impact resistance, Charpy (at -15°F), V-notch specimen, ft-lbs.	15

Returning to corrosion resistance of COR-TEN, note on Figure 6-13 that the rate of material loss for COR-TEN in the marine atmosphere is even superior to carbon steel in the semi-rural atmosphere. The mechanism from which this benefit results is the formulation of an extremely dense and tightly grained oxide layer acting to guard the base metal from further corrosion. If the oxide layer becomes damaged in service, it re-forms and the protective surface is substantially self-healing.

The chemical composition of COR-TEN which makes possible the improved characteristics is as follows:

Carbon	.12 max	Silicon	.25 - .75
Manganese	.20 - .50	Copper	.25 - .55
Phosphorous	.07 - .15	Chromium	.30 - 1.25
Sulfur	.05 max	Nickel	.65 max

The difference between COR-TEN and a steel of AISI No. 1010 is the addition of the elements in the right hand column. The end result is, of course, a higher cost for COR-TEN as compared to plain carbon steel, but the differential is only $0.028 per pound or an increase of 35% as compared to plain carbon steel (1020). The gain in strength is greater than the increase in cost. Thus, the improved corrosion resistance is essentially a no-cost gain.

In many applications, the improved corrosion resistance of COR-TEN leads directly to dramatic maintenance savings by the elimination of periodic paint jobs. Highway bridges are an example. No suggestion is made that COR-TEN be applied to container construction without any surface protection. However, the steel suppliers state that paint life will be doubled when applied to COR-TEN as compared to plain carbon steel.

Stainless Steels. The ability of stainless steels to resist corrosion makes this section the appropriate place to review their characteristics. The corrosion resistance characteristic is, in general, proportional to the alloy's chromium content, and, within limits, to the nickel and molybdenum content. The higher the alloy content the greater is the corrosion resistance of a stainless steel. The curve of Figure 6-14 shows that the corrosion rate of an alloy steel subjected to atmospheric corrosion varies with chromium content from a high of 8 mils per year to a low of 0.2 mils per year. The low value occurs in a leveling off at approximately 10% - 11% chromium content and this is considered the minimum alloy content for classification as a stainless steel.

As a group, the stainless steels provide a combination of resistance to corrosion and oxidation, high strength and hardness, and excellent fabricating characteristics. In many applications, the ease of cleaning stainless steel results in maintenance cost reductions. Lower cost products are sometimes made possible by a reduction in the amount of material in applications where stress governs due to the high UTS of several alloys.

Consider a few of the properties of Type 301. This alloy is non-hardenable by heat treatment (being in the austenitic

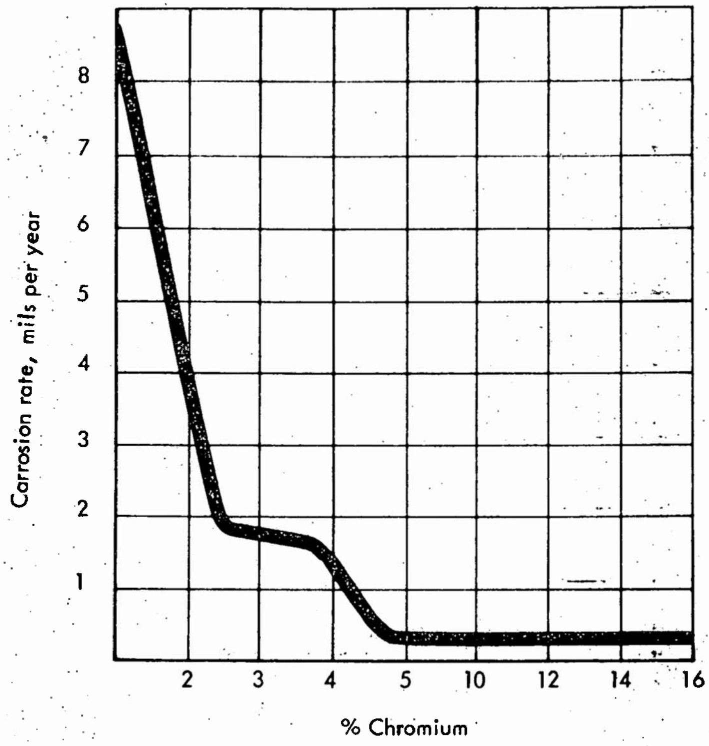


Figure 6-14. Effect of Chromium Content on Atmospheric Corrosion Resistance

category) but can be cold worked for strength improvement. Typical mechanical properties include:

UTS, annealed, psi	110,000
3/4 hard	175,000
Yield Point, annealed, psi	40,000
3/4 hard	135,000
Elongation, annealed, %	60
3/4 hard, %	10

A rather recent development in the field of stainless steel technology has been the production of alloys which have many of the useful properties of the popular types but are substantially less expensive. ARMCO Type 409 (SAE 51409) is referred to as muffler-grade. Crucible Steel Corporation has an E4 composition which it designates structural stainless steel. Composition and properties of these two stainless steels is contained in Table 6-12.

TABLE 6-12

COMPOSITION AND PROPERTIES OF
SPECIAL STAINLESS STEELS

Item	ARMCO 409	Crucible E4
Composition, % of alloy element		
Carbon	.05	.06
Manganese	.30	.60
Phosphorus	.02	.025
Sulfur	.01	.025
Silicon	.50	.35
Chromium	11.00	11.25
Titanium	.50	.24
Nickel	--	.75
Ultimate Tensile Strength, lbs/sq.in.	70,000	70,000
Yield Point (0.2% offset), lbs/sq.in.	45,000	41,000
Elongation, %	25	30
Density, lbs/cu.in.	.278	.28

Both of these alloys have found some acceptance in container construction at the present time. The Crucible E4 is being used in end frame construction of aluminum paneled containers for Sea Land. The ARMCO 409 alloy has been used as panel and framing material in containers supplied by Great Dane Manufacturing Co. It may be noted in Table 6-12 that both compositions have 11% of chromium which meets the criterion for stainless steel. Also, both alloys contain titanium, which suppresses hardening during welding. Both alloys have corrosion resistance in the weld area comparable to the base metal.

6.2.5 Cost Data for Steel

Quotations are furnished by the suppliers on the basis of the quantity and specifications of the buyers. At the time of this report, the following values are considered to be sufficiently accurate and current to meet the needs of materials evaluation:

Hot rolled sheets (1020) -- base price, $/lb.	.075
Width extra, for container sheets	.0025
Length extra and cutting to size	.0050
Surface treatment extra	.01
Hot rolled sheets (1020) with extra costs	.0925
Hot rolled sheets (LAHS) with extra costs	.1075

COR-TEN sheets with extra costs	.1210
Low carbon, martensitic sheets with extra costs	.18
Stainless sheets, muffler (structural) grade, base	.29
Width extra, in range of 36-48 inches	.03
Length extra and cutting to size	.02
Stainless sheets, muffler grade with extras	.34
Structural shapes, low carbon, base	.0690
Extra for cutting to length	.005
Extra for special shapes	.008
Structural shapes, low carbon, with extras	.0825
Structural shapes, LAHS, with extras	.0915

6.3 Properties of Structural Plastics

Natural plastics (resins) such as shellac and related products, have been in use for many centuries. The modern plastic industry is generally considered to have started with celluloid. While investigating possible substitutes for ivory for billiard balls around 1870, J. W. Hyatt developed a method of making solid plastic from cellulose nitrate under pressure. This advance not only introduced plastics to industry, but also motivated the development of the molding presses and other tooling to process this new material. The next major milestone was the development of the phenolformaldehyde family of resins by Leo Baekland (patented 1909) who gave his name to what is now known as bakelite.

During World War II, radar development spurred the need for housings which would withstand the weather and loadings in aircraft installations, which would be transparent to radiation through the radar spectrum, and which could be manufactured in small quantities, odd shapes, and very large sizes. The discovery of resins which polymerize without the evolution of water vapor or other gases at room temperatures and pressures was the solution. The first practical family of resins for severe structural applications were thus the polyesters.

6.3.1 Classes of Plastic Materials

Currently there are about 20 - 25 families of resins commercially available in quantity and perhaps an additional 30 - 40 more or less readily available. A few of the useful plastics are:

Acrylic (Plexiglass)
Fluorocarbon (Teflon)
Polyamide (Nylon)
Polyolefin (Polyethylene)
Phenolics (Bakelite)
Styrene
Vinyl
Polyester
Epoxy
Silicone
Isocyanate

There are also combinations (analogous to alloys of metals) to take advantage of special characteristics of several families, for example, ABS, a combination of styrene and an elastomer; and polyamide modified epoxy.

Thermoplastics Versus Thermosets. In addition to the different families of plastics which vary from each other by their chemistry, there is another distinctive property which separates them. Celluloid, polyethylene, vinyl, acrylic, and others are softened on exposure to heat and set (harden) when cooled. This property is called thermoplasticity and those plastics which exhibit this phenomenon are called thermoplastic. No chemical change occurs when passing through the molding cycle and they can be shaped by melting, usually under pressure, into a cavity of any desired form, then cooled. These materials can generally be remelted and reused.

Thermosetting compounds undergo irreversible chemical changes in converting from raw material to finished molding and cannot be softened by heating nor reused. Sufficient heat degrades and decomposes these materials. The group includes bakelite, melamine, polyester, epoxy and urea.

Cross-compounding has produced some degree of each property in a structural plastic. Additionally, the natural properties of plastics have been enhanced by the addition of various materials. Both thermosets and thermoplastics may be molded with fibers which add considerable strength and rigidity.

Chemical Characteristics. Polyesters, the most common of plastics in fiberglass reinforced products, are produced from glycols and dibasic acids. Curing is either by using organic peroxides such as MEK peroxide or benzoyl peroxide at temperatures of 80° - 300°F or by curing at elevated temperatures. Little pressure is required in either process but shrinkage is high, about 6% - 8%. The products range from flexible, rubbery plastics to tough and hard surfaced.

Epoxies are a low pressure group of plastics containing reactive ethylene oxide groups. The resins include a broad range of products containing amines dibasic acids, sulphur compounds or other resins. Epoxies tend to suffer less than other low pressure resins from shrinkage while curing. They have excellent adhesion properties, which leads to their high use factor in bonding applications as applied to laminating. They are extremely moisture resistant.

Phenolics. The phenolics are condensation products of phenol and formaldehyde, widely used in the impregnation of fibrous materials, including paper and asbestos, in addition to glass. A particularly attractive feature of reinforced plastics manufactured from phenolic resin is the retention of mechanical strength at high temperatures. The material is fire retardant, and shows excellent resistance to strong mineral acids and organic solvents. It may react with strong alkalis, however. Phenolics are generally solids, but for laminating are supplied as a solution, usually in alcohol. As with other plastics, the water absorption potential is low, but will increase when reinforced with a fibrous material.

Composition of Reinforced Plastics. Numerous formulations and molding processes are employed to produce materials which have properties suited to various practical needs. Even though literally thousands of formulations are in use, the basic constituents of reinforced plastics are:

Resin or combination of resins;
Fillers including pigments;
Diluents;
Catalyst or catalyst system;
Reinforcing material or combination of materials.

The resin determines the chemical, electrical and thermal properties as well as supplying the matrix in which the reinforcing material is imbedded. The resin or matrix separates the fibers, thereby preventing abrasion.

6.3.2 Application Survey

Polyester Resins. Of the many resins available, the polyester family is the most widely used (perhaps 75% or more of the resins used in reinforced plastics are within this family). Epoxy resins are next. Polyesters can vary from extremely flexible to very hard and rigid; from water sensitive to chemical and weather resistant; and from flammable to nonburning. They offer the widest range of physical properties and processing conditions of any of the resins. They can be cured at room temperature and pressures or up to 300°F and 1000 psi. Shelf life is up to one year. They accept a variety of fillers and additives to control viscosity, increase fire resistance, increase chemical resistance and weatherability. They also provide a good bond to the reinforcing material. Table 6-13 illustrates some of the resins available, their characteristics and typical uses.

TABLE 6-13

TYPICAL APPLICATION GUIDE FOR POLYESTER RESINS

Polyester	Characteristics of the Cured Resin	Application
General purpose	Rigid moldings.	Trays, boats, tanks, boxes, luggage, seating.
Flexible resins and semi-rigid resins.	Tough, good impact resistance, high flexural strength, low flexural modulus.	Vibration damping: machine covers and guards, safety helmets, electronic part encapsulation, gel coats, patching compounds, auto bodies, boats.
Light stable and weather resistant	Resistant to weather and ultraviolet degradation.	Structural panels, skylighting, glazing.
Chemical resistant	Highest chemical resistance of polyester group, excellent acid resistance, fair in alkalies.	Corrosion resistant applications such as pipe, tanks, ducts, fume stacks.
Flame resistant	Self-extinguishing, rigid.	Building panels (interior), electrical components, fuel tanks.
High heat distortion	Service up to 500°F., rigid.	Aircraft parts.
Hot strength	Fast rate of cure, "hot" moldings easily removed from die.	Containers, trays, housings.
Low Exotherm	Void-free thick laminates, low heat generated during cure.	Encapsulating electronic components, electrical premix parts-switchgear.
Extended pot life	Void-free and uniform, long flow time in mold before gel.	Large complex moldings.
Air dry	Cures tack free at room temperature	Pools, boats, tanks.
Thixotropic	Resists flow or drainage when applied to vertical surfaces.	Boats, pools, tank linings.
Room Temperature	Hand Layup	Large parts and/or thick sections.

Other Resins. Several other groups of resins have properties which make them suited to specific applications. By contrast to the polyesters, epoxies are more expensive, have critical curing cycles, and require a post-curing process to develop maximum strength. On the positive side, they have superior weather and chemical resistance, lower creep tendency, more resistance to crazing, superior adhesion, better shelf life, and are better able to carry metallic fillers. The phenolics similarly have advantages and detractions. They are more brittle, have less shelf life, and are colored brown and black only. However, they are less expensive, perform well at higher temperatures, and can be formulated for better flame resistance.

Reinforcement. The principal reinforcement in use today is glass fiber. With a tensile strength of 550,000 psi and no serious limitations, its suitability is clear. The technology of glass fiber manufacture is well developed at this time, having evolved from a long history of glass making. The fibers are drawn from an oven as continuous filaments which run between 0.0002 - 0.001 inch diameter. The machines generally handle 204 continuous filaments at a time, and this is called a strand. Strand densities are also available in multiples of 51 filaments up to 408. A staple fiber is a discontinuous filament, generally 8 to 15 inches long produced by high speed air jets. Yarn is made from either filaments or staple fibers which are twisted together; after twisting they may be plied to increase diameter and strength.

Yarn is seldom used as is, but is woven into a diverse variety of cloths. Table 6-14 shows a few of the available variations. Style No. 1000 shown in the table is in widespread use and review of a few of its characteristics will clarify the use of the table. The count indicates the number of yarns in each direction per inch of fabric -- 16 in the length direction (warp), and 14 in the width direction (fill). The yarns are described by letters and numbers: E - glass composition, C - continuous filament, G - strand size, (filament diameter is 0.00036 and number of filaments per strand is 204), 150 - strand count (150 x 100 = yards per pound), 4/ - number of strands twisted together, 2 - number of plys of twisted strands, weave - plain (over and under) of most familiar fabric construction, 450 x 410 - actual tensile strength in pounds per inch of fabric in each direction.

TABLE 6-14

PROPERTIES OF GLASS FABRIC

	Ave. Roll Length	Count	Warp Yarn	Fill Yarn	Weave	Weight Oz/ Sq.Yd.	Thickness (Inches)	Breaking Strength
7 1/2 oz	125	16 x 14	ECK 75 1/3	ECK 75 1/3	Plain	7.50	.0100	335 x 316
1542	125	18 x 17	ECG 150 3/2	ECG 150 3/2	Plain	8.50	.0120	370 x 370
807	250	54 x 52	ECDE 150 1/2	ECDE 150 1/2	Crowfoot	8.60	.0095	350 x 330
143	125	49 x 30	ECE 225 3/2	ECD 450 1/2	Crowfoot	8.78	.0090	611 x 56
181	125	57 x 54	ECE 225 1/3	ECE 225 1/3	Satin	8.90	.0085	340 x 330
150181	125	57 x 54	ECG 150 1/2	ECG 150 1/2	Satin	8.90	.0085	350 x 325
1000	125	16 x 14	ECG 150 4/2	ECG 150 4/2	Plain	9.76	.0140	450 x 410
10 oz.	125	16 x 14	ECK 75 2/2	ECK 75 2/2	Plain	9.76	.0140	450 x 410
1034	125	16 x 14	ECG 150 4/2	ECG 150 3/4	Plain	12.00	.0160	460 x 685
182	125	60 x 56	ECE 225 2/2	ECE 225 2/2	Satin	12.40	.0130	440 x 400
173864	125	17 x 17	ECG 150 3/3	ECG 150 3/3	Plain	12.90	.0150	535 x 485

Rovings, that is untwisted yarn, may be woven and used as a reinforcing material. Woven rovings are generally used in thicknesses in the range of 0.030 - 0.050 inch and breaking strengths between 500 - 1,000 pounds. Woven roving has advantages by contrast to glass cloth in that its cost is less while it provides good bulk for building up thickness in an overlay. However, the compacted strands are difficult to saturate with the plastic material.

Chopped fibers, especially in the form of random mats (similar to cotton felt), are also in wide use. The optimum length of the fiber segments appears to be about two inches. An alternate means, in addition to the formed mats, is to apply the chopped fibers by blowing directly onto a mold with resin in a wet layup process. There are pros and cons for using chopped fibers as compared to woven cloth or roving. This technique has low cost, provides equal strength in all directions, has good interlaminar bonding, and easily builds up to the required thickness. However, thickness control and general uniformity of product are more difficult than with cloth and the strength is less for a given quantity of glass.

At this time, mat and woven roving are preferred by panel suppliers due to their good balance between cost and strength. The suppliers have continuing research programs underway to further improve the bonding between fibers and the matrix. Finishes on fibers are being developed which influence mechanical bonding or chemical bonding.

While other fibers have specialized applications, their strength-to-weight and cost are not as favorable as glass. Chrysolite asbestos has 50% more strength than glass, is difficult to wet-out during fabrication, and has been used with silicones, epoxies, and some polyesters. Synthetic organics such as nylon and orlon can be used to produce fibers with a tensile strength of 117,000 and 80,000 psi respectively. Their application as a reinforcing fiber has been in cases where specific chemical resistance was required. Natural fibers such as cotton, linen, and paper are widely used in high pressure phenolic molding -- where strength requirements are not severe. Metal fibers such as copper, nickel, titanium, and molybdenum have been used in experimental quantities particularly where thermal and electrical conductivity of the composite had to be increased. Inorganic fibers such as zirconium oxide, boron nitride, and graphite (the so-called whisker filaments) have strengths approaching one million psi and open up completely new horizons in lightweight structures. However, for the foreseeable future, the premium cost of the whisker composites will exclude them from serious consideration as container structural materials.

Diluents. Polyester resins, as purchased, usually contain 30% to 40% monomers (generally styrene). Additional diluents are used to reduce cost, increase wetting-out, increase heat resistance, and increase weatherability. They may detract from the strength and reduce chemical resistance. In the particular case of styrene there is a benefit in the wetting-out of the reinforcing fiberglass. It does, however, lower the laminate strength and weatherability.

Fillers. Various characteristics of reinforced plastics can be altered by fillers. The inorganic fillers can perform such changes as improve surface hardness and smoothness, minimize porosity and shrinkage, reduce the tendency of the matrix to run as when placed on a vertical wall, and enhance the self-extinguishing fire suppression feature. Overall, the effective use of fillers can control the cost of end products without detracting from satisfactory performance. Among the widely used fillers are clay, calcium carbonates, and finely divided silica. Also in the filler category are compatible pigments, both inorganic and organic, which provide wide options of permanent and uniform color.

Catalysts and Catalyst Systems. In order to initiate and complete the chemical reaction of changing the liquid monomer resin to a solid polymer material, a catalyst is required. Parts to be press molded at elevated temperatures and pressures (100 - 2,000 psi; 225 - 300°F) require a catalyst sensitive to these conditions. Benzoyl Peroxide is one such, probably the most popular, and is used in concentrations of 1/2% to 2%.

Parts to be molded at room temperatures and pressures require a different catalyst system to initiate the reaction. Methyl Ethyl Ketone Peroxide in combination with Cobalt Naphthenate is a widely used system. These chemicals cannot be mixed directly together due to the possibility of explosion. The proportions to be used vary, depending on the ambient temperature and the time required to work the part.

6.3.3 Production and Molding Methods

Open Mold Process (Hand Layup, Sprayup). This technique uses a one-face mold, thereby generating a part having only one finished side -- that which is formed against the mold face. It is the only process available for the manufacture of large moldings (in the range of 20 - 200 feet long) but is also suited to many smaller jobs. The process is performed at room temperature as a general rule, but sometimes a vacuum is used to achieve a denser product. Fillers are not used in the open mold process, since the difficulty of removing entrapped air offsets the savings in raw material cost.

The process consists of the following steps. The gel coat is applied as a thin layer (about 0.020 inch) of resin sprayed against the mold face, pigmented as desired and catalyzed to cure rapidly. Resin mix, including diluent and catalyst, is applied against the cured gel coat. The reinforcement is placed or sprayed into the resin and worked so as to completely wet the fibers. Alternate layers of resin and reinforcement are added until the proper thickness is obtained.

Closed Mold Process. This is generally a high pressure molding process. The layup is usually the reinforcement and the resin mix formulated for high temperature, high pressure work. Pre-impregnated reinforcing materials supplied in roll form have become very useful in reducing fabricating costs and improving end-product quality.

Continuous Laminating. Thin flat sheet and corrugated panels up to 1/8 inch thick and 4 feet wide are made in highly specialized equipment which add resin to mat between collophane sheets on a continuous conveyor. The work passes through forming and heating platens, is cured, and saw trimmed. Extrusions or pultrusions are made in a similar manner, but instead of mat, the reinforcing material is continuous strands. The continuous laminating process has the highest rate of production and highest equipment costs of all molding processes.

6.3.4 Mechanical Properties

Ultimate Tensile Strength. The dominant factor in the strength of a fiberglass reinforced plastic is the quantity and type of reinforcing fibers. The influence of the quantity of glass is shown in Figure 6-15 for both fabric and mat bases with a polyester matrix. The slope of the curve for fabric is obviously quite steep --

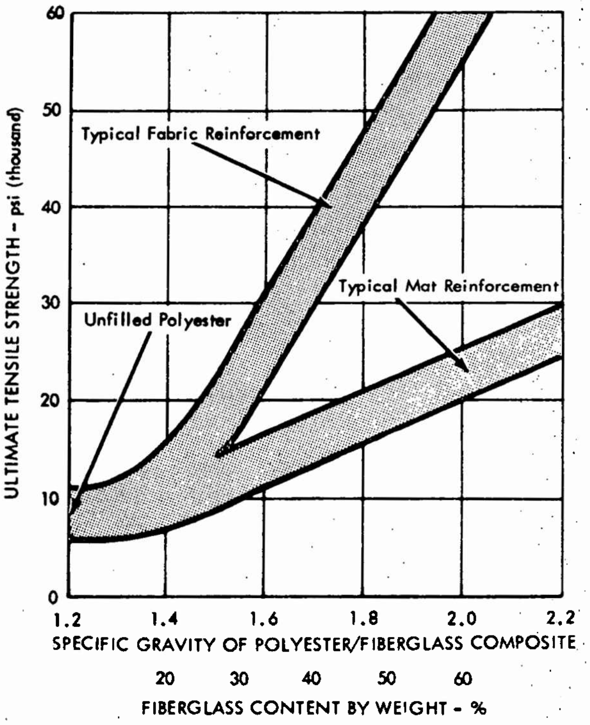


Figure 6-15. Variation of Average Strength of FRP with Fiberglass Content

tensile strength goes from 18,000 to 65,000 psi (3.6 fold increase) as the glass content goes 27% to 67% (2.5 fold increase). The simplified curves of Figure 6-15 neglect the fine points of fiber directionality in the case of fabric reinforcement.

The data of Table 6-15 amplifies this relationship between reinforcement and properties by showing the strength figures for a variety of reinforcement patterns. It is interesting to trace the strength improvement starting with the value for cast polyester as a reference. Note that even unreinforced polyester is indicated to have a range of strengths between 6,000 - 13,000 psi. It is only necessary to recall from the previous discussion that the amount of fillers, diluents, and catalysts is highly variable. A strength of 8,000 psi is most frequently assigned to unfilled polyester. The addition of random glass fibers approximately doubles the strength into the range of 10,000 - 25,000 psi. While chopped strand mat can produce a useful structural material, the use of woven material, either roving or fabric, leads to strength levels for Fiberglass Reinforced Plastic (FRP) which are in the range of efficient metals. Notice that cloth reinforcement in a polyester matrix can reach a strength of 75,000 psi.

A graphical presentation of the main trends of the table is contained in Figure 6-16. Note on the figure that the non-reinforced polyester has a better compressive strength than tensile

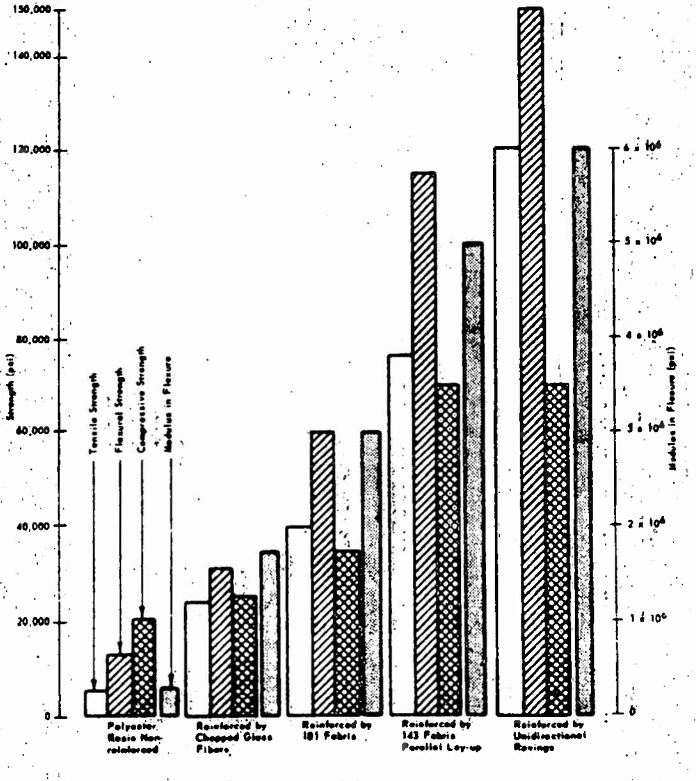


Figure 6-16. Examples of the Effect of Fiberglass Reinforcement on Strength and Modulus of FRP
(Source: U.S. Naval Civil Engineering Laboratory, Ref. 6-5)

TABLE 6-15

AVERAGE VALUES OF FRP PHYSICAL PROPERTIES

Laminate	Material	% Reinf.	Direc- tion	Tensile (ksi)		Flexural (ksi)		Compressive (ksi)		Shear (ksi)		Barcol Hardness	IZOD Impact Ft-Lbs/In	Bearing Strength
				Strength	Modulus	Strength	Modulus	Strength	Modulus	Strength	Modulus			
Chopped Strand Mat	Glass Polyester	20	All	10	1,000	15	1,000	19	1,100	10	400	50	4.5	40
		60	All	25	1,800	40	1,800	45		20		55	18	50
				18	1,200	22	1,200	18	1,600					28
Alt Plies Mat & Wov. Rov.	Glass Polyester	30	0°	18	1,000	25	1,100	17	1,000	10	450			
		40		25	1,400	30	1,500	21	1,600	13	450			
Woven Roving	Glass Polyester	40	0°	28	1,500	30	1,500	17	1,700	10.5	500			
		55		32	2,000	35	2,200	22	2,400	13	500			
Cloth Reinforced	Glass Polyester	Various	0°	18	1,000	12.5	600	20	2,000	12	500	55	19	
			0°	65	2,800	90	3,500	60	4,000	23	700	65	35	
	181		0°	38	2,400	45	2,500	30	2,900					
			90°	35	2,250	41	2,350	31.6	2,800					
	143		0°	75	5,400	78	4,500	45	4,900					
			90°	9	400	15	1,360	19	1,500					
Cloth Reinforced	Glass Epoxy	Various	0°	35	2,000	40	2,000	35		14		62	5.5	
			0°	85	3,500	120	4,600	80		25		66	25	
	181		0°	45	3,000	65	3,200	45	3,280					
			90°	42.5	2,850	57	3,040	38	3,140					
	143		0°	85	4,700	110	5,000	60	5,120					
			90°	10	2,000	22	1,930	26	2,080					
Filament Wound	Glass Epoxy			80	4,000	100	5,000	45						
				250	9,000	270	7,000	70						
Cloth Reinforced	Glass Phenolic		0°	21.5		19	1,350	50		18		50	6	
Cloth Reinforced	Cotton Phenolic		0°	6.8	670	14.5	620	10.6	680					
Reference	Cast Polyester	None		6	300	8.5		13				50	.2	
				13	640	23		36				60	.4	

strength. However, as glass content increases, the tensile strength goes up correspondingly and becomes greater than the compressive strength since fibers are most efficient in direct tension. It may be readily observed on Figure 6-16 that FRP with chopped glass fibers is intermediate between unfilled polyester and FRP with fabric reinforcement.

Some of the complexity of evaluating the properties of FRP arise when studying the preceding table and figure. Note that fabric styles 181 and 143 are 8.90 and 8.78 ounces per square yard respectively, while the tensile strengths of the figure show the FRP with the lighter fabric (even though the difference is slight) to have substantially higher tensile strength. Referring back to Table 6-14, it may be seen that fabric 143 has a much higher proportion of its fibers in the warp yarn, i.e., along the length.

The directional characteristics of the strength of an FRP composite may be observed on a polar type of curve as in Figure 6-17. At 0° and 90°, the tensile strength peaks since these are the directions of the warp and fill yarns. The particular laminate represented by curve A on the figure has strength values in tension of 38,000 and 35,000 psi in the two principal directions. The laminate was made by parallel plying, i.e., aligning the yarns in each ply in the same direction. Note that the strength at 45° is down to 17,000 psi, which is about one-half the peak value. By

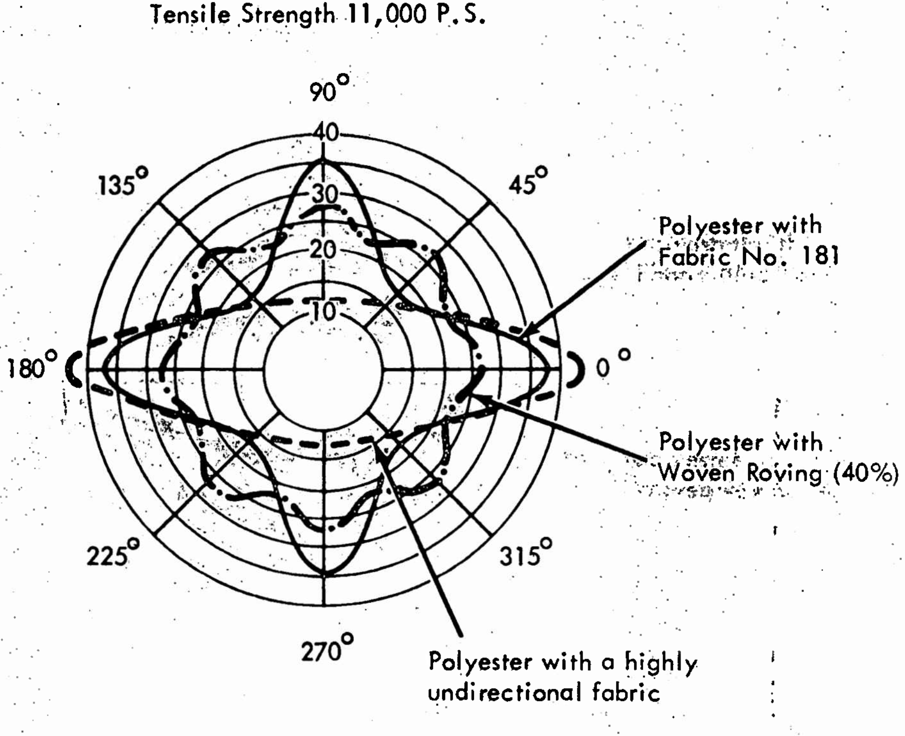


Figure 6-17. Directional Characteristics of Typical FRP Composites

rotating alternate plies 45° a nearly isotropic material can be obtained as shown by curve B. Note, however, that for approximately equal amounts of glass that B does not match A in peak strength and cannot develop up to 30,000 psi. The strength of the composite can be made unidirectional, as in the case represented by curve C, by using fabrics with very little fill yarn. The non-woven fabrications (mat, sprayup) do not exhibit these directional properties since the glass fibers are deposited randomly in all directions.

Stress-Strain Relationship. FRP composites exhibit linearity in their stress-strain curves only up to a very limited point in their useful range of deflections. A typical stress-strain curve (see Figure 6-18) then departs from linearity and yielding gradually occurs through the remainder of the stress range. Failures occur abruptly at the ultimate strength. This is similar to wood and to highly brittle steels and causes FRP composites to be classed as a brittle material. The point beyond which FRP no longer obeys Hooke's Law is known as the proportional limit. Due to the negligible amount of plastic deformation, the material will not dent. When an

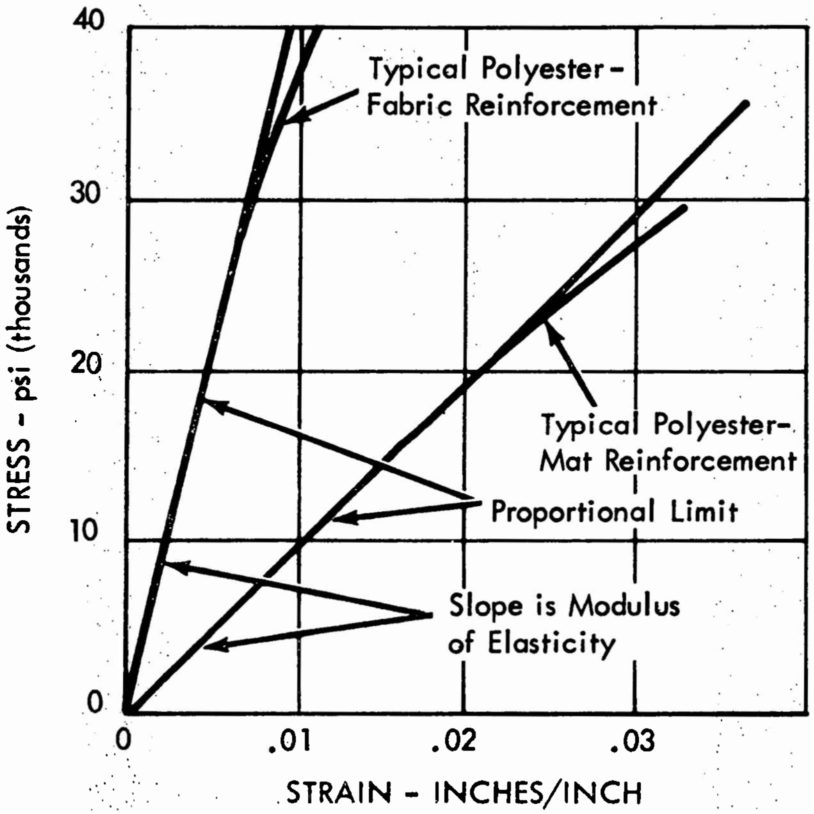


Figure 6-18. Stress-Strain Relationship for Typical FRP

impact is high enough, the material will break or tear through. This is a disadvantage at points of high stress. Ductile materials would deform drastically till the stresses were rearranged; in RFP regions of concentrated stress must be avoided or additional material must be placed in the area. Safety factors should be based on ultimate strength and be large enough to allow for this lack of ductility.

Weathering Effects on Strength. Extensive weathering tests conducted in various places in the U.S. from Florida to New Mexico to Alaska over a period of three years, showed serious losses of strength. Flexural strength losses up to 40% were experienced in polyester matrix FRP composites. Epoxy materials under similar testing lost only 15% of their flexural strength. Another variable influences the effect. The first group used a glass fabric with a Garan finish; the epoxy group used fabrics with a Volan A finish. Newer finishes improve strength retention considerably better than the above test results.

It should be noted that these finishes apply generally to the cloth. Mat rarely can be treated and, hence, its strength falls off more seriously than fabric. The loss in strength is usually accompanied by an erosion of the surface or the laminate and exposure of the glass fibers, the erosion being greatest on exposure to salt-air atmosphere. Conversely, a great deal of strength can be maintained by painting the surface or by the application of a gel coat.

The problem of water immersion is closely related to weathering. Various scattered tests have shown that the strength of a laminate varies inversely to its absorption of water and this absorption rate is about the same whether immersed or subjected to exposure at 100% humidity. In either case, after exposure for one year flexural strengths can be expected to drop 20% to 30% even in those laminates with improved finishes. It should be noted that these strengths still satisfied wet strength values required by military specifications.

Temperature Resistance. The ability to withstand temperature is primarily a function of the resin. The curves of Figure 6-19 show an epoxy resin laminate which can be used indefinately below 400°F and its loss of strength at 450°F. Polyesters under similar conditions would be limited to approximately 250°F. However, silicone resins would generally be satisfactory up to approximately 525°F.

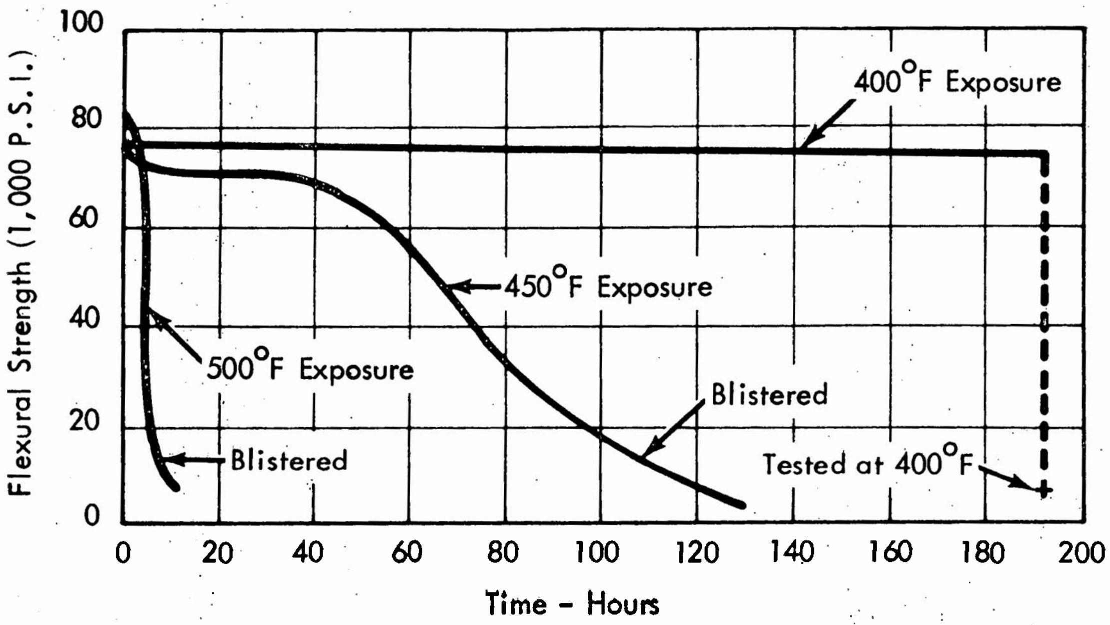


Figure 6-19. Loss of Strength at Elevated Temperatures

6.4 Composite Sandwich Materials

The term composite is becoming to mean primarily the kind of material produced when high strength fibers, particularly boron and graphite, are combined with a matrix material. Fiberglass reinforced plastics are such a material. The problems of evaluating such materials have become apparent when the various forms of fiberglass were considered. In addition to a full catalog of woven fibers with variations in the yarn and in the relative distribution of fibers between warp and fill directions, there were also rovings, chopped fiber mats, and numerous options for the matrix.

Such composite materials could be used directly in container construction and are in fact produced in panel form, usually containing corrugations. Several companies are marketing FRP panels designed to be used as interior liners to replace plywood liners. The claim is made that weight savings are possible and that greater durability results. This is obviously true, but the material cost is much higher.

The ultimate problem is how to get the high performance material in the right amount in the right place. Sandwich materials are another type of composite which attempt to solve the problem by combining face materials with a relatively thick but low density core.

Sandwich materials are efficient in bending and compression due to their disposition of the high performance material as far as practical from the centroid or neutral axis of the composite.

6.4.1 Core Material Characteristics

The required characteristics of the core material in an efficient sandwich construction are equally as important as the high strength required in the face or skin lamina. In the following listing, it will be seen that the required characteristics are mainly derived from the core's function of disposing the face material in an advantageous position.

- Low Density - Large quantities of core material are required and since the contribution of the core to the strength of the composite is minimal, low density is essential.
- Low Bending Modulus - At the interface of the core and face material, the core must match deflections with the face. Since the face will be able to resist high stress and the core will not, its strain should not produce excessive stress. This can be achieved with core materials of low modulus of elasticity. A rule of thumb in the industry is that moduli of face and core material should be in the ratio of 100:1. It appears as a consequence of the present investigations that the ratio should be related to the ratio of strengths of the face and core material. Thus, a very high ratio of moduli (say on the order of 100:1) would be justified if the strengths were drastically separated.
- Good Shear Resistance - There will be relatively high shear loadings in the core due to bending in the plane of the sandwich. This mode of failure can ultimately lead to unsatisfactory performance of the sandwich regardless of the strength available in the face material.
- Good Compression Resistance - Normal loadings which apply bending to the sandwich may be concentrated to the extent that the face, which is by definition thin, needs to be backed up to prevent local failure.
- Environmental Resistance - Since face material may be penetrated, it is not reasonable to assume that the core material is always protected from hazardous environments. In the case of sandwich constructions for the container application, moisture resistance is necessary.

- Adhesive Acceptance - The bond between the face and core is an integral and vital part of the construction. Thus the surface of the core must be suitable for the acceptance of a high strength adhesive.

- Joining Suitability - The sandwich will need to be joined to adjacent structure in a manner that will enable the transfer of structural loads. What with thin faces and a low density core, there are potential problems. Compression resistance in the core facilitates clamping but other joints are used.

- Low Cost - Since the face material is generally expensive, the cost of a composite is made competitive by keeping the core material cost to lowest feasible value.

Plywood (Douglas Fir) serves as a relatively efficient core material and is in wide use in sandwich panels for container construction. It satisfies the requirements to a degree and has a practical balance in its characteristics. However, it is clearly not ideal. Its specific gravity varies with moisture but is on the order of 0.58 (corresponding density is 0.021 lbs/cu.in.). The result is that the core material in an FRP/plywood panel weighs about 2.25 lbs/sq.ft. This value is obviously high since even the core material exceeds by a clear margin of about 30% the weight of metal in a sheet-stiffener aluminum panel. Additionally, the modulus of plywood (at 1.95 million psi) is higher than ideal for use in combination with FRP, thus leading to a situation where the material is subjected to higher stresses than a core material is normally expected to resist. The bending strength of plywood similarly exceeds what core material is capable of and a delicate balance results. Nevertheless, when an FRP/plywood panel is subjected to critical bending loads, failure is most likely to occur in the outer plywood laminations just under the overlay or face material. In summary, it may be observed that plywood's properties are intermediate between an ideal core-type material and primary load carrying material. Douglas Fir plywood would be more efficient in a sandwich with a face material such as aluminum or steel.

Balsa wood has been used in applications where the weight of core material had to be kept low. Its specific gravity is approximately one-third that of Douglas Fir. It has a further advantage that its modulus is less in proportion to Douglas Fir than ratio of the allowable bending stresses. Balsa, however, is very poor in its resistance to moisture and is prone to rotting. Additionally, it is a relatively high cost material. Thus, while balsa wood does offer some gains as compared to Douglas Fir plywood, it is not likely to be the ultimate solution to a sandwich core need.

Honeycombs meet several of the requirements for efficiency in the role of core material of composite sandwich constructions. Both aluminum and stainless steel honeycombs have been used on aeronautical structure applications. However, the difficulty of achieving a good bond between edge of the honeycomb and the face materials results in a high product cost that can be tolerated only when there is a justification for ultra lightweight construction. Honeycombs of reinforced plastic have also been developed for core application, but the cost result is comparable to that of metals. Resin impregnated paper honeycombs offer promise of leading to efficient sandwiches at appropriate cost levels for container application. Some fabricators apply a plastic foam to the surfaces of the paper honeycomb to increase the glueing area. Concurrently, the foam decreases the buckling tendency of the paper walls of the honeycomb and improves the resistance of the composite sandwich to concentrated loads on the surface. The main limitation of resin impregnated paper honeycombs is their low resistance to shear stress.

Another approach to improved core characteristics, and a promising one, is the use of plastic foams. Polystyrene and polyurethane foams have been used in some applications. The former is very flamable and difficult to handle during assembly, while both are of relatively low strength (when expanded to a density of about 6 lbs/cu.ft.). The applications include reuseable freight containers.

A polystyrene foam core sandwich construction is the dominant feature of a container developed by the Dow Chemical Company. The face material in the prototype units is a fiberglass reinforced plastic. However, the company has investigated other face materials and offers both aluminum and steel as options in place of the FRP. The weight of the container is 3,500 lbs. so there is no apparent improvement in tare weight due to the use of the particular composite sandwich. This should not be considered a reasoned conclusion since the company has not as yet released any detailed data on the design in its technical brochures and, thus, no analysis of the design can be performed. Additionally, the container has elements of conventional design practice within its approach, as for example metal framing buried within the sandwich material along the edges. Even if no weight reduction has been achieved, if the sandwich panels have superior bending strength and localized impact resistance, then this particular sandwich construction will be an effective use of material.

The polyurethane core construction is incorporated in a development by the Litewate Transport Equipment Corporation. No metal structural members are included in the container at all. The entire structure is molded in one piece. This design illustrates the nebulous boundary between materials and structural design. The inner and outer faces of the sandwich are joined by integral ribs formed during the one piece molding.

The method of fabrication of Litewate units commences with a box-like mold into which the woven roving for face reinforcement is first placed. Then slabs of foam are wrapped completely with woven roving. The dimensions of these slabs are 3 in. x 5 in. It may be seen at Figure 6-20 that when the wall panel is complete, the thickness of the slabs controls the thickness of the sandwich and the width of the slab controls the spacing between ribs. The slabs are placed in the mold side by side. After forced impregnation with resin and curing the composite structure is complete. Since the ribs provide a shear tie between the two face surfaces, a relatively light core is feasible and, in fact, a density of the core foam of 2 lbs/cu.ft. is used. Many of the products of Litewate are intended for refrigerated use; hence the thickness dimension appears to be selected on the basis of insulating rather than structural necessity.

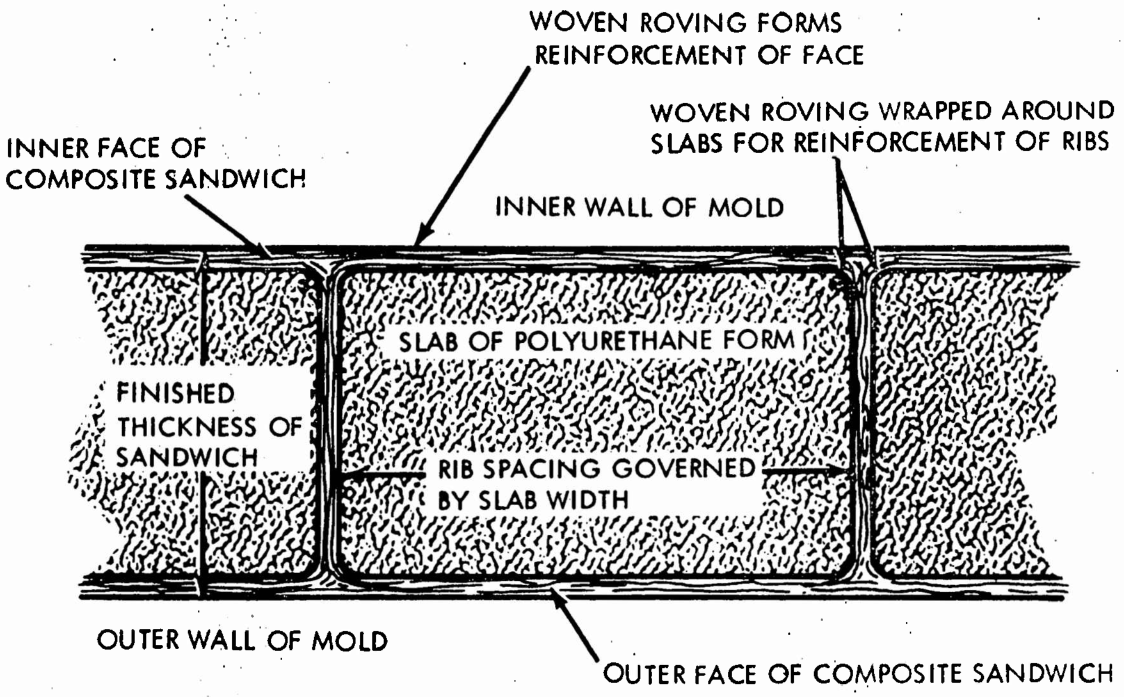


Figure 6-20. Construction Detail of Litewate Ribbed Composite Sandwich

6.4.2 Face Material Characteristics

The material which comprises the face of the composite sandwich is the main load resisting part when the sandwich panel is subjected to bending. Thus, it is apparent that the face material must be capable of taking direct stress in tension or compression at high levels. It was noted under core characteristics that a low modulus of elasticity was required in the core to keep core stresses down. An industry empirical rule was noted that the modulus of the face should be the greater of the two by a factor on the order of 100. Thus, the corollary is obvious that the face should have a high modulus.

The secondary requirements are analogous to those of the core material. Additionally, the face must be especially resistant to the environment. It must have high abrasion resistance. The surface of the face material must be compatible with high strength adhesives. Since the face material is used in low thicknesses and contributes to the efficiency of the sandwich by virtue of its spacing from the centroid of the section, strength-to-weight ratio is not so critical as other properties.

The FRP/plywood composite sandwiches in wide use as container panel material are deficient in the moduli relationship required for structural efficiency. The moduli of the face and core are in the ratio of about 2:1 -- not nearly a satisfactory condition. The consequence is that if the available strength in the FRP is at the level of 35,000 - 38,000 psi (as in the case when glass fabric No. 181 is used in a polyester matrix, with balanced properties in all directions), failure would have definitely occurred in the adjacent plywood. Selection of an FRP with a lower working stress is no solution since the modulus of the face material would also go down -- both strength and modulus being related to the glass content of the FRP.

If the advantages of plywood as a core material are to be exploited, it is likely that the use of metal faces will evolve to a greater degree. Such composite sandwich material is presently in wide use as door stock. Such firms as MET-L-WOOD supply panels in various thicknesses up to 1-1/2 inches and with faces of plain carbon steel, stainless steel, and aluminum alloy. The bonding or adhesion of metal faces to plywood cores has been achieved in a completely satisfactory way. The structural requirements on doors obviously warrant the sandwich composition with the heaviest option in both face and core constituents. The question arises, however, as to what the overall serviceability of panels would be if thin faces, say steel under 0.020 inch thickness and relatively thin cores were to be used in container construction. At this time, development work is being done on a sandwich panel of high strength martensitic steel on plywood. The use of steel on plywood appears to be a promising approach to mating a face material to a compatible core.

6.4.3 Weight of Composite Sandwich Panels

Typical FRP/plywood panel stock is approximately 3.2 lbs/sq.ft. The lightest panel of this type potentially useable would be 2.55 lbs/sq.ft. The weight difference between the most commonly employed panel material and the lighter option is 0.65 lbs/sq.ft., or for two side panels and the front end of a container, a total weight differential of 250 lbs. It should not be expected, however, that the lighter FRP/plywood panel would perform in the comparatively damage resistant way that 3/4 inch panels are doing at present. Some details of weight breakdown are:

Plywood core,	5/8 in. thick	1.8 lbs/sq.ft.
	3/4 in. thick	2.2 "
FRP overlay,	24 oz. woven roving, both sides	1.0 "
	18 oz. " " " D	0.8 "
	2 oz. chopped strand mat	1.0 "

6.4.4 Costs of FRP/Plywood Material

There are at least as many variables in pricing composite sandwich panels as there were for the several metals for which data was presented. Nevertheless, a few approximate cost figures will enable the development of overall efficiency parameters. Most of the cost of the end product panel is in the material and processing of the FRP overlay. Plywood varies about an approximate mean of $0.15/sq.ft., depending on market conditions. Some typical approximate quotations for panels are:

3/4 in.Plywood - 2 1/2 oz. chopped glass mat, hot pressed-$0.81/sq.ft.

3/4 in.Plywood - 24 oz. woven roving, hot pressed - 0.91/sq.ft.

Delivery charges must be added to the above, since there are relatively few points of supply and the practice in the trade is to include freight as an identifiable cost extra -- on the average of $0.08/sq.ft.

6.5 Material Performance Comparisons

The difficulties of evaluating materials when the options include composites with particular orientation of fibers and laminations have been stated by Lovelace and Tsai of the Air Force Materials Laboratory (Reference 6-6). In the case of evaluating candidate materials for application to containers, numerous complexities have become apparent through the preceding examination of the properties of the individual materials. A few noteworthy points to consider when bringing the individual materials into a unified comparison are:

- Effectiveness of the final product is dependent, to a degree, on low tare weight so the strength/weight parameter is important.

- Cost of the final product is critical so the <u>cost/strength</u> parameter must enter into comparative rankings.

- The marine atmosphere to which containers are habitually exposed is highly corrosive, thus the materials must be corrosion resistant -- inadequate capability leads to shortened service life and continual application of surface protection, both of which affect cost.

- Mechanical properties in addition to strength affect the serviceability of the end product and the manufacturing processes which may be employed.

- The several materials are unequal in their progression from raw materials to a finished product -- the particular case in point is the supply of FRP/plywood stock in large enough sizes to be used directly as panels whereas metal sheet stock needs further fabrication.

- The materials have properties which affect their design efficiency and fabrication processes -- one obvious case is the supply of aluminum alloy sheet stock in the hardened condition, thus limiting its formability.

Obviously, a single-valued merit ranking for the candidate materials is not feasible. The comparisons performed in this section, therefore, include attention to all the critical parameters with maximum use of graphical displays to enable the application of engineering judgments.

6.5.1 Strength-to-Weight Ratios

In weight-critical structural applications, the strength/weight ratio parameter quickly displays the relative efficiency of the available materials. For convenient reference to the values used in ratio calculation, Figure 6-21 shows the density and Figure 6-22 shows the ultimate tensile strength for a broad range

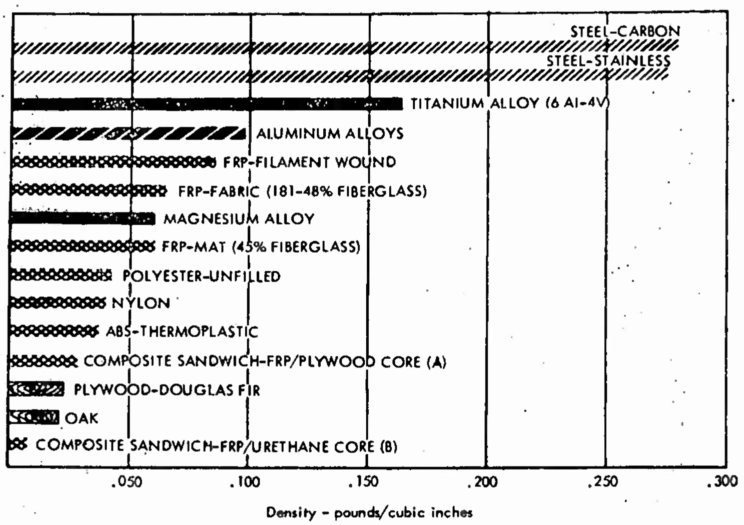


Figure 6-21. Material Comparison by Density

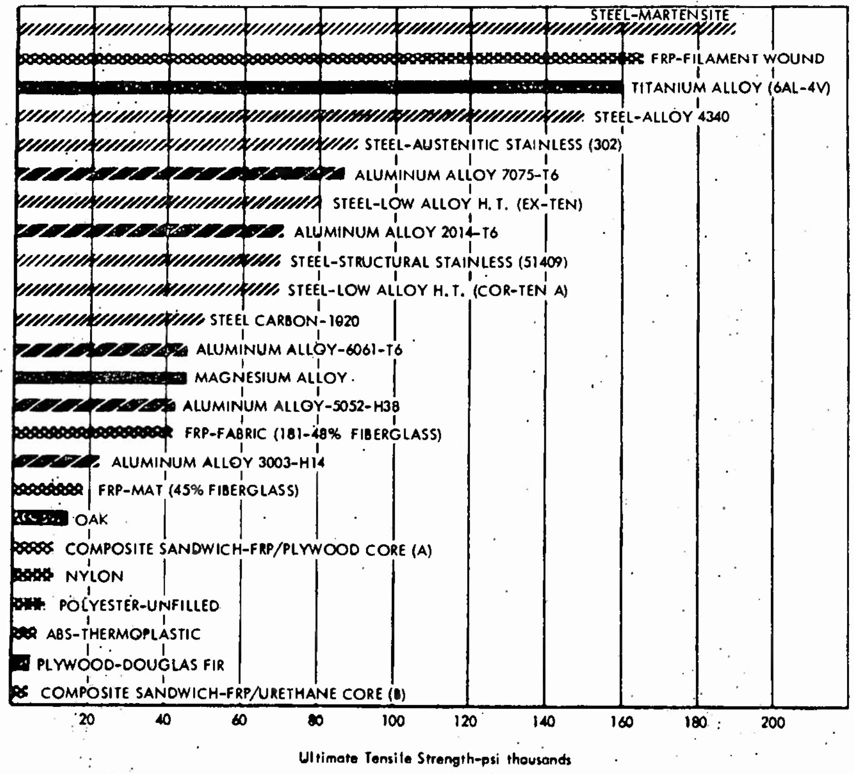


Figure 6-22. Material Comparison by Strength

of materials. The point that may be noticed immediately is that FRP has several different values depending on the form of the reinforcing glass fibers, even though average values are taken for each form of the fibers. On the UTS chart, the most apparent information is that aluminum alloys and steels are intermixed in the range from 4,000 psi upward. On both the charts, wound-filament type constructions and titanium alloys are included for reference purposes showing the outer range of the state-of-the-art in materials. The first is not applicable at this time due to its limited development status -- the technique has been applied only to a few specific structures. The second quickly drops out of consideration on a cost basis. Note on both charts the composite sandwich materials A and B:

A - FRP/plywood, 3/4 in. core, 24 oz. woven roving, polyester overlay, total thickness - 7/8 in. weight 3.2 lbs/sq.ft.

B - FRP/urethane, 7/8 in. core, 24 oz. woven roving, polyester overlay, total thickness - 1.15 in.; weight 1.15 lbs/sq.ft.

These compositions were selected as representative of composite sandwich types which are candidate materials. Their strength is a synthetic value based on the tensile strength of each in proportion to the amount by volume in the composite.

Strength/weight ratios are shown on Figure 6-23. Eliminating the two reference items (titanium alloys and filament wound structures) it may be seen that two aluminum alloys rank highest. However, these alloys are widely used in aeronautical structures applications but not in marine structures, being deficient in corrosion resistance due primarily to their copper content. The aluminum alloys in container construction are, however, in the upper middle of the spectrum. Note particularly that these aluminum alloys are in the hardened state.

Steels cover a wide range from the ultra high tensile alloys down to mild steel (1020) at the lower end of the rankings. Note that at best, steel does not have the strength/weight ratios of aluminum alloys as presently used in container construction. The consequence of this observation is profound. The widely circulated claim that steel produces the strongest container structure can only be true if the weight of the end product exceeds that of the comparable aluminum structure in proportion to the strength/weight ratios. The result of current design practices is, however, that steel containers are quite close in tare weight to aluminum. The weight penalty of current steel containers is not sufficient to compensate for its unfavorable ranking in strength/weight ratio even when the possible design advantages offered by steel are exploited (covered in Section 7).

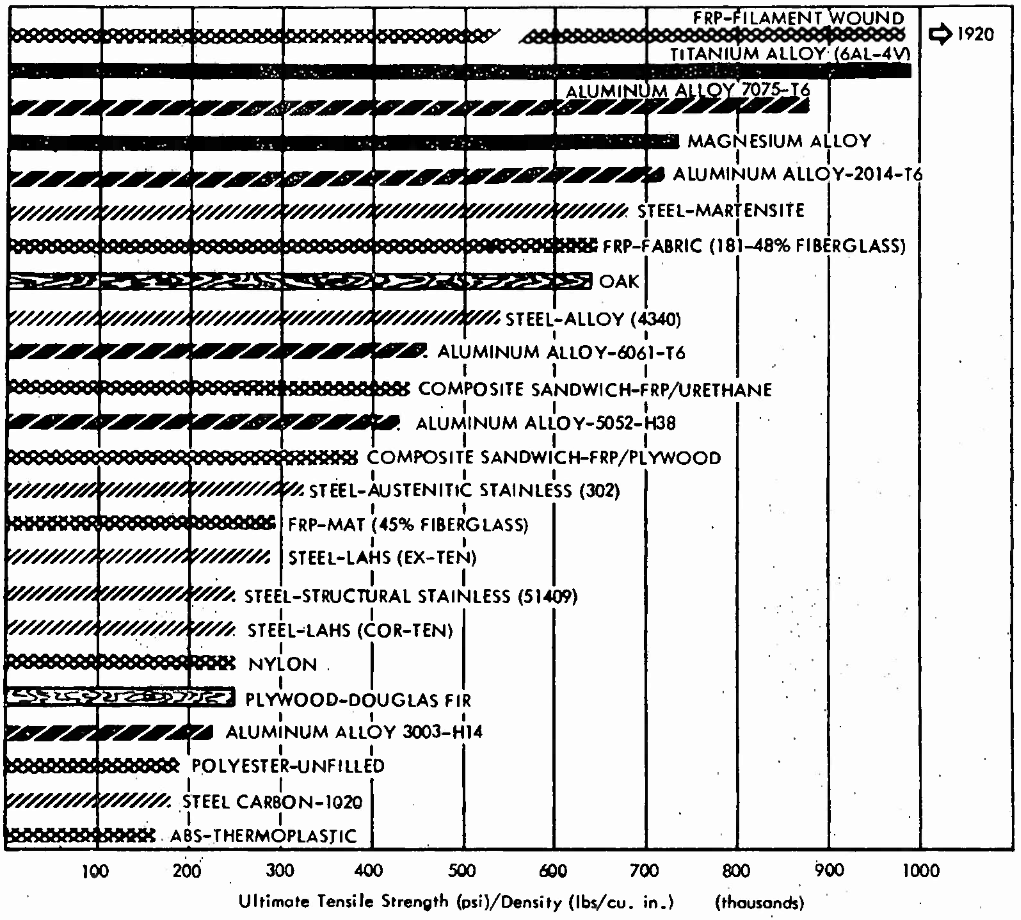


Figure 6-23. Material Comparison by Strength/Weight Ratio

FRP materials fall in the mid-range on strength/weight ratio generally behind the aluminum alloys. It would be possible to select an FRP with a highly unidirectional characteristic to its reinforcing fabric and show FRP superior to aluminum. However, with a reasonably balanced fabric and polyester matrix, FRP ranks just ahead of aluminum alloy 5052-T6. Reference to Figure 6-17 shows, however, that even a balanced fabric such as 181, which loses only 10% of its strength in the transverse direction, there is a loss of approximately 50% in the 45° direction. For a composition with chopped strand glass mat, FRP falls behind the common aluminum alloys. When FRP is put into a composite sandwich construction with either a plywood core or a low density urethane core, the resulting strength/weight ratio ranks it behind aluminum.

The differences between the materials on the basis of strength-to-weight are not so great so as to lead to any immediate eliminations. Mild steel could possibly be eliminated in view of the superior steels just ahead of it. It should be realized that steels which rank high in strength-weight will lead to designs which have thin sections and are, therefore, more vulnerable to corrosion. However, ABS plastic, which is even lower, leads to useful sandwich constructions that meet certain specific requirements in an advantageous way.

6.5.2 Cost/Strength Parameter

The introduction of a cost parameter in material performance comparisons is essential, since the application of engineering materials invariably includes economy as a decision factor. In the several previous discussions on materials properties, some key items of cost data were noted. There is an element of uncertainty in the prices. The suppliers will quote only approximate levels when no firm order is contemplated. Additionally, it is well known that discounting of posted prices occurs in industry under the influence of supply and demand.

The cost/strength parameter is derived from the cost of a quantity of the material to resist a unit tensile load. The cost per pound is converted to cost per cubic inch for each material and to the cost of a volume which is of unit length and of sufficient cross-section to fully utilize its UTS to resist the unit load. The results are plotted in Figure 6-24.

The advantage to steel is immediately obvious. Most of the low ranking (favorable) positions are occupied by steel. The higher strength steels are in the most favorable positions showing that, in general, costs do not rise in proportion to the gain in strength. It is also apparent that no cost penalty must be paid for the improved corrosion resistance of COR-TEN. However, the fully stainless group of steels is not in this favorable position. Structural (muffler) grade of stainless is above the important alloys of aluminum and an austenitic stainless, type 302, despite its high strength, is near the top on cost/strength. This is obviously the price to be paid for the total combination of properties offered by this type of stainless steel. The presence of oak among the best ranking steels is an anomaly which can be explained by its anisotropic character which provides substantial strength in one direction only.

Aluminum alloys are in the mid-range positions. There is a sharp increase from steels to aluminums. Then, the aluminum alloys increase from the stronger alloys upward, similar to the behavior noted for the steels. Thus, economy considerations would lead to selection of the higher strength alloys.

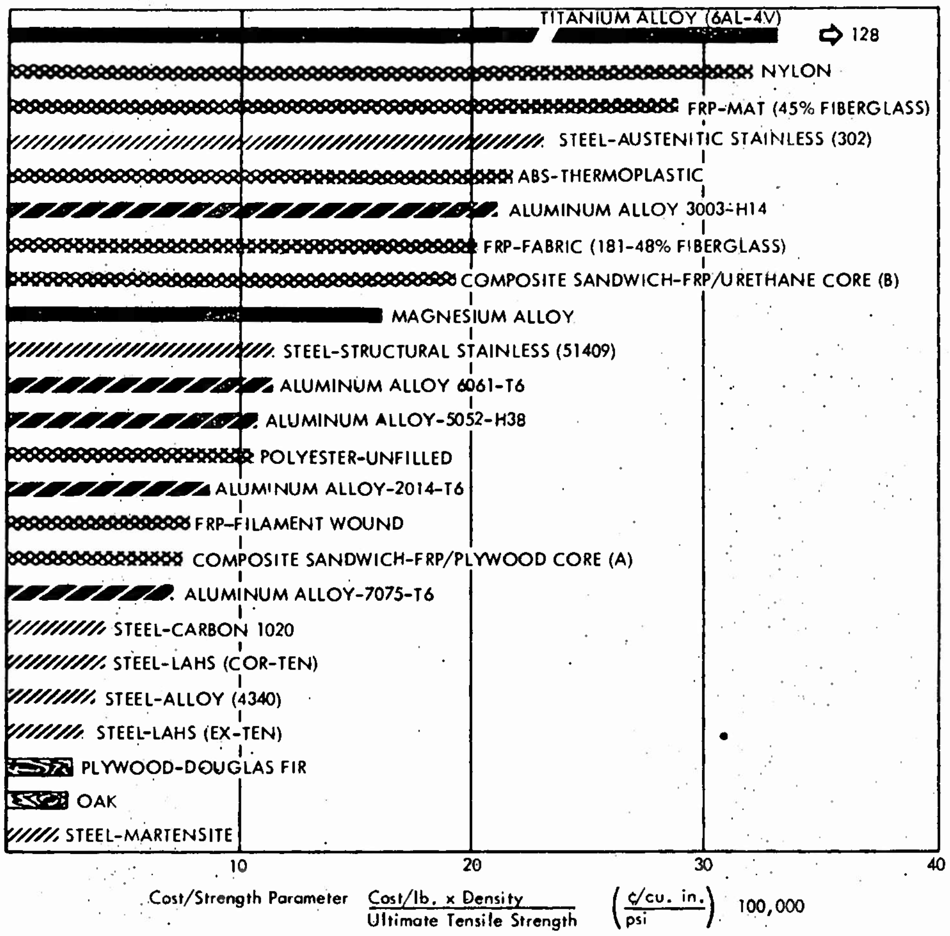


Figure 6-24. Material Comparison by Cost/Strength Parameter

Some interesting shifts show up on Figure 6-24. The typical FRP compositions are high on the scale, ranking above 20 on the cost/strength parameter. FRP with mat reinforcing is highest, but it is free from a highly directional character to its strength. In a composite sandwich with Douglas Fir plywood, the new material has an excellent position in cost/strength. The beneficial shift is due to the favorable position of wood on the cost/strength scale. On the strength/weight scale, the result was the opposite where the position of FRP was degraded when it was in the composite sandwich. Had more variations in the composition of FRP been plotted, it is possible that the trend of steel and aluminum showing better cost/strength for higher strangth materials would have repeated.

The suitability of polyester as a vehicle for fiberglass reinforcement is indicated on a cost/strength basis. While only a few representative plastic products are shown, polyester has a 2:1 advantage over the nearest alternative plastic. Additionally, it offers the advantages of a thermoset over a thermoplastic in temperature resistance.

6.5.3 Overall Rankings

Despite all the previous remarks on the pitfalls which must be faced in comparing materials which have inherent dissimilarities, an attempt is made in this section to perform a ranking. The first step is an aid to assimilating the major results. A cross-plot of strength/weight against cost/strength is presented in Figure 6-25. This plot enables a simultaneous comparison of many materials on the basis of these two very important performance parameters for materials of engineering. <u>The favorable position on the plot is low and to the right</u>.

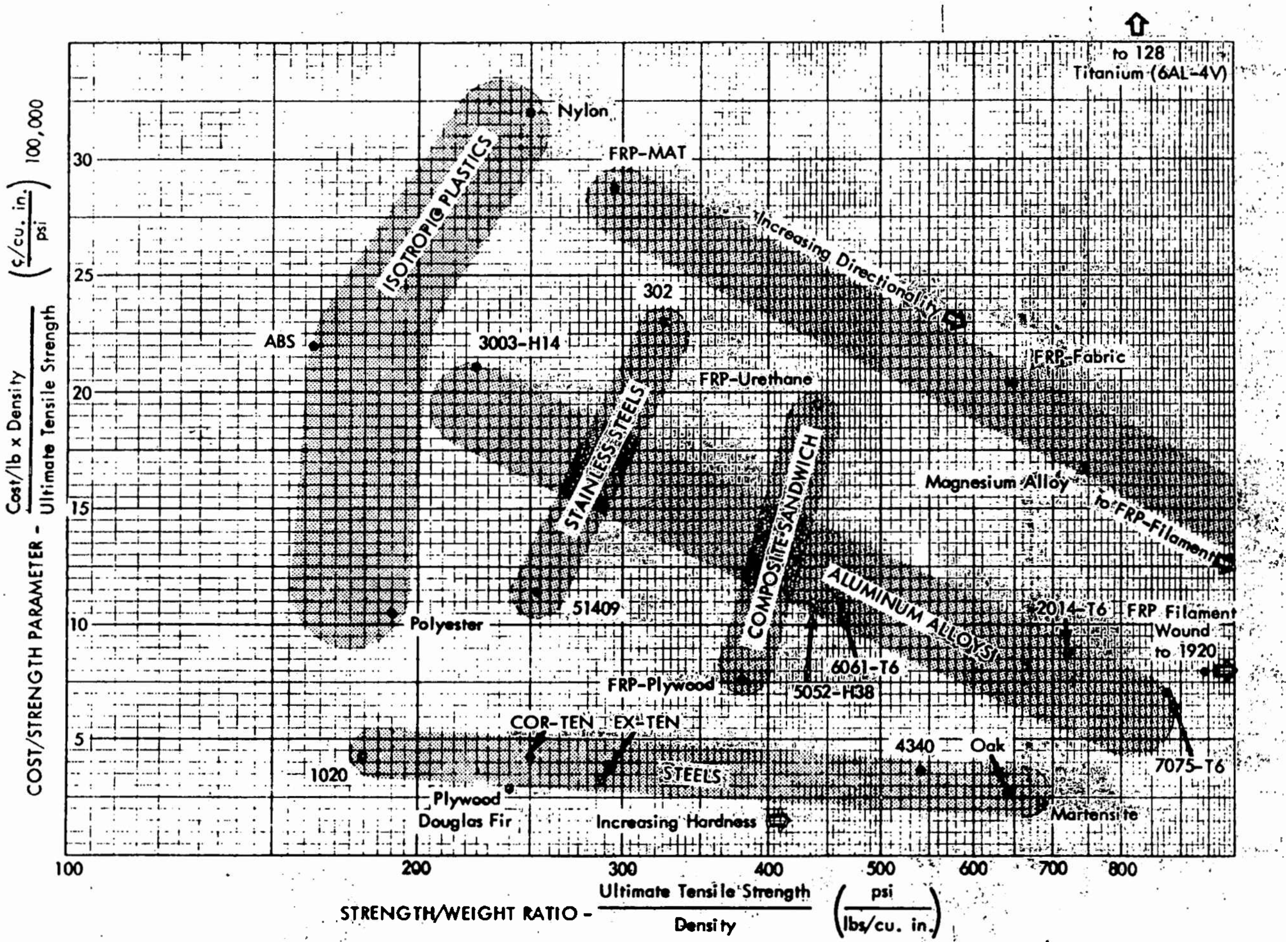


Figure 6-25. Cross-Plot of Two Structural Efficiency Parameters

Aluminum Alloys. The alloys of aluminum are in the most favorable position overall. Their region on the cross-plot is low and extends well to the right. The most frequently used alloys in structural applications such as freight containers (5052-H38 for sheet and 6061-T6 for extrusions) are medium in their ranking with respect to the other alloys. Their elongation, in the range of 6% to 10%, enhances their use where high intensity loads may lead to overstress. Their corrosion resistance rating is excellent in industrial atmospheres and good to very good in marine atmospheres. Their workability and formability limitations in the hardened states (hard states are implicit in their strength levels) do not prevent the evolution of reasonably satisfactory designs for stiffened panels. (The inefficiencies found in present aluminum panel designs are not believed to be an essential consequence of the properties of the alloys.)

Aluminum alloys are available with superior properties as compared to the two alloys most used in containers. Despite the higher unit cost of alloy 7075-T6, it is in the most favorable position of the aluminum region on the cross-plot. It, thus, offers opportunities for both weight and cost savings. Its relative corrosion resistance is lower than the two alloys identified above, but is nevertheless fair in marine atmospheres -- and still comparable to FRP. It appears more applicable to extrusions than to sheet stock in view of the lower corrosion resistance. An experimental alloy under development at Olin Aluminum, designated X5090, is expected to offer a 60% gain in strength as compared to 5052 with a lesser increase in cost.

By comparison with FRP as a face material for sandwich constructions, aluminum alloys are preferred by their position on the cross-plot. The aluminum alloy region is clearly lower than the FRP region. While the FRP region does extend well to the right, the apparent benefit is sacrificed to directionality in the properties of FRP.

By comparison with steels, the aluminum region is unfavorably higher. However, the clear advantage to aluminum alloys in corrosion resistance cancels the apparent cost benefit of steel.

FRP and Composite Sandwich Constructions. Fiberglass reinforced plastics occupy an unfavorably high region on the cross-plot. However, they do extend well to their right and can thus lead to lightweight structures. As their strength/weight ratio improves they also become more attractive on a cost/strength basis. The associated disadvantage is an increasing unidirectional characteristic of their strength properties. In the extreme case, which is the filament-wound type of FRP structure, their strength/weight ratio is about twice the value of the next nearest competitor among the metals.

Whether or not filament wound structures could be adapted to a workable container design is a question that awaits further development effort.

When FRP is combined with a core material to produce a composite sandwich, the resultant products occupy a region which is well down on the cross-plot. FRP/plywood benefits substantially from low cost/strength position of Douglas Fir plywood. However, the composite sandwich is a material adapted to special applications. The plotted position contains a bias in that the plywood strength has been credited to the sandwich material in proportion to its volume in the composite. In a panel application, where bending governs the design, much of the core material is lightly stressed and the favorable plywood strength/weight ratio does not lead to efficient structural design. The additional problem of a proper match of moduli between face and core material in a composite sandwich has been identified and since it limits the utilization of the FRP strength, there is a further disadvantage to FRP/plywood. When FRP is used as a face material with alternative core materials, for example foamed urethane, the cross-plot indicates that a gain in strength/weight is accompanied by a loss in cost/strength, as compared to the case of the plywood core.

On the positive side, FRP/plywood and similar sandwich constructions, have favorable properties which do not appear on the cross-plot. It was noted above that the mass of material in the core leads to structural inefficiency in bending applications. All metal structures can be put into a form which will resist bending by judiciously locating the material into flange and web members, thereby producing light weight products. However, in a container panel application, the mass of material in the core of a composite sandwich provides a useful insulating property. Service experience with FRP/plywood containers has shown that many commodities are carried which do not require the controlled temperature of a refrigerated unit, but which are harmed by extremes of temperature encountered during shipment. There is sufficient insulating effect in an FRP/plywood panel to smooth the extremes in the daily temperature excursions and to thereby safeguard those commodities.

By comparison with aluminum alloys, FRP must be ranked lower overall. As a material for general use, it suffers from a high range of its cost/strength parameter. It can be a useful material when the directionality characteristics of the high strength/weight compositions is adapted to specific applications. In composite sandwich constructions with a plywood core (recall that the plotted point has two favorable elements of bias) there is a great gain in cost/strength, but there is also some loss in strength/weight. In corrosion resistance, the use of a polyester matrix leads to materials which are rated good-fair under long-term exposure in the marine environment -- not quite the equal of aluminum alloy 5052. Corrosion resistance could be improved by the use of epoxy resins as the matrix, but then the resulting product would be more than twice as high on the cost/strength scale.

Steel. The great advantage of steel is its low position on the cost/strength scale. This indicates that the least cost structure to meet a given strength requirement is most probably steel. However, it frequently turns out that corrosive conditions lead to high maintenance cost for surface protection and reduce the life of a steel product -- clearly the case with steel containers. *Thus, the potential advantage of steel becomes lost*. Improvements in strength/weight, for example martensite, while seeming to make steel a stronger candidate material to the transportation industries appear to worsen the position of steel, at least for applications of sheet stock. Consider that higher strength steels will lead to thinner sheet gauges that are vulnerable to the loss of a few mils of material.

Several steels which have received relatively low interest in the container industry appear -- on the basis of the cross-plot -- to warrant further investigation. In particular, COR-TEN clearly surpasses plain carbon steel (1020) on a comparison of strength/weight without any penalty on cost/strength. *The improved corrosion resistance, thus, comes along as an extra benefit*. The extent of this benefit is uncertain. Bridges have been built of COR-TEN and the maintenance savings from no periodic painting have been substantial. U. S. Steel Corporation makes no claim for the corrosion resistance of COR-TEN in a marine environment. However, the tests of Inland Steel Corporation show a benefit in terms of lost material on unpainted surfaces exposed to the marine atmosphere which ranges generally between 3:1 and 8:1, depending on the test conditions.

The data on the cross-plot contain an advantage for steel which is not obvious. The strength values which underly both strength/weight and cost/strength are not the maximum values attainable by fully hardening each of the steels (except the case of martensite) whereas strength values quoted for aluminum alloys are the maximum hardness values. Thus, the steels are readily workable and each could be put into nearly any desired corrugation geometry.

The downward trend of cost/strength and the improved strength/weight for higher strength materials that was observed for aluminum alloys recurs in the case of steels. In short, the price differential for the higher quality materials is less than the proportion of improvement in the properties of the material. An interesting case in point is the chromium-nickel-molybdinum alloy (4340) in the right hand side of the steel region on the cross-plot.

At a UTS of 150,000 it is only 1/4 hard and has an elongation of 18%. This is an aircraft-quality material and is used in tubing and bar stock. The alloy has an advantage of approximately 20% in strength/weight and 70% in cost/strength over aluminum alloy 7075-T6 as used for aluminum framing extrusions. No data on its resistance to the marine atmosphere was found. However, as a framing material its corrosion resistance is less vital than if it were contemplated as a sheet material. Possible applications for an alloy of this quality are in the end frames of containers as a replacement for plain carbon or low alloy, high tensile steels presently used; or as a framing material for an all-steel container where the panel material would have adequate corrosion resistance, possibly COR-TEN or structural grade stainless (alloy 51409).

SECTION 7

DESIGN CHARACTERISTICS

The findings presented up to this point lead to an enigma. On the one hand, the FRP/plywood paneled containers are shown by the damage statistics to be the least prone to damage. The influence of damage carries through to maintenance costs and full life cycle costs in subsequent sections of this report, and it may be seen that FRP/plywood containers benefit in the final comparisons from their superior damage resistance. On the other hand, the aluminum alloys used in container construction have properties which make it appear to be superior as a structural material. Similarly, steel has structural efficiency properties which are relatively better than its performance when it becomes a container material.

The obvious possibility exists that the designs which transform the materials into useful end products are not all equally efficient. It is, therefore, necessary to examine some of the design characteristics of containers. This section will examine the main design features. There will be no attempt to obtain the precision of results usually associated with detailed stress analysis. Rather the intent here is to develop enough information to perform an overall assessment of the state-of-the-art in design.

7.1 Design Criteria

The manufacturing industry is under a number of influences as it prepares designs. No evidence was uncovered in the field survey work that a formalized and rational set of criteria are promulgated in the manner followed by project offices of the military departments. Nevertheless, these influences can be examined to determine their validity and completeness. The term influences is used to connote a situation in which some design criteria are firmly applied and others are loosely applied.

Least Life Cycle Cost. The steamship lines and other transportation companies must give some recognition to life cycle costs because the domestic operators do not purchase the lowest cost containers -- all-steel units. However, it is also apparent that no full-scale attempt is made to ascertain what design criteria would lead to a least life cycle cost. The cost analyses in Section 10 suggest the possibility that an additional expenditure in initial cost could reduce a container's susceptibility to damage and bring maintenance down to a point where the investment increment would be more than offset.

Tare Weight. There is undue emphasis on tare weight, although the field survey shows it to be losing importance in decision making. A number of shipping operators in responding to questions on preferred attributes ranked tare weight behind ruggedness and maintainability, cost, and useable cube. (See Section 10 for analysis results which show that life cycle costs including revenue benefits are least sensitive to tare weight.) Nevertheless, two important containership operators are very weight conscious and the others do not disregard weight altogether in their procurement actions. There are times when highway weight restrictions are the limiting factor on the load being hauled and least tare weight is clearly advantageous.

Low tare is obviously desirable from the manufacturer's viewpoint. Containers have a material cost which is an unusually high proportion of final cost. Thus, the designer is under pressure to use material in the most efficient way. See Table 7-1 for a sampling of container tare weights taken from the equipment register (Reference 7-1) and other published container characteristics.

TABLE 7-1

TARE WEIGHT AND USEABLE CUBE
FOR STANDARD 20-FOOT CONTAINERS

Tare Weight	Cube	Tare Weight	Cube
3,133	1,090	4,030	1,101
3,200	1,130	4,100	1,077
3,500	1,130	4,450	1,130
3,530	1,091	4,500	1,093
3,530	1,112	4,500	1,118
3,570	1,098	4,660	1,100
3,640	1,098	4,870	1,116
3,660	1,095	4,900	1,118
3,710	1,098	4,980	1,119
3,750	1,113	5,070	1,123
3,800	1,112	5,071	1,098
3,970	1,090	5,200	1,112

Useable Interior Cube. The revenue producing capability of a container is directly proportional to the useable interior space that can be loaded with cargo. Where stiffened panels -- whether corrugated or with attached posts -- are used they detract from cube. Very little design effort appears to have been put on maximization of cube other than the specification of FRP/plywood panels and the new aluminum plate design which are obviously superior to thin gauge metal panels which are stiffened and strengthened by deepening the section. The range of values encountered in the field may be seen in Table 7-1.

Structural Loads. In the course of pointing out the differences between trailers and containers in Section 3, the several ways of engaging a container for transfer of restraint were noted. The ANSI-MH-5 document, as described in Section 4, places quantitative values on handling loads. These loads are taken literally by the manufacturing industry and are used in proportioning members.

The loads as specified in the standards are the result of committee deliberations. They are not loads that can be assigned any probability of occurrence. Furthermore, they are not a complete description of all loads which will act on a container during its service life. No dynamic loads are included in the standards except that static lifting (i.e., non-accelerated) is required with twice the normal load of the contents to approximate the effect of a highly accelerated lifting.

The transportation companies are obviously aware of the shortcomings of the standardization documents. It appears that instead of attempting to define the handling and natural environments more comprehensively and precisely, that they simply add design-type requirements. For example, the problem of misalignment of spreaders as a crane operator attempts to engage a container's top corner fittings is well known. Instead of requiring that a container be able to resist the load due to mishandling and specifying the magnitude of the load, the purchaser simply specifies that a protective plate be placed at the top four corners.

Side panels are another case in point. Various loads during handling and transportation cause damage to the panels. Instead of specifying that loads of a particular description and magnitude be resisted, the purchaser simply specifies that the panel material be of a particular composition of materials that he believes will stand up better in service.

End wall construction could also be included as another example. It was determined during the field survey work that a railroad requires reinforcing plates at the end wall in its containers. By specifying this feature, they are recognizing that the end wall load requirement due to railroad humping does not come up to loads that are actually experienced (and often enough to create a repair problem).

7.2 Structural Efficiency Assessment

This critique of the structural efficiency of some of the vital members of a shipping container will consider not only the design condition as actually established in the industry, but also the full range of criteria as discussed above. The approximate analytical techniques used are considered by the authors to be suitable for the purpose of the efficiency assessment.

7.2.1 Side Panels

For the purposes of considering panel efficiency, it is assumed that the frame is relatively rigid and capable of providing a foundation for the panel. The possible loading conditions are:

- Normal static load on panel, uniformly distributed -- due to contents which fill container solidly bearing on panel under steady lateral acceleration.
- Normal impulsively applied load, uniformly distributed -- similar to above except that contents may have clearance with respect to walls and may impact panel with an initial velocity; or well-packed container may be subject to acceleration pulse.
- Normal concentrated loads -- similar to above either static or impulsive due to non-uniform bearing of contents on wall.
- Normal highly concentrated impulsive load applied by hard object -- different from above in that this type of loading would not induce bending or membrane tension but rather tearing or crushing types of stress.
- Distributed shear -- due to joint action with longitudinal upper and lower rails to form built-up girder and resist box bending as container is lifted at its ends or in the center on the bottom.
- Edge compression -- due to transfer of load from end frame under stacking condition in which case the condition is localized at either end, or due to application of handling gear which grasps container near center and produces a crushing tendency on box.

The first item in the listing is contained in the standards at a value of 0.6 times the weight of the contents. This amounts to 24,000 pounds against a panel for a nominal container tare weight of 4,800 pounds. The uniform pressure is:

$$P/A = 24{,}000/146 \times 144 = 1.14 \text{ psi}$$

(Nominal inside dimensions of 19 ft-6 in. by 7 ft-6 in. are used in the area computation.) This being the sole design condition used in the industry, the emphasis in panel efficiency examination will be centered on pressure loading.

A "beam strip" or two-dimensional type of analysis is sufficiently accurate. The justification follows. The maximum stress (s) and deflection (y) of a plate are given by the following expressions (taken from Roark's widely used volume, Reference 7-2), for the case of all edges fixed and a uniform load over the entire surface:

$$s = \beta \frac{wb^2}{t^2} \qquad \text{and} \qquad y = \alpha \frac{wb^4}{Et^3}$$

where
w ~ the pressure load in lbs/sq.in.
a ~ the length of the long edge
b ~ the length of the short edge
t ~ plate thickness
E ~ Young's modulus

and α and β are from the table

a/b	1	1.2	1.6	2.0	∞
β	0.3078	0.3834	0.4680	0.4974	0.500
α	0.0138	0.0188	0.0251	0.0277	0.0284

The a/b ratio for a container panel is 2.5. The table shows that for this value the coeficients β and α are very close to their asymptotic values. Thus, the long dimension of the panel is insignificant and the load is in effect resisted by elements of the plate supported across the short dimension.

Aluminum Sheet and Post Construction. There are many variations in sheet thickness, cross-section of the posts, and spacing of the posts. A representative construction is given by Figure 7-1 where the posts are spaced at a distance of 18 inches apart. Many designs have posts spaced at 24 inches and consequently

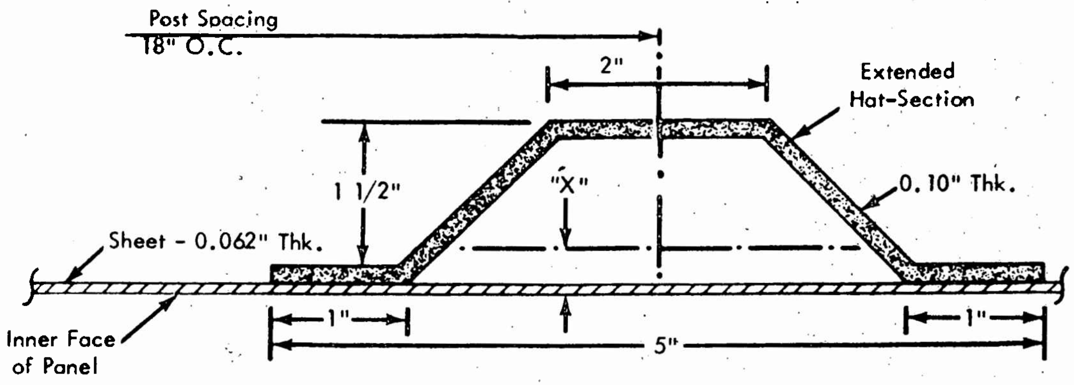


Figure 7-1. Typical Arrangement of Members in Sheet and Post Panel Designs

have less load carrying capability and greater deflection under load. Similarly, the sheet thickness of 0.062 inches is at the high end of the range and designs are encountered which have a thickness of only 0.050 inches.

The moment of inertia for the composite strip beam is found by combining the sheet and stiffener contributions. The centroid (which locates the neutral axis of the beam strip in bending) is found to be 0.295 inches from the inner face of the panel (dimension X on the figure). This result is immediately significant. It indicates that even with the posts spaced 18 inches apart, the centroid of the composite section is only about 1/5 the way out from the inner face of the panel. The composite moment of inertia (I) for the 18-inch wide strip beam is 0.485 inches^4, or 0.0269 inches^4 for a 1-inch strip. The stress due to uniform pressure is found to be

$$s = \frac{Mc}{I} = -\left[\frac{wl^2}{12}\right]\left[\frac{c}{I}\right] = -\left[\frac{1.14 \times 90^2}{12}\right]\left[\frac{1.080}{0.0269}\right]$$

$$= -\ 31{,}000 \text{ psi.}$$

The maximum stress is in the outer fiber of the post (value of c, distance from the neutral axis to the outer fiber is 1.375 - 0.295 = 1.080 inches). For an extrusion of alloy 6061-T6 with an UTS of 45,000 psi the margin of safety is:

$$\text{M.S.} = \frac{45{,}000}{31{,}000} - 1 = 0.45$$

While this may appear to be safe, it should be noted that the underlying assumptions are unconservative. For the fixed-ended beam the maximum stress is adjacent to the supports. The maximum positive moment is at midspan but is only one-half the negative moment. For a condition of supported rather than fixed ends, the maximum moment is at midspan and is 50% greater since the factor 12 in the denominator of the bending moment expression becomes 8. Thus, if ends were not fixed the margin of safety would be used up completely. The true condition is difficult to determine and obviously brings the top and bottom rails into the analysis since their tendency to rotate under the pressure load will reduce the end fixity.

The stress in the sheet material in the vicinity of the posts is less than the stress level at the post outer fiber. The stress is 8,500 psi, being determined by the distance from the centroid to the unsupported face, 0.295 inches, as may be seen in Figure 7-1. Thus, the unsatisfactory situation is that most of the material in the section, being in the sheet rather than the post, is stressed to a comparatively low level. Note the weight distribution below:

Weight of Sheet: 0.895 lbs/sq.ft.

Weight of Posts: 0.82 lbs/running ft.

$$0.82 \times \frac{12}{18} = 0.55 \text{ lbs/panel sq.ft.}$$

Panel Weight: 1.445 lbs/sq.ft.

Thus, 62% of the panel weight is in the sheet.

The situation may be even more unfavorable. Since the posts in the case under analysis are 18 inches apart, the region between posts is relatively unsupported. Being under a state of stress, its dimension from the neutral axis will tend to be relieved and the sheet material will be even further unloaded.

The problem seems to be recognized by the industry. A recently proposed section for extruded posts to be used as panel stiffeners is shown in Figure 7-2. Note that the additional thickness of the off-side part of the section will have the effect of moving the centroid away from the sheet. Thus, the section modulus of the sheet plus stiffener section will go up substantially more than the increase in weight of the extrusion and the sheet material will be more highly stressed.

The alternative to thickening the extrusion is to space the posts at closer intervals. Then, the posts would produce a similar result as thickening in that the section modulus goes up with the additional posts but also the sheet becomes more productive as the dimension X (see Figure 7-1) increases.

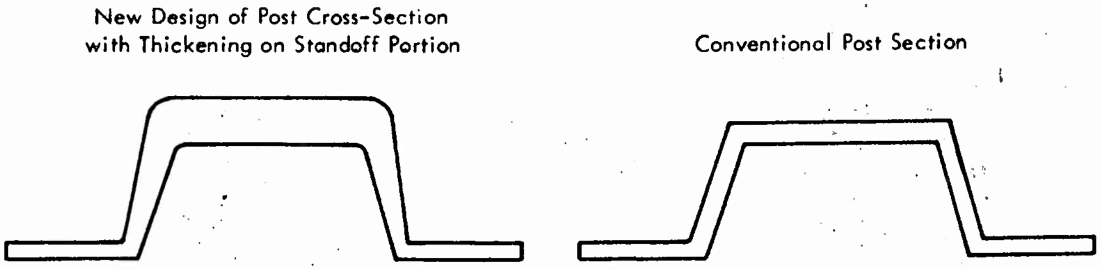


Figure 7-2. Recent Post Extrusion Design

The question of post spacing has corollary problems. Even when a section is conceived which will move the neutral axis in a favorable direction to the maximum degree for the amount of material involved, reducing the spacing between posts leads to an increase in manufacturing costs. It would also lead to a surface with more probability of damage. Of course, posts can be placed on the interior of a container which makes them less vulnerable to outside hazards but more so to the cargo loading type of damage. Note should be taken here of use of interior plywood liners which are intended to cut down on damage to the container during cargo loading operations. These liners may be half high or the full height of the interior panels; all cases observed have 1/4 inch thickness. The weight of this material is 0.75 lbs/sq.ft. This is an appreciable amount of non-structural weight considering that the aluminum panel is only 1.445 lbs/sq.ft.

The possibility of deepening the section of a panel stiffener has not been raised. It should be realized that the space between posts is lost from the cargo carrying cube of a container. Thus, aluminum containers of sheet and post panel construction have an initial disadvantage as compared to FRP/plywood panels and the disadvantage could not be accentuated. However, it would be a reasonable avenue to pursue if a minimum weight container were to be required and the other attributes were to be further compromised.

The deflection of a panel under load is an informative piece of information. Again, starting with an assumption that the ends of a beam strip are fixed, the deflection is:

$$y = \frac{1}{384} \cdot \frac{wl^4}{EI} = \frac{1}{384} \cdot \frac{1.14 \times 90^4}{10 \times 10^6 \times .0269}$$

$$= 0.752 \text{ inches}$$

Since the stress for this case has been computed to be 31,000 psi and alloy 6061-T6 of the post extrusion has a yield point of 40,000 psi, this is an elastic deformation and the test load could be expected to produce no permanent set in the structure. However, it should be recalled that for supported rather than fixed ends the deflection of the midspan increases by a factor of five and might, therefore, go as high as 3.76 inches. The result on deflection is thus even more sensitive to the restraint provided by the side rails.

While the question of the panel-rail interaction will be covered as a topic under integrated design, several observations will be made here in passing. In one widely used design, the posts are joined to the bottom rail by four bolts, two of which pick up the bent over end of the cross member. Thus, at the bottom, considering the effect of the cross members, the fixed end assumption is reasonably accurate. On the same design, the attachment at the top is quite different. There are only two fasteners at the juncture of the post with the rails and the roof bows are not nearly comparable to bottom cross members in restraining the panel edges from rotation.

A number of conclusions can be drawn from just these few calculations. It appears that aluminum sheet and post panels are designed to resist the side pressure loading requirement with only a minimum margin of safety. This conclusion is reached by examining a case with the heaviest sheet observed in field (namely 0.062 inches thickness) and close spacing of posts (18 inches apart). While the resultant panel weight of 1.445 lbs/sq.ft. would seem to be minimum weight construction, there is nevertheless a clearly discernible inefficiency in the design since the sheet is very lightly stressed under the design condition and it constitutes the major part of the total panel weight. Otherwise stated, the peak stress is in the outer fiber of the hat-section stiffener (or as it has been referred to most frequently, the post member) which results in comparatively little of the material being worked up to near its limit. Several possible ways of getting the material into a more efficient balance can be envisioned. One is to use a non-uniform distribution of material in the post with a thickened part in the top of the hat. Alternatively, the usual taper in the protruding leg could be cut down and the flanges could be made narrower, both of which will get more material out to the top of the hat. A deeper section is probably out of consideration from a structural point of view because the distance from the neutral axis to the outer fiber (given by "c" in the stress formula) is already out of proportion to the moment of inertia of the section. But the unfavorable effect on useful cube is even more important.

Aluminum Plate Construction. An aluminum container recently announced in the industry journals has aluminum panels which are of one piece plate stock with a material thickness of 3/16 inch. (The conventional practice in the metalworking industry is to designate thicknesses of 1/4 inch and greater as plate rather than sheet. However, this design is so radically different that the small liberty in terminology is being disregarded.) Thus, the panel weight is 3.6 lbs/sq.ft. or 2.5 times that of sheet and post construction. For both side panels the increase in weight is about 600 pounds. The weight is recouped by replacing steel member of conventionally designed aluminum containers with aluminum to produce an all aluminum unit. Corner fittings of steel are about 240 pounds and end frame straight sections of steel are about 720 pounds. Thus a saving of about 460 pounds or even higher could be made by using aluminum alloys in the end frames. Additionally, heavier panel will add to the box girder's ability to resist bending when lifted at the corners. A further weight saving in upper and lower rails should therefore be possible -- on the order of 100 pounds. It appears that the design could be produced with little or no weight increase as compared to aluminum containers with stiffened sheet panels and steel end frames. At the time of this report exact details of the design have not been in hand to examine its features more precisely. It should be noted that the heavier aluminum panels (minus the assumed saving in rail weight) and the substitution of aluminum for almost 1000 pounds of steel (the replacement material being about three times higher on the cost/strength scale) will both add to the cost of the aluminum plate design.

Corrugated Steel Panel Construction. Panels of corrugated steel may be observed at several points in the report, for example Figure 5-9. There are distinct differences between panels stiffened by corrugation and the sheet and post construction common to aluminum. Most important is the symmetry of the section about its centroid. Thus the "flange" material of a beam strip is at a uniform state of stress in both flanges. This is a definite advantage over sheet and post construction with a high stress concentration on the outer surface of the post.

Corrugated panels offer the possibility to control the depth of the section so that a desired combination of thickness and weight can be achieved. Taking arbitrary limits of panel thickness between 1-2 inches the weight of panels to provide resistance to the pressure load are 3.7 (thickness is 0.109 inches) and 1.4 (thickness is 0.025 inches) lbs/sq.ft. respectively. The low figure produces a panel which is lighter than an aluminum panel when the material would be expected to reflect a higher weight because of its adverse strength/weight ratio. The thickness of the panel is thus a stronger variable in controlling structural weight than the properties of the material.

Consider the case of the shallower section. It is obviously a heavy panel by comparison even with FRP/plywood which is about 3.2 lbs/sq.ft. Note however that its overall thickness at 1.0 inches is very close to that of FRP/plywood and that such a panel could produce a container with near maximum cube. It should also be noted that the sheet thickness at 0.109 inches is capable of producing a damage resistant panel since most of the designs encountered in the industry have substantially less material thickness. It appears almost axiomatic that a panel design which meets the design requirement with the least weight, and therefore would normally be regarded as efficient, will have thin metal gages and be subject to a high damage rate. Conversely, a panel which is designed to meet a damage resistance criterion will be heavier than one designed to meet the side pressure condition.

Numerous options can be considered between the weight limits for steel of 1.4-3.7 lbs/sq.ft. The attitudes in this study have been conditioned by the severity of the damage problem and the greater relative importance (at least for standard 20-foot containers) of cube over tare weight. Additionally, in the case of steel panels, thin gages can only worsen the generally harmful effect of corrosion. Thus there is an inclination to regard the heavier panel as a point of departure. Then, referring to Figure 6-25, the cross-plot of materials performance parameters, it may be seen that weight saving is possible by selection of steels with UTS in the range of 150,000 psi and upward. Recall that the temper of these steels does not inhibit forming into corrugations. Steel panels can therefore be envisioned which have the following properties:

- Corrugation depth of 1.0-inch or slightly greater -- roughly a 30% reduction over conventional sheet and post approach to panel stiffening.
- Sheet material thickness in the range of 0.055 - 0.060 inches and panel weight in the range of 1.8 - 2.0 lbs/sq.ft. -- roughly a 30% increase over aluminum panels without liners but no increase over aluminum panels with plywood liners and a 40% reduction as compared to FRP/plywood.
- Excellent damage resistance since the gains in strength/weight over the other materials is appreciable and not dissipated by a weight reduction.

The optimization of steel panels must also include a determination of the ratio of material in the flange to web -- considering a section of the corrugation as a beam strip. Factors to be considered include the advantage of maximum flat surface to avoid engaging obstructions during handling and transportation. Maximum flat surface also could reduce the expense of repainting. However sufficient webs must be in the corrugation to resist shear as the panel is under bending and to control the possibility of sheet bending due to concentrated loads applied between rigidizing webs.

The attractiveness of steel panels is obviously lessened by the corrosion danger. This problem is highlighted at numerous points in the report -- in the materials, maintenance, and cost analysis. Several candidates having superior corrosion resistance can be considered without a major sacrifice of performance in strength/weight. The low weights estimated for a 150,000 psi material could be approached with a fully stainless steel with a higher cost. Structural grade stainless is comparable in cost/strength to the aluminum alloys in wide use. COR-TEN does not match the highest strength steels in strength/weight but could be considered as a corrugated panel candidate on the basis of cost/strength and corrosion resistance improvements.

FRP/Plywood Panels. The performance of these panels is covered by Reference 7-3 which reports on analyses and tests conducted at the American Plywood Association. This reference finds that strengths determined by test were in general agreement with calculated bending resistance. However, there does seem to be as many unders as overs.

The particular case of a panel with woven-roving reinforcement is discussed in the APA report. The test results described show that localized failure occurred in the outermost parallel tension ply of the plywood core when the "... reinforcement probably has sufficient reserve strength that the sandwich can carry additional applied moment ...". The remarks in Section 6.4 on matching of the modulus and UTS of face and core materials appear to be supported by the test results.

There is very little that can be added to the consideration of FRP/plywood as a material. Numerous combinations of matrix and reinforcing fibers were discussed.

7.2.2 Rails

The most conventional designs incorporate longitudinal rails which are aluminum extrusions. The section designs which were examined during the study show basically flat geometry. Since the rails are the members which give a container much of its resistance to bending -- as for example when lifted at the corners -- they may be either in tension or compression. The top rail is more likely to be in compression than in tension, in which case it is a slender column (even though engaged by the side panels and roofs). A column design would normally attempt to locate the material of a section so as to produce a maximum value of the least radius of gyration of the section. Flat sections are poor in this regard. (The field survey work indicated that buckled sections can be frequently observed.) There appears to be an opportunity to develop a section design which will maximize resistance to buckling. A closed section extrusion which would have suitable surfaces for attaching panels and other structure would appear to offer a gain in design efficiency.

Design of sections for some rails contain a characteristic which must be rated as deficient. It may be recalled from the damage investigation in Section 5.4 that there are instances when protruding flanges are torn. This kind of damage is more serious than it appears on cursory inspection since the members are vital when lifting maximum gross weight. A design goal for rail cross-sections might include beveling or even some degree of rounding.

There is an interrelation between resistance to denting/bending/tearing and buckling resistance. A deformation in a slender column can lead to eccentric load paths which accelerate buckling. Thus a section design which will best resist localized abuse can enhance buckling resistance of rails.

Whether welding would be a preferred means of joining panels, roofs, and cross members to rails is a moot question. There are reasons of manufacturing interest, which appear elsewhere in the report, why welding is avoided. From the structural point of view it is also not favored in the industry because of potential loss of strength in the heat affected part of the member. During this investigation it was noted that rail failures in some cases went through bolt holes and it is believed that the stress concentration at that location contributed to the failure. In short the structural efficiency of welded joints may be sufficient to accommodate the detrimental effect of the heat on materials properties and result in a gain in efficiency as compared to joints producing stress concentration. Obviously, whichever joining means is preferred should be provided for in any attempt to develop a section with superior buckling resistance.

7.2.3 Bottom Structure

This area in the conventional design practices in the container industry appears to offer the greatest potential for weight saving. The attention of a critic is first drawn to the load paths when a cargo is subjected to inertial loading. The forces of the cargo bear on floor boards which distribute and transfer the loads to cross members. There is no direct load transfer to rails when flooring is aligned longitudinally. Cross members transmit loads to rails which in turn transmit loads to end frames. Thus the load path due to hoisting or ship heave and pitch follows a tortuous path from its origin to the its points of resistance. The possibility is attractive that all bottom structure could be put into an integrated structure which would stress the material up to efficient levels under non-redundant load paths.

The use of oak flooring is worthy of special note. It is efficient for its purpose. It enables the use of nailed down chocking lumber. With the general absence of any means for cargo restraint, this is an important feature. It resists the wear of warehouse trucks and cargo movements. Nevertheless, flooring is typically in the range of 500-600 pounds. Without going into a major development as described in the previous paragraph, there may be an opportunity to develop another suitable wearing surface which would probably not be nailable and then build in nailing sections at convenient locations.

7.3 Concepts for Design Improvement

Concentrating on panels, the potential of aluminum as a structural material appears to be unexploited to the maximum degree. Stiffening of panels by the sheet and post approach is not efficient. Consideration could be given to corrugation patterns which balance the material about the centroid and offer the opportunity to further optimize the balance of material between flange and web (as beam strips). If the required formability of the material leads to a lower strength temper, this should not be regarded as unacceptable but rather as a tradeoff with the gain in design efficiency.

Panel sections which have continuous outer skins and corrugated cores have been under development in the aluminum producing industry. Additionally, the roll bonding process by which such panels can be produced in efficient cross-sections may require additional development. This type of process is capable of producing high strength joints -- as demonstrated by its use in the aircraft industry where a highly stressed helicopter hub was produced by diffusion-bonding of several titanium sections.

The continuing effort to produce a minimum weight design without any sacrifice of strength, cube, general ruggedness, and the like, might be served by the maximum integration of all structural members. This is, of course, not a novel proposal. The matter of potential gains in the bottom structure has been noted. It has also been noted that heavier panels might enable lighter rails. The point being made here is that this approach does not appear to have been applied to the total container design.

SECTION 8

MANUFACTURING CONSIDERATIONS

There is an influence on the processes of the manufacturing industry on the state-of-the-art in containerization. This section will, therefore, briefly note some of the highlights of the plant and practices used by the industry for the several types of containers. A general impression was gained during the investigation that some of the manufacturing companies put great emphasis on continuously upgrading the efficiency of their production operations with the objective of controlling costs and quality. Obviously the market for the final product weighs these factors heavily in making procurement decisions.

From the viewpoint of progress in evolution of design, the manufacturing processes which are tailored to current designs have a retarding effect. For the purposes of this study, it is important to appreciate the general nature of the industry. Some of the companies disclose very little information on their manufacturing processes in order to protect proprietary advantages they believe they hold.

8.1 Fabrication of Aluminum Panels

The sheet material used for panel fabrication is so-called trailer stock supplied in coils. It was noted in Section 6.1.5 that there is a price advantage for trailer stock of about $0.06 per pound as compared to flat sheet. Undoubtedly there is a further saving in materials handling in the plant for the coils as compared to flat sheets.

Uncoiling and cutting operations to produce the required lengths for panel sections are performed on equipment similar to that shown in Figure 8-1. Note that the coil stock shown is about 50 inches wide which is about the limit for the lowest price level. The machine shown in Figure 8-1 performs the additional functions of corrugation and application of a coating to protect the material during plant operations. Sheets of either aluminum or steel may be processed.

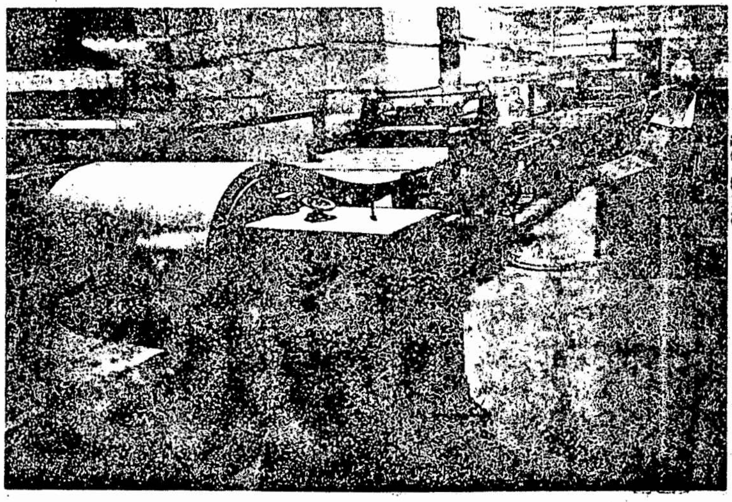


Figure 8-1. Uncoiling, Corrugating, Shearing and Coating of Sheet Material
(Source: Dorsey Trailers, Inc.)

Undoubtedly the radius of curvature in corrugations applied to aluminum sheets is limited by the workability of the hardened material. Corrugation is more frequent in the fabrication of panels for trailers than for containers. In the former case, thinner material gage is satisfactory and the sheets are in greater need of the stabilizing benefit.

In most designs, the uncoiled sheet segments are joined with vertical seams. The sheet length would then correspond to the height of the container, corrected to the actual location of the joint with the rails. The width generally corresponds to twice the distance between posts, plus an allowance for overlap. Thus, for post spacing of about 24 inches, the sheet width would be 50 inches, corresponding both to the limiting point of the lowest price range and the estimated dimension of the coil in the illustration.

The fabrication of the panel then proceeds to the riveting phase where sections are joined together and posts are added -- in a single operation. An automatic riveting machine is shown in Figure 8 2. While the panels shown in the illustration are destined for trailers, the operations for container panels would be generally similar. This machine has seven operating heads and can install rivets at a rate of 6,000 per hour. Dorsey states that the high pressure applied to the rivets gives positive assurance that all holes are filled and that the load bearing capacity and weather tightness of the joint is maximized.

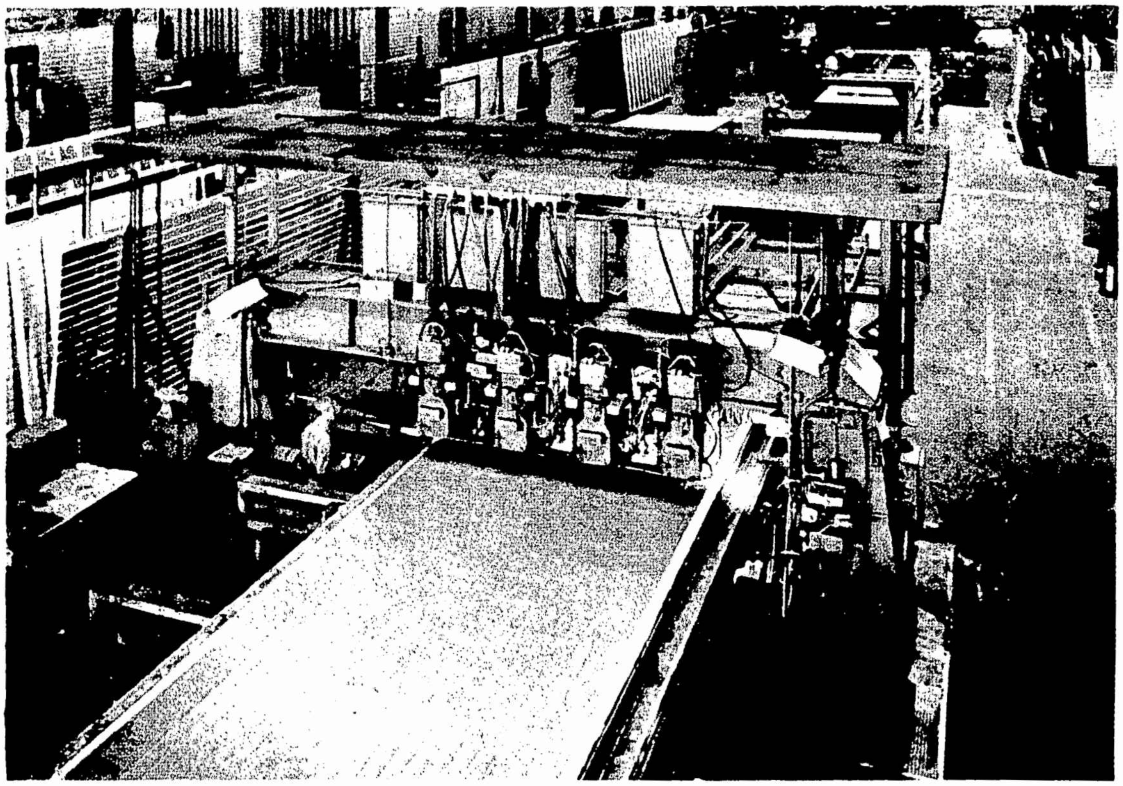


Figure 8-2. Use of an Automatic Riveting Machine for Panel Production
(Source: Dorsey Trailers, Inc.)

8.2 Fabrication of FRP/Plywood Panels

The fabrication of FRP/plywood panels obviously has little in common with the traditional metal working processes of the trailer and container manufacturers. Thus, the first major difference is that a new element is introduced into the industry -- the fabricator of the composite sandwich panel. Indeed, still a third element is present in some cases as the face sheet material may be of the sheet molding compound type manufactured by a company other than the panel supplier.

The sheet molding compound approach is frequently used when the fiberglass reinforcing material is in the form of chopped strands, but there is no inherent limitation on the form of fiberglass that can be used. The process of sheet molding compound attempts to obtain the most uniform dispersion of the strands that is possible. The difficulty that is encountered sometimes is that the shelf life of the compound prior to curing during the final layup to the plywood core is inadequate and a poor bond results. However, at least one supplier claims to have a resin formulation which has extended shelf life to the point where the problem does not exist.

The lamination of face stock to the plywood core may be performed under heat and pressure (see Section 6.3.2 for notes on hand layup and sprayup) where two face sheets of sheet molding compound are bonded to the core. The large press of Figure 8-3 is used for the operation. Brooks & Perkins states that the press produces finished laminated products with a superior bonding plane and with uniformly smooth surface finish.

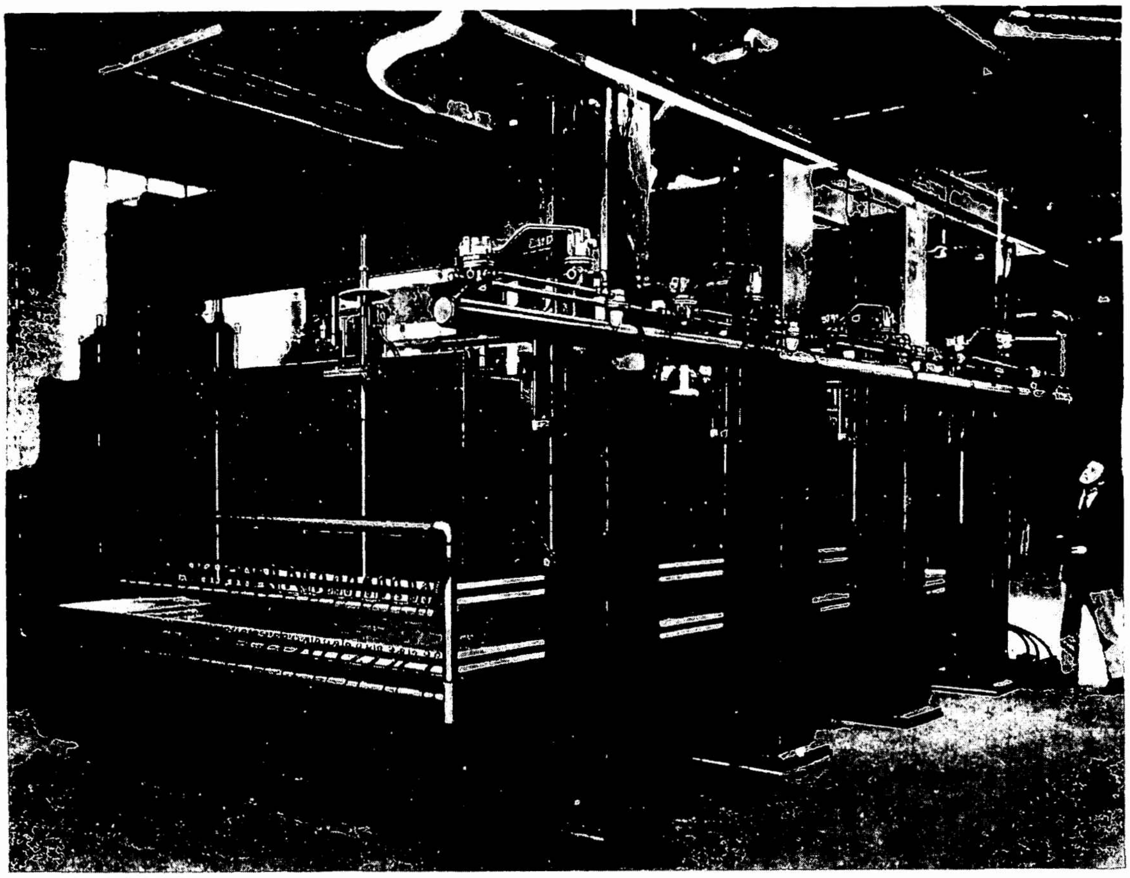


Figure 8-3. Large Stepping Press for Laminating FRP and Plywood - 2,160 Ton Operating Force
(Source: Brooks & Perkins, Inc.)

Panel fabricators are able to supply the one-piece member in the size required. At the present time, panels are available for 40-foot containers. The plywood core stock is edge bonded to assure a continuous structural member.

8.3 Container Final Assembly

The major subassemblies are brought together to perform the final assembly operation. The end frame members -- corner castings, verticals, header, and sill -- being of steel in most constructions, will have been welded together into a subassembly in most procedures. Similarly, the bottom structure and the roof will have been put together as a subassembly. Where dissimilar materials are to be joined, the barrier material -- tape, liquid or both, as the case may be -- is applied. Caulking is also applied to those joints where that type of seal is required. A typical assembly operation for FRP/plywood type containers is shown in Figure 8-4.

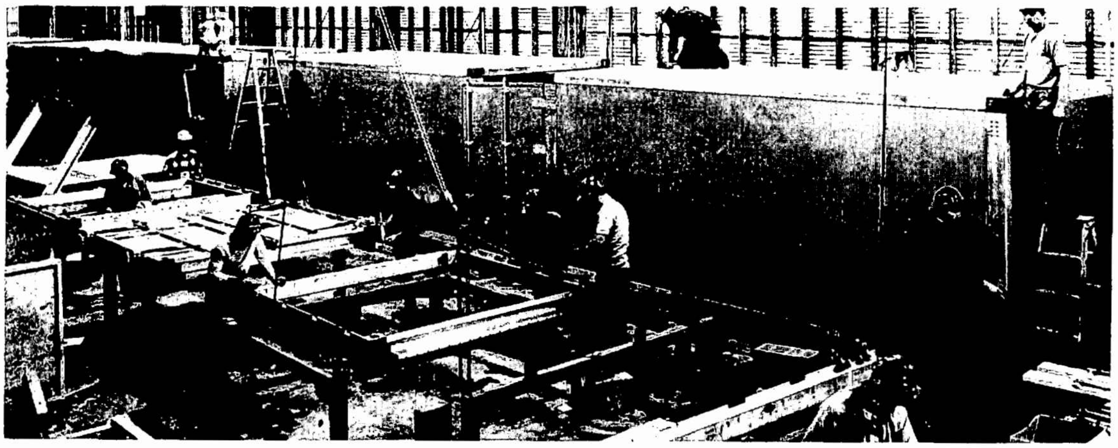


Figure 8-4. Assembly Operations for FRP/Plywood Type Containers
Source: Weyerhaeuser Company

8.4 Adaptability of the Industry to Innovation

The major impression gained by the authors during the survey of manufacturing is that the large-scale producers would find it difficult to adapt to major design innovations. The investment in automatic production machinery is undoubtedly very great and the present machines have much useful life remaining.

The case of the new aluminum plate design runs contrary to the general impression. However, this is a premium cost product and has not yet become established in the market. Additionally, there is a clear possibility that if aluminum welding were to be used extensively, and if the mechanized equipment for efficient, high speed welding were to be applied, production costs could be reduced below the present level prevailing in riveted construction. Thus, if a new design were to offer a prospect of reduced fabrication costs, the difficulties of introduction would certainly be eased.

If the innovation is limited to panel design, the situation is different. Those manufacturers who have initiated production of FRP/plywood containers procure panels from a specialist producer and could change over to a new source without difficulty. The main problem they would face would be the suitability of the equipment they now use to perform the joining of panels to frame members. The prospect of obsoletion of major production equipment is not present in the case of the FRP/plywood container suppliers.

SECTION 9

THE MAINTENANCE BURDEN

During the course of investigation, there was a progressive validation of the critical importance of maintenance from operator reports and by data from all other sources. With the high frequency of damage occurrence in service, the problem of container availability arises which bears directly on the operator's ability to provide revenue producing equipment to shippers. Additionally, the cost of maintenance directly affects the operator's economics to a significant degree. Accordingly, this report covers the essential details of the container maintenance burden in sufficient detail to justify cost estimates.

9.1 Maintainability Fundamentals

The military departments have formalized the terminology, the techniques for quantification of the maintenance burden, and the practices of assurance. MIL-STD-721B (Reference 9-1) on definitions, and related documents, are the basis for some of the useages in this section. The fact that the containers and their associated systems are operated by commercial enterprises is no detriment to the carry-over of the military approaches to maintainability.

9.1.1 Maintainability and Maintenance

The characteristics of design and installation which affect the performance of maintenance, specifically the time required, are related to maintainability. The definition of maintainability says that it is the probability that an item will be retained in or restored to a specified condition within a given period of time when maintenance is performed in accordance with prescribed procedures and resources. Thus, it may be seen that maintainability attempts to measure the inherent quality of design and assumes, for the purpose, that the maintenance environment is standardized. The concept is most useful in evaluating alternatives during a development and design phase for a new system or equipment item.

One of the more important characteristics of maintainability is accessibility -- a measure of the relative ease of admission to the various areas of an item where work is to be performed. An example where the several different container types can be distinguished on the basis of accessibility is the case of plywood liners used with aluminum panels. Reports of operators and independent maintenance facilities indicate that the necessity to remove these liners increases the job cost and complexity in many instances of repairs to panels. All containers encounter an accessibility problem when the cargo is present. The Truck/Trailer Manufacturers Association (TTMA) Maintenance Manual (Reference 9-2) recommends removal of all cargo before maintenance is performed. Obviously, the operator will avoid this if at all possible, since the cost is substantial, even exceeding many repair jobs.

Maintenance is the aggregate of all actions necessary for retaining an item in or restoring it to a specified condition. This includes both corrective and preventive maintenance. The former is the result of a failure and the item must be restored. The latter attempts to avoid failure by a sequence of inspection, detection, and prevention of incipient failure. Note that two terms have been introduced which have specialized useage in maintenance work: specified condition and failure. The essentials of specified conditions are obviously those covered by the standardizing specifications such as watertightness, load resisting capability, and dimensional correctness. Each operator may amplify these conditions to meet his own needs. Failures will be discussed in more detail under the next heading.

A maintenance engineering analysis task is included in military development projects. Recall that the maintainability definition referred to "prescribed procedures and resources." The analysis task identifies specific maintenance actions that will be performed at each level of activity -- organizational, intermediate, and depot. A determination is made of the necessary tools, test equipment, facilities, personnel, and technical data. Support needs by time and place are planned. Personnel requirements are expanded to include skills and numbers.

9.1.2 Reliability and Failures

The definition of reliability states that it is the probability that an item will perform its intended function for a specified interval under stated conditions. If an item is unable to perform within specified limits it is, by definition, in a failed state. Thus, the notions of reliability and failure are intimately related.

While the industry tends to use other terminology, the two concepts do apply. There is clearly some probability that a container will perform its intended function for a specified interval under stated conditions. The conditions of service are not precisely defined but this situation is also encountered in military systems applications.

Of the several terms which may be used as analogous to reliability, ruggedness probably fits best. It implies both strength and durability. During extensive communications with the industry, there were no difficulties of understanding with this term. For example, this term was used as the steamship operators were questioned about the qualities they sought in their container procurements. (It has been noted in Section 4 that ruggedness ranked ahead of low tare weight, useable cubic space, and other attributes.)

The matter of reliability, in the general sense (or ruggedness, which is more appropriate to apply to containers), bears on the total maintenance burden. It governs the frequency of occurrence of failures. The frequency of occurrence of failures in turn governs the amount of maintenance to be performed. Thus, it often is a tradeoff during the evolution of an item's characteristics and ultimately during its design, of reliability and maintainability. For example, if maintainability is good and reliability gains lead to high cost, the optimum design may be reached by sacrificing reliability.

It should be noted that failures are generally categorized as either catastrophic or degradation. In the field of containerization, as in most others, degradation failures are much more frequent. That is to say that the article in question may have passed into the failed state in that it cannot perform within specified limits. It may nevertheless be capable of performing much useful work. For example, a container may have a tear in a protruding flange of its lower side rail and it may, therefore, be limited in the weight which it will carry. It could continue to operate in this degraded mode. However, with a complete severing of the rail, safety considerations may dictate that the container must be removed from service, obviously a catastrophic failure. In the case of a penetration of a side panel, a temporary patch might be applied which would enable the container to continue in service. Since such a temporary patch is unlikely to be able to pass a specification test for watertightness, the container would be operating with a degradation failure.

9.1.3 Availability

The combined effect of maintainability and reliability is described by the concept of availability. The definition states that availability is the measure of the degree to which an item is in an operable and committable state at the start of a mission, when the mission is called at an unknown (random) point in time. It is a direct and logical step from the definition to an expression of the measure of availability in the form of a ratio of the percentage of time available (in an up state) to total time. The way in which reliability and maintainability enter can be seen in the expression below:

$$\text{Availability} = \frac{\text{Up Time}}{\text{Total Time}} = \frac{\text{MBTF}}{\text{MBTF} + \text{MTTR}}$$

where

MTBF - Mean time between failures

MTTR - Mean time to restore

The distribution of various time elements is shown in Figure 9-1, taken from Reference 9-1. Note that MTBF and MTTR taken together must equal the total time. Thus, the various elements of delay during which no actual maintenance is being performed are

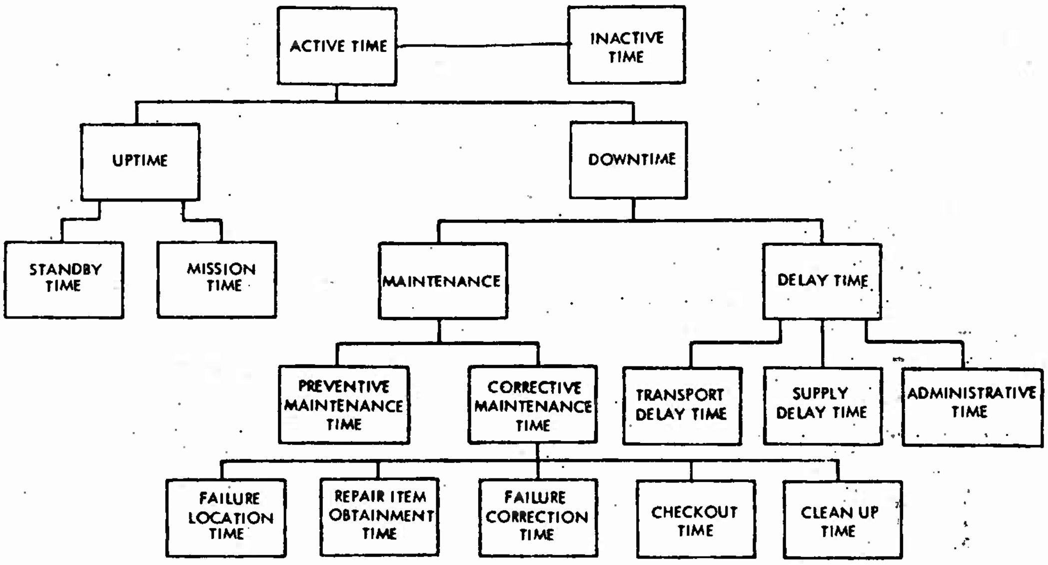


Figure 9-1. Distribution of Time Elements Related to Availability

included in MTTR. The commercial and military maintenance operations certainly share in common, at one time or another, the several delay components shown. For example, transport delay time might include the movement of a container to a maintenance contractor's facility. A further delay from the time of arrival until work is scheduled and actually starts might be chargeable to administrative time. Supply delay time covers periods during which work cannot be performed for lack of materials. Note that uptime includes periods when an equipment item is actively in use for mission-oriented purposes and when it is on standby. There is an additional category designated inactive time, when the item is not in service at all and the elapsed time is not chargeable at all against any standby or delay periods.

9.1.4 Quantification Indices

Several parameters are useful in attempting to quantify the burden due to maintenance. The first is MTTR, which has been introduced above. It is a measure of time during which the system or equipment item is unavailable for service. It is, therefore, of importance in determining the size of the inventory or fleet. Note that the MTTR is an <u>average</u> for the total population or for various subgroups having similar design features or similar conditions of maintenance resources. Note also that there is a possible discrepancy in MTTR. When the interest in MTTR is associated exclusively with the unavailability of an equipment item, the total of corrective maintenance time should be construed as the total of all downtime for maintenance, including delays. If MTTR is being analyzed to examine work distribution, the corrective maintenance time might exclude delays. This parameter specifically does not indicate the amount of maintenance work done. It is determined by the expression:

$$\text{MTTR} = \frac{\text{Total Corrective Maintenance Time}}{\text{Number of Maintenance Actions}}$$

The amount of maintenance effort is given by the Maintenance Support Index (MSI) which relates the maintenance hours to the operating time:

$$\text{MSI} = \frac{\text{Total Maintenance Man-hours}}{\text{Total Operating Time}}$$

9.2 Maintenance Procedures

A survey of maintenance procedures is reported here. This is part of the background essential to an understanding of what goes into an operator's maintenance budget. Obviously the damage situation (covered in Section 5) must be noted while considering the repair work. In accordance with the established concepts, maintenance in both categories, preventive and corrective, are included.

9.2.1 Inspections

The transportation companies, steamship lines in particular, make maximum use of their opportunities to perform inspections. The port terminals of the lines invariably include an adequate, covered facility for performing the inspection. (The schematic of Figure 4-3 does conform to actual practice.) Empty containers are passed through the inspection facility and cleaned prior to their dispatch to a commodity shipper. Upon the return of a loaded container back to the port terminal prior to transfer aboard ship, an inspection is performed again. Loaded containers coming off an inbound ship are inspected prior to their dispatch to the consignee. Containers which move primarily from the port terminal to another port, and which are stowed at the port with less than full lot goods, are subjected to similar inspections although the total number will be less in this type of operation.

Weathertightness. One objective in these frequent inspections is to assure watertightness. The exteriors are examined for evidence of tears or any penetration of the panels which would admit water. If the container is empty, a search is made for entering light rays in the closed and darkened interior. Water spray may be applied and then a check made for leakage from the outside to the inside. Some operators report the use of smoke bombs which are set off in the closed interior and then provide visual evidence of a leak path by the passage of smoke to the outside. Doors are checked for distortion and proper locking. (Obviously, many of these inspections are applicable only to empty containers.)

Structural Soundness. The inspection opportunities are further used to determine that no serious structural damage exists on the container and that it will continue its transit safely. Framing is checked for cracks and dents. Old repairs are examined to determine their present serviceability. Corner castings are examined for evidence of cracks and general soundness.

9.2.2 Preventive Maintenance

The industry as a whole reports that preventive maintenance, other than the essential checks, is neglected. One operator reported that the only opportunity the line had to do anything about preventive maintenance was during a strike of longshoremen when no cargo was moving. This situation arises due to the inadequate maintenance float in most of the container fleets. Much of the preventive maintenance that does get performed is close to the border with corrective maintenance. Nevertheless, there are a number of items of work which do fall in the category of preventive maintenance and which are sometimes performed.

Cleaning. Cleaning is performed, when possible, prior to dispatch of an empty container to a shipper in order to foster good customer relations. The types of practices recommended by the Aluminum Association (see Reference 9-1) are known and observed where possible. Additionally, the maintenance guide published by the Truck Trailer Manufacturers Association states a number of guidelines for care and preservation of containers which are followed at times. One line reported that steam cleaning equipment is used on their aluminum units. Cleaning solutions of a mildly acid type are used on aluminum.

Steel containers present more of a problem, since care needs to be observed during cleaning to avoid chipping any paint. FRP/plywood units are easily cleaned as the surface tends to resist soilage by much of the grime encountered in service.

Painting and Coating. In the case of aluminum containers, the general impression that surfaces are not painted turns out to be incorrect. Several lines using aluminum containers have a colored finish which makes it apparent that paint is used, for example Sea Train Lines. Others use an aluminum colored paint for protective purposes, and there is no evidence that the container has been painted. The durability of these finishes is not a critical matter and only minor fragments of information have been available. A rough estimate of the serviceability of the original paint surface is seven years. Thus, it is probable that an aluminum container will get one repainting during its useful life.

Steel surfaces present an entirely different and much more serious problem. The need for a corrosion preventing coating is much greater than the case of aluminum, and there are difficulties in getting a durable and fully protective finish. It should be noted that the remarks here apply to steel members of aluminum containers, for example end frames, unless a stainless steel has been used. For both original painting and repainting, the preparation of the surface must be correctly performed. This includes thorough removal of mill scale by blasting or pickling. All other foreign residues on the surface must also be removed. Those maintenance facilities which perform repainting with only a minimal cleaning and scraping report a durability of the job of less than three years. On the other hand, with full surface preparation and one of the better compositions of surface coating, durability of the job can exceed seven years.

In the field of marine coatings, care is taken to differentiate in the use of the terms paint and coating. The zinc-rich inorganic coatings, while they obviate the need for paint, are considered to be more closely related in function to galvanized surfaces, whether the zinc is deposited by electrolytic action or by hot dip. In short, the coatings act primarily to provide galvanic protection to the surface and are designated galvanic coatings. On the other hand, barrier coatings, the most prominent of which is paint, act to protect a surface by excluding harmful agents from contact with the parent material. Some of the properties and application data on coatings suitable for use on intermodal containers are summarized in Table 9-1.

In the application of galvanic coatings, it is of the utmost importance that no surface film remain between the coating and the steel. Thus, surface preparation is very critical and thorough sand blasting is practiced. However, the effectiveness of the coating is not harmed by small discontinuities. Barrier coatings, on the other hand, require an absolutely continuous surface to assure no entry of moisture. This is best achieved by applying multiple coats. A total thickness of five mils is considered necessary for a durable barrier. Note in Figure 9-2 (data available

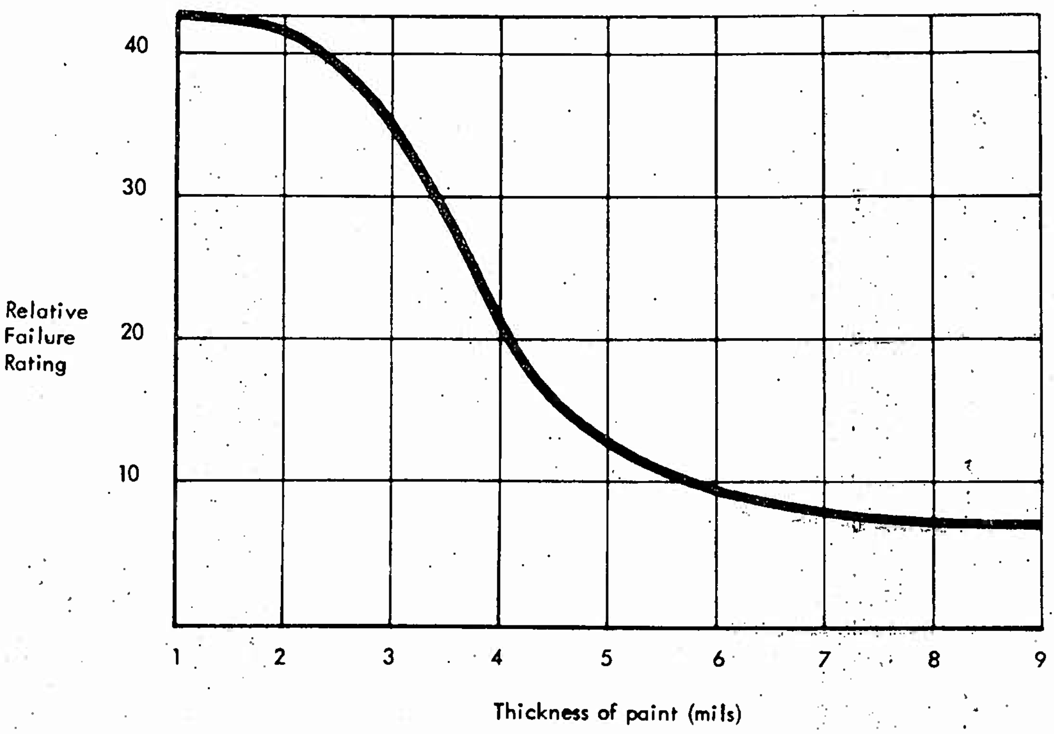


Figure 9-2. Relative Durability of Paint Surfaces

TABLE 9-1

COMMON MARINE COATINGS
APPLICATION DATA

ITEM	PRIMERS			METAL COATINGS		PAINTS			
	INORGANIC ZINC STEEL PRIMER	WELDABLE INORGANIC ZINC STEEL PRIMER	ALKYD INHIBITIVE PRIMER	INORGANIC ZINC-RICH COATING	ALUMINUM PAINT	VINYL COPOLYMER PAINT	VINYL ACRYLIC PAINT	AMINE EPOXY PAINT	ISOPHTHALIC ALKYD PAINT
RECOMMENDED DRY FILM THICKNESS PER COAT (MIL)	3/4	3/4	2	3	2	1 1/2	1 1/4	5	2
NO. OF COATS REQUIRED	1	1	1	1	2	2	2	1	2
THEORETICAL COVERAGE PER COAT (FT^2/GAL)	565	750	315	332	250	235	240	185	665
APPLICABLE SURFACES	Abrasive Blasted Steel	Abrasive Blasted Steel	Blasted Steel or Mechanically Cleaned Metal*	Abrasive Blasted Steel or Zinc Primer	Blasted Steel or Aluminum	Inorganic Zinc or Alkyd Primer	Inorganic Zinc or Alkyd Primer	Inorganic Zinc or Alkyd Primer	Alkyd Primer Only
APPLICATION METHOD	Airless or Conventional Spray	Conventional Spray	Airless or Conventional Spray, Brush	Conventional Spray	Airless or Conventional Spray, Brush, Roller	Conventional Spray, Brush, Roller	Conventional Spray or Brush	Airless or Conventional Spray	Conventional Spray, Brush, Roller
DRYING TIME	30 Min. To Topcoat 24 Hrs.	30 Min. To Topcoat 24 Hrs.	4 Hrs*	30 Min.	2 Hrs. Each Coat	1st Coat 2 Hrs., Topcoat 2 - 8 Hrs.	1st Coat 2 Hrs., Topcoat 4 Hrs.	8 Hrs.	Between Coats 8 Hrs. For Service 24 - 48 Hrs.
TOPCOAT	Inorganic Zinc Vinyls, Epoxys	Inorganic Zinc Vinyls, Epoxys	Isophthalic Alkyds, Epoxys	None or Recommended Topcoat	None Required	----	----	----	----
WEIGHT PER COAT PER FT^2	.30 oz.	.38 oz.	.50 oz.	1.50 oz.	.40 oz.	.23 oz.	.16 oz.	.75 oz.	.20 oz.

* Alkyd inhibitive primers are incompatible with zinc primers and galvanizing.

in Reference 9-3) that the curve is flat beyond a thickness of six mils. The phenol and vinyl based paints are considered best for resistance to ocean atmospheres. Epoxy based paints are also coming into wide use.

9.2.3 Corrective Maintenance

A brief review of the extent of damage disclosed in Section 5 is sufficient to show that repairs are a major factor in operations and maintenance of containers. As in most other facets of operations and maintenance, the individual operators each have procedures tailored to their own needs. Maintenance is influenced by the port characteristics on the trade route, by the facilities that can be established in each port terminal, and by the labor availability. Thus, some lines depend totally on their own resources for repairs, others use independent maintenance contractors, and still others use a mix by sending out work when the capacity of their own maintenance facility is inadequate to the work load.

Several steamship lines report that the efficiency, hence cost, of their maintenance work varies with priorities and urgencies. Under normal conditions, repair work is scheduled so that the optimum number of mechanics of the appropriate skills are assigned to a job. However, normal conditions do not prevail for as much of the time as they would like. Frequently the large number of containers unavailable for service threatens to degrade the timeliness of container movements to shippers. Under emergency conditions, work is forced through the shop at the fastest possible rate. This means that extra manpower is applied to the jobs, extra shifts are scheduled, and costs are forced up due to inefficiency and premium labor rates.

Several principles are observed by all maintenance facilities whether those of the steamship lines or independent contractors. The repair job must restore the container to its original structural capability. There is no practical way to establish by testing that this has been done. Therefore, damaged members are replaced with new members of equal cross-section or size, and of the same material and treatment as the original. Salvaged parts are not used in repairs. Joining of members is performed in a way that produced a nearly identical result to that of the original. Fasteners must be of equal strength. An example is the case of a fractured aluminum side rail. Welding would be avoided, as the alloy was not selected to provide for welding and its heat treatment might be destroyed.

9.2.4 Typical Repair Jobs

Patching of Aluminum Panels. A cutout around the damaged material is made of rectangular or square shape, using electric or manual shears. The edges are smoothed by filing. Ready-made aluminum patches are available from material suppliers with pre-drilled holes and rubber adhesive sealing. Alternatively, a patch may be cut from the same sheet stock as the original, normally alloy 5052-H38. In either case, the patch overlaps the cutout by about two inches. The holes in the patch are used as a template to drill holes in the parent material of the panel. Spacing of the rivet holes is determined by the need to compress the sealant in order to obtain a watertight joint. For patches prepared on site, the sealant might be a non-drying latex base caulking or a self-adhering rubber tape. Pop rivets are used to avoid bucking from the inside, especially if a field patch is being applied to a loaded container.

The problem of applying patches expeditiously is often complicated by the presence of a plywood liner as commonly used with aluminum panels. Most liners extend only up half the height of the side wall, so that patching at locations above halfway avoid the liner. The general rule is that the liner section must be removed and replaced when the patch job is performed. A number of steamship line reports indicated that this had a noticeable effect in increasing maintenance costs for aluminum paneled containers.

Replacing Sections of Aluminum Panels. When damage is extensive, say extending over more than 8 - 10 inches in any direction, the entire panel section is replaced. The old section is removed by drilling or knocking out the old rivets. The replacement section, of the same alloy as the original, is fitted with the overlapping exposed edge toward the rear. Drilling of the replacement section is performed in place, but oversize rivets (as compared to the original) are used to allow for reaming out the old holes. A typical cross section through the joint is shown in Figure 9-3. Typical rivet sizes are 3/16 inch for the vertical joint, which includes the attachment of the side posts, and 1/4 inch for the horizontal joints between the panel and the rails. All joints are sealed with material as described at the patching job.

Repairs to Steel Panels. Minor puncture damage in steel panels can be, and frequently is, repaired by riveting a sealed patch over the cleaned up cutout in a way similar to what was described for aluminum jobs. In many cases, especially where extensive

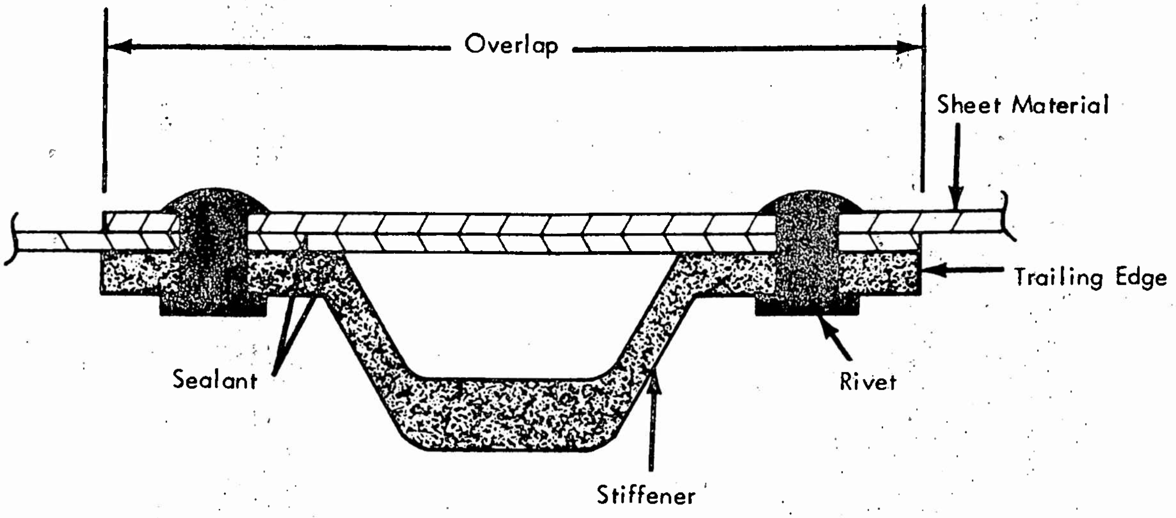


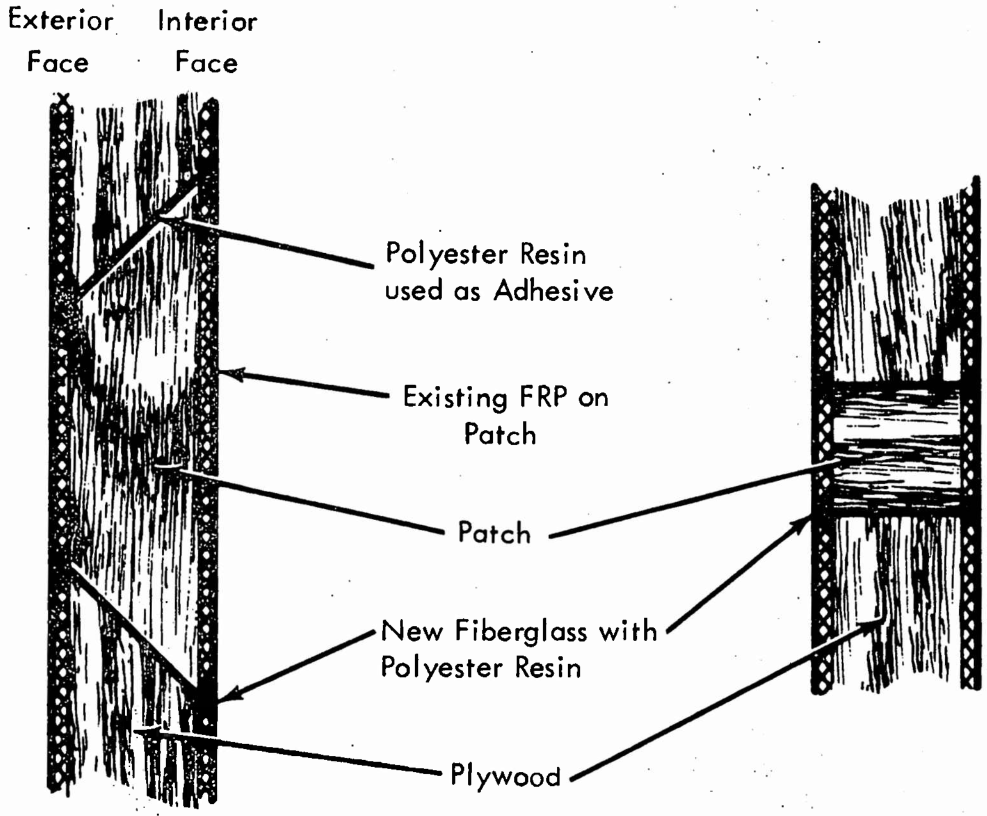
Figure 9-3. Typical Panel Overlap and Post or Stiffener

straightening up is required along with patching, an entire section of panel from top to bottom is cut out. One of the difficulties in performing these repairs is the necessity to stock replacement panel sections to match the rigidizing corrugation pattern of the original panel. The cutout is carefully performed to enable the patterns to be matched up when the replacement material is welded into position. After welding is completed, the area of damage is prepared for and refinished with a protective coating.

Patching of FRP/Plywood Panels. Large damaged areas can be repaired by the patch method. An area 50 inches by 33 inches has been patched and then successfully tested for minimum ANSI-ISO requirements. This is near the limiting size. Larger damaged areas require panel replacement.

Damage to FRP/plywood panels is repaired by cutting away an area, usually rectangular in shape, and sufficiently large to reach sound wood. A powered hand saber saw is used. The edges of this cut are beveled at a 45 degree angle with the smaller surface area outward. If the damaged area is small, say less than six inches across, the edges may be normal to the container walls (see Figure 9-4).

A patch of the same thickness FRP/plywood is then cut to fit. A bead of polyester resin is applied to the edges of the hole and the resin is allowed to dry and set. The original gel coat is then sanded off down to the reinforcing glass to a width of 2 - 4 inches each side of the joint between patch and existing wall.



TYPICAL PLYWOOD PLUG PATCH

PLYWOOD PLUG PATCH FOR SMALL HOLES

Figure 9-4. Typical Patches in FRP/Plywood Panels

This is done on both the interior and exterior sides. A coat of polyester resin is brushed onto the sanded area and a 4 inch width of woven roving in tape form is rolled on to cover the joint. Then, polyester resin is brushed on, thoroughly saturating the woven roving tape. When it has dried and set, another coat of polyester resin is applied and allowed to dry.

If the damage is extensive, an entire vertical section of the side wall from upper to lower side rail may have to be replaced. The width depends on the size of the area damaged. Vertical cuts are made with the edges of the cut beveled at a 45 degree angle as in the case of a large patch. The damaged section is then unbolted from the side rails. Caulking compound is laid on all surfaces where metal and wood will be joined. A replacement section is cut to fit, bolted to the rails, and the joints between the repair section and existing wall treated in the same manner as a patch repair.

FRP/plywood panels may suffer damage of a type which results in delamination but no surface rupture. Successful repairs can be completed by drilling small holes through the panel material and forcing catalyzed resin through the holes into the delaminated areas. Pressure is then applied and the resin cured.

The surface of a panel may develop small cracks through service useage. These are repaired by removing the damaged area of the overlay down to a feathered edge. Then the catalyzed resin with impregnated chopped strands of fiberglass is applied. The composition usually includes sufficient filler to prevent the wet resin from running down a vertical surface.

Repairs to Side Rails. If the damaged section extends over a substantial length of the rail, say about one-third or more, it is replaced. This is a major job which involves dismantling the entire side of the container. The rail must be disconnected from the panels and end frames and, if an upper rail from the roof or, if a lower rail from the cross members. Therefore, splicing of rails is frequently the means to restore these members to serviceable condition. The splice may be a channel section as shown in Figure 9-5. Here again, the material should be disposed to provide an equally strong section as the original and the alloy should be the same. The splice is joined by rivets or bolts but never by welding, presumably because of the heat treatment problem. If forklift pockets are provided in the side rails, the job becomes extremely difficult and the cost is up accordingly.

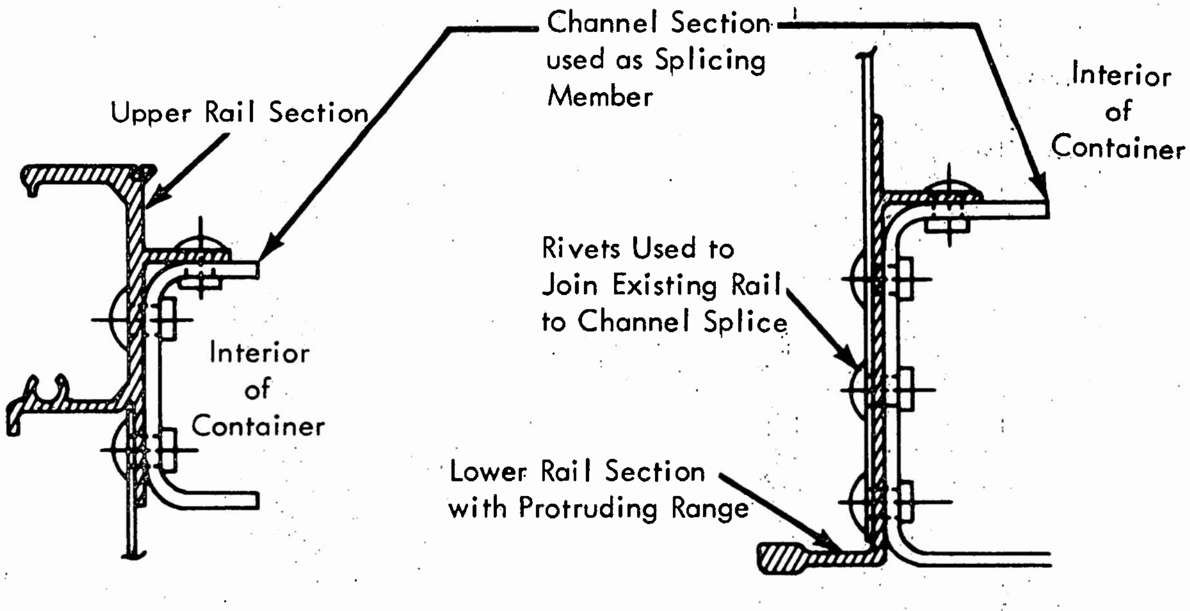


Figure 9-5. Splice (Channel Section)

Repairs of Roof Damage. Breaks and holes in the roof are promptly and effectively repaired to prevent entry of water and consequent damage to the contents. In general, small penetrations are repaired in a manner similar to that by which side panels are patched. However, the tendency to replace the entire roof surface is greater than in the case of side panels. Aluminum roof stock provides a one-piece surface which after the application of sealant is riveted at one end, stretched taut, and riveted at the other. Riveting along the sides is then performed. In the case of steel, the old surface is removed by torch cutting and the one-piece replacement surface welded into place. RFP/plywood roofs are relatively simply replaced. After removal of the damaged roof panel, surfaces are prepared for sealing and the new stock is bolted to framing members.

9.3 Maintenance Facilities and Manpower

A maintenance system includes facilities, manpower, special and standard equipment, and publications and other technical data required for the performance of work. The first two of these warrant description as part of a documentation of the maintenance burden. In the matter of equipment these are, in the main, simple tools which have been mentioned in passing under Maintenance Procedures. Similarly, maintenance manuals are not critical to the performance of work.

The operators organize their maintenance activity in a way similar to the several echelons of maintenance used in the military establishment. At the lowest level, analogous to organizational maintenance, the simplest jobs are performed and a mobile repair unit manned by personnel with relatively few skills is employed. A repair facility is available at the port terminals of the major container operators, analogous to intermediate level maintenance. Additionally, most all the operators make use of independent maintenance contractors who are well equipped and can undertake the largest jobs.

9.3.1 Mobile Repair Units

A simple shop truck provides operators with a mobile repair unit. The main use of these units is to facilitate repairs in place, especially when the work can be done without removing the contents. Typical jobs are the application of patches to side panels and roofs to promptly restore watertightness. As a general rule, the jobs are completed within one or two hours. Much of the repair work is temporary in nature. The equipment carried in the shop truck includes hand tools for metal working and carpentry, riveting guns, and a supply of parts such as ready cut patches with sealer and fasteners. Tools for performing simple adjustments and repairs to refrigeration units are also included.

The work load in mobile repair units is highly variable. Shortly before the sailing of a ship, the number of containers at the terminal will peak and inspections will disclose much work to be done. The number of jobs may go to 30 - 40 per day. After the offloading of inbound units, a similar peak can be expected. Between ship sailings, the mobile units may be inactive with the workmen being transferred to the shop for inside work.

9.3.2 Operator Maintenance Shops

The size of these shop facilities varies from one operator to another and from port to port. For example, Matson operates major facilities at Oakland, Wilmington, and Honolulu with minor facilities at Seattle and Portland. When a steamship line makes extensive use of independent maintenance contractors, it will have only simple facilities at its terminal.

In general, the facility is a garage-like structure immediately adjacent to an inspection station. The average capacity is in the range from two to six bays where a single container job goes into each bay. A job may be in work anywhere between two hours and three days. When possible, the major repair jobs are scheduled for slack periods, especially the time between ship sailings.

Substantial amounts of work other than on dry cargo freight containers are performed in these shops. Between one-third and one-half of the total work load is devoted to over-the-road chassis. This involves maintenance of hitches, lights, axles, and tires. Additionally, refrigeration units need overhaul and repair. Tank containers need work on piping and valves. At some facilities the shop provides service on mobile handling units.

An adequate stock of repair parts is kept on hand at these facilities to avoid supply delays. It is necessary that each model be supported. The need to standardize is now becoming apparent in the industry. In addition to material for panel patching, stocks include panel stiffeners for aluminum units, rail splice stock, door hardware, and roofing stock.

9.3.3 Independent Maintenance Contractors

The major port areas are served by maintenance contractors independent of the steamship lines. They perform work for the lines which are not sufficiently into containerization to support a maintenance facility or those which do have a facility as described above but which develop a peak work load from time to time beyond their capacity. There are also lines which send out only major jobs either for reasons of a lack of labor skills or to avoid clogging the facility with long duration jobs. Additionally, leased containers which do not conform to a line's standard units and which need overhaul prior to return to the lessor are usually sent to an outside repair shop.

The practice in the industry is that all jobs are bid competitively by sources found by the steamship line to be reliable in workmanship and schedule-keeping. A typical bid is shown in Table 9-2 in which the level of cost breakdown is obvious. Note that the breakdown includes no burden or profit, these being included under labor and parts items, similar to the manner in which automotive repairs are commonly costed.

TABLE 9-2

TYPICAL BID BREAKDOWN FOR MAJOR CONTAINER DAMAGE

Cost Element	Parts	Man-Hours	Labor Cost
Replace doors	$345	17	$ 68
Replace two plywood liner sections	15	1	4
Replace five posts - one side	50	10	40
Replace three panel sections	63	9	36
Replace door sill	24	7	28
Wash and paint	15	5	20
Transport to facility	--	--	20
Totals	512	49	216

TOTALS FOR PARTS AND LABOR $ 728

These firms vary in size. The average shop has a capacity of about 300 jobs per month. One of the larger shops in the Port of New York area has a capacity of 900 jobs per month. This company occupies an area of about eight acres and may have as many as 100 containers in its yard awaiting work. Several of these maintenance companies also provide mobile service to steamship lines which have such a limited number of containers that their operation warrants no maintenance facilities at all. Usually this service is provided under long-term contract rather than job by job.

9.3.4 Manpower Skill Requirements

All the required skills are available at maintenance facilities of both the steamship operators and the independent maintenance contractors to perform the full scope of work as noted in the previous sections. Recall that this includes chassis, refrigeration, and handling equipment overhaul and repair jobs. A container line maintenance facility at a major port may have a work force of 30 - 50 men distributed over two shifts. Lines which operate partially converted ships may have 12 - 20 workmen. The usual mix of skills on such work forces follow approximately the following proportions:

Metal workers, general mechanics shipbuilders	9
Welders	3
Carpenters	2
Engine Mechanics	1
Refrigeration Mechanics	1

In general, the labor force is drawn from the longshoring union having cognizance over the particular sea coast. In small facilities, the level of competence compares to that found in automotive body shops. At the larger facilities, new personnel are trained and brought up to journeyman status over a period of about six months, presupposing that the individual has mechanical aptitude and some previous skill development. During this period, the man works for the first half of the time with a representative from the manufacturer's plant. Subsequently, he works alongside a fully experienced repair mechanic. Assuming satisfactory progress over this period, he is then regarded as fully qualified to undertake independent repair assignments.

9.4 Cost Estimates for Maintenance

The importance of maintenance costs in the total life cycle costs has warranted the fullest possible investigation of the subject. Several different approaches were followed and the results of each are clearly in agreement. Following the cost summarization data below, there are detailed cost analyses by job, which enable the reader to appreciate the way in which the aggregated maintenance costs build up.

9.4.1 Maintenance Cost Summarization

Determination from Operator Supplied Data. This approach uses the data obtained during the field survey work at steamship operators. The quality of these data is not high. In some cases, it appeared that the operators were willing to supply the cost data to only an approximate value so that their proprietary information would not be disclosed. Others appeared to have only approximate data. In all cases, maintenance cost data covered the entire container fleet of the operator, and no breakdown for subclasses of containers were available.

In most cases, the operator supplied maintenance costs appear to omit some cost elements. The figures most readily available were budgetary plans which include only direct costs. Various indirect costs related to operation of the maintenance facility, services to employees beyond direct compensation, and the general administrative burden are not included. However, when maintenance work is sent to an outside contractor, the costs incurred are comprehensive covering all direct and indirect cost elements. The maintenance cost data obtained from the ship operators did not show any segregation as between costs due to work at the facility versus costs due to work sent out.

In addition to the limitations of the data due to quality and comprehensiveness, there are many unknowns. For example, in no case was there a segregation of maintenance costs for work performed at foreign ports or home ports. Labor costs are substantially lower at most foreign ports. Some lines operate exclusively at port terminals which provide a more protective handling environment and consequently damage rates run lower (for example, see Figure 5-1). Additionally, despite the advantage of working only with average values, maintenance costs tend to increase with the age of the container fleet and some lines have many containers of advanced age.

In order to protect the proprietary interests of the lines, the raw data will not be shown but the analysis procedure will be discussed and the results presented. The input data consists of total annual maintenance costs for each steamship line. The container fleet size and composition was taken from the published equipment register (Reference 9-4) and additionally was refined by data from the field survey. The container population was broken down to three categories only -- aluminum, steel, and FRP/plywood. Thus, no distinction is drawn as to whether the framing members are all aluminum or a mix of steel and aluminum, no differentiation is made between aluminum panels with exterior or interior posts, owned and leased units are lumped together, and so on. Where damage is caused during over-the-road transport and the highway carrier incurs the maintenance cost, it does not show up in this analysis.

Thus, the data consists of total maintenance costs and total container population in three categories for each of six steamship lines. The problem is to determine the fraction of maintenance costs applicable to each container type and then unit maintenance cost for each type. Stated in analytical form, the coeficients a, b, and c in the following equation must be determined for a set of T, X, Y, and Z:

$$T = aX + bY + cZ$$

where

T = total annual maintenance cost for the fleet of container
a = maintenance cost per unit per year for an aluminum container
X = number of aluminum units in the fleet
b = maintenance cost per unit per year for a steel container
Y = number of steel units in the fleet
c = maintenance cost per unit per year for an FRP/plywood container
Z = number of FRP/plywood units in the fleet

Obviously, if precise data were available, only three operator inputs would be required for the determination. The technique we used recognizes the uncertainty in the data and produces a best fit line to the data points by regression analysis. This statistical technique establishes a relationship by means of an equation between a dependent variable and one or more independent variables such that the sum of the squares of the deviation of the actual values of the dependent variable from the calculated values is a minimum. Thus, the regression coeficients (the annual unit maintenance costs) do not necessarily match any single operator's experience but include the effect of all data inputs. The results are shown in Table 9-3.

TABLE 9-3

ANNUAL UNIT MAINTENANCE COSTS BY OPERATOR DATA

Type of Container	Annual Cost Per Unit	Error	Range
Aluminum	$113.47/yr.	± $11.13/yr.	$102.34 - $124.60/yr.
Steel	$301.65/yr.	± $69.76/yr.	$231.89 - $371.41/yr.
FRP/Plywood	$ 69.39/yr.	± $26.76/yr.	$ 40.63 - $ 94.35/yr.

The results confirm a consensus attitude that appears to exist among operators. Many reports were received that the FRP/plywood containers are the least costly to maintain in operation and that the line would be progressively increasing its proportion of these units. Note also that despite the wide range for each container type, there is no overlap. This indicates that if additional data were to be available and the range for each of the annual unit costs were reduced, it is not likely that any changes would result in the relative cost ranking.

Another check is possible. In Table 9-4 below, the total annual maintenance cost as reported and as calculated compare very closely. The calculated values are obtained by inserting the regression coeficients (annual unit maintenance costs) into the original equations.

TABLE 9-4

COMPARISON OF REPORTED AND CALCULATED ANNUAL UNIT MAINTENANCE COSTS

Ship Line	T Reported	T Calculated	T Minimum	T Maximum
A	287,500	275,500	165,000	382,000
B	1,105,000	1,134,100	945,000	1,314,500
C	1,000,000	1,054,200	871,100	1,230,000
D	717,000	523,300	446,100	590,000
E	1,256,500	1,275,600	1,135,600	1,416,600
F	138,500	125,700	113,500	138,100

Determination from Damage Data. A second approach proceeding from data which is completely independent of the above has produced another set of annual unit maintenance costs. The two sets are consistent. In this case, damage data previously presented in Section 5, is used to develop cost of repairs, which are then augmented by preventive maintenance cost. These data are lumped together as to the steamship lines from which they originate but are segregated by container type.

The two main variables in extending the damage data, which is on a cargo shipment cycle basis, to annual unit maintenance costs are in establishing the mean costs of each damage code and the mean number of cycles per year. Detail examination of costs by job is included subsequently in this section. Then, based on a probable mix of jobs to repair damage within each code, a mean cost of corrective maintenance is estimated to be:

Damage Code	Damage Estimate	Mean Repair Cost
1	$ 0 - 50	$ 40
2	50 - 200	125
3	Above $200	300

Reports from operators enabled the estimate of the number of cargo shipment cycles per year. The numbers reported ranged from a low of eight on trade routes to South America to a high of 15 across the North Atlantic. Estimating was performed weighing those values associated with the most heavily trafficed trade routes and a mean of 12 cargo shipment cycles per year obtained.

Maintenance for repair of damage, based on the damage survey statistics, are shown in Table 9-5. The costs for containers of FRP/plywood show up to be clearly lower which obviously follows from the damage data. Note that steel containers are highest although fairly close to aluminum -- even before preventive maintenance is included. This is not surprising when the data of Section 6 on materials evaluations is fully assimilated. Recall that the strength-to-weight ratio for the aluminum material in container applications is roughly twice as good as for steel, while the weights (after subtracting an allowance for common members) are roughly in the ratio of 1.0:1.4. The evident superiority of the

TABLE 9-5

MAINTENANCE COSTS FOR DAMAGE REPAIR
(per Cargo Shipment Cycle)

Handling Environment	Aluminum (External Posts)	Aluminum (Internal Posts)	Steel	FRP/ Plywood
Average for All Systems	$11.61	$11.34	$13.40	$5.91
Fully Containerized Systems	9.11	6.08	8.95	4.59
Converted Ships - Deck Gantry Cranes	11.26	11.67	14.35	6.52
Partially Converted Ships - Conventional Deck Gear	14.49	16.21	16.90	6.58

FRP/plywood units can also be readily appreciated on the basis of the materials evaluation and the design considerations of Section 7.

Annual unit maintenance costs are shown in Table 9-6. The values are obtained by multiplying the costs per cargo shipment cycle of the previous table by the average number of trips per year -- essentially the corrective maintenance element -- and adding the cost of painting -- essentially the preventive maintenance element. Details on the cost of painting are presented later in this section. The results are that a reasonably satisfactory paint job can be performed for $380 and the total surface of steel containers would be renewed every three years. The superior quality galvanic coatings now coming into wider use were not included in these costs. This corresponds to the present practice of industry as disclosed by the field surveys. The steel end frames of the other container types are assumed to be similarly renewed. For purposes of carrying maintenance costs forward to full life cycle costs, the two variations in design of aluminum containers are considered as one.

TABLE 9-6

ANNUAL UNIT MAINTENANCE COSTS –

BUILDUP FROM DAMAGE DATA

Cost Element	Aluminum	Steel	FRP/Plywood
Damage Repair (12 x results of Table 9-5)	138	161	71
Surface Maintenance (1/3 x cost of paint job)	7	126	7
TOTAL	145	287	78

The main effect conveyed by this table is that steel, which was only slightly behind aluminum, falls substantially behind due to the high cost of painting. It will be noted in the details of the cost breakdown of painting and coating that much of the cost goes into surface preparation. It will also be noted that the zinc-rich inorganic coatings have a durability of at least twice that of the more common protective paints while their cost is not nearly up in the same proportion. A problem arises, however, in the wisdom of applying the superior coating as a maintenance procedure at the three year point in the container's life span since the container's probable life expectancy is so short that the cost advantage of the better coating may not be realized. The rational alternative would be to apply the superior coating at the time of manufacture. In the event that were to be done, the surface could be expected to last for the full life of the container, providing that it was not damaged. Additionally, the cost of applying the coating during manufacture would be less than the cost of the maintenance job. Since this is not being done in the industry at this time, the more favorable cost situation was not assumed.

Note also in the table that both aluminum and FRP/plywood containers are in substantially the same relative position after surface maintenance is added, since the sum for protection of steel end frames is the same for each. There is no allowance for periodic repainting of aluminum containers. The situation in the industry is that most aluminum containers are painted. In some cases, for example Sea Train Lines, the colored surface makes this immediately evident. Many other operators use aluminum paint so there is no visible evidence that a protective coating is applied. However, the sheet material used in manufacture is purchased with the finish applied and its cost effect is contained in the initial price. The basis for the omission of a repainting job at about the midpoint of the life span of aluminum containers is that the protection is not clearly necessary.

Comparison of Results from Two Sources. The most striking observation from comparing the two sets of results is that they are very close. The final figures derived by both the approaches are shown in Table 9-7.

TABLE 9-7

COMPARISON OF ANNUAL UNIT MAINTENANCE COSTS

Source	Aluminum	Steel	FRP/Plywood
1. Operator Reports	$113	$302	$69
2. Damage Survey	138	287	78
3. Ratios - Line 1	1.6	4.4	1.0
4. Ratios - Line 2	1.8	3.7	1.0

It should be appreciated that both approaches contain large approximations. In the case of the operator supplied annual maintenance costs, aggregated for the total operations of the line, the source data were not claimed to have a high degree of accuracy. In addition, the accounting methods of these commercial organizations probably result in many indirect cost items associated with the maintenance activity showing up in a total burden or overhead account for the line rather than as a maintenance expense. Additionally, the damage incurred on the highway may be repaired by the highway common carrier. The opinion is held by the authors of this report that the operator supplied maintenance costs will be on the low side of the real costs. In the statistical treatment of this data, there is an underlying assumption that annual unit maintenance costs are constant through the wide range in operating environments.

The maintenance costs developed from the damage data have equal uncertainties. The population of over 10,000 containers observed was rated as typical by Marine Surveys, Inc., who specialize in these kind of surveys. Voyages through very heavy weather were excluded. The cost of repairs within each damage code were developed by detailed study of specific jobs and the mix of jobs to get the average corresponded to the types of damage actually observed. The average annual utilization and painting costs were based on data obtained by the industry survey. The bias which appeared in the damage survey due to the preponderance of FRP/plywood containers in the category of fully containerized shipping systems (where the damage rate runs lowest) has been removed.

The difference in the level of the two sets of annual unit maintenance costs shows that those derived from operator reports are lower -- as expected. However, the amount of the difference for all container types is small enough to establish the validity of the results. Additionally, the ratios of the maintenance costs for the several types are in very close agreement. Of the two sets, the results from the data originated in the damage survey are believed to be most realistic and are carried forward to the life cycle cost analysis of Section 10.

9.4.2 Maintenance Cost by Repair Job

There are a number of repair jobs which recur frequently enough so that a reasonably accurate estimate of costs can be performed. It should be realized that there are no absolutely standard costs. Indeed, it was noted under Section 5.2 that jobs are usually bid competitively when steamship lines use independent contractors.

Labor Costs. Labor is generally provided by longshoremen's unions at rates which are fixed for each skill category in the port. There is variation in rates from one port to the next, even on a common seacoast. The range is from \$4 - \$12. Labor is the dominant item in repair costs (in the U.S.) running to about two-thirds of the job in most cases.

Material Costs. While the raw material costs are nominal, the material is stocked in a form that is as ready to use as possible. Recall that under procedures, it was noted that ready-made patches with rivet holes drilled and sealant applied are in common use. The maintenance facilities stock aluminum hat-section extrusions corresponding to the cross section of panel stiffeners for each lot of containers. The independent maintenance contractors are prepared to work on containers of the major manufacturers and accordingly stock all section profiles in wide use. This same applies to corrugation patterns for steel containers. FRP/plywood panel material is stocked in sizes up to a complete panel of 20 ft x 8 ft. The panel cost is in the range of $140 - $155.

Typical Job Cost Breakdown. The most common jobs are covered by the amounts in Table 9-8. Note that most of the jobs are well defined work items. Those having greatest variability, for example to straighten a deformed side rail where the amount of straightening is difficult to describe, have been omitted. Nevertheless, there was substantial variability between the maintenance sources supplying cost data. There is only a rough correspondence between the amounts in Table 9-2 and this table.

TABLE 9-8

TYPICAL COSTS ON REPAIR JOBS

	ALUMINUM		STEEL		FRP/PLYWOOD	
Job Description	Material	Labor	Material	Labor	Material	Labor
Replace Post	$ 15	$ 21	-	-	-	-
Replace Panel Section						
Plain Sheet	20	45	$ 10	$ 80	-	-
With rivet holes predrilled	25	30	-	-	-	-
Replace Side	-	-	-	-	$ 180	$200
Replace Rail						
Lower	55	90	25	130	55	90
Upper	55	60	25	150	55	60
Splice Rail						
4-ft section	12	50	-	-	12	50
10-ft section	30	80	-	-	30	80
Replace Crossmembers	20	25	10	25	20	25
Replace Floor	200	210	200	210	200	210
Replace Roof	100	200	50	275	180	200
Replace Corner Post	90	100	90	100	90	100
Replace Castings	30	45	30	45	30	45
Replace Door Sill	20	50	20	70	20	50
Replace Door	180	120	180	120	180	120
Patch Small Holes	1	7	1	15	1	7

9.4.3 Cost of Surface Protection

The growing use of galvanic coating described previously in this section leads to the use of the term surface protection rather than simply painting. Costs can be developed on the basis of the unit operations of which the job is composed, plus the cost of materials. The data contained in References 9-3 and 9-5 appear to be authoritative and are included in Table 9-9. The cost of the coating material is by supplier data. The significant result from examination of these data is that the galvanic coating job increases the cost of surface protection by 25% on a job basis. Note, however, that the longer life of the superior coating turns out to yield the job with the lowest annual costs.

TABLE 9-9

COST ELEMENTS OF CONTAINER COATINGS

Item	Zinc-rich Primer/ Epoxy Paint	Zinc-rich Inorganic Coating	Aluminum Paint	Alkyd Primer And Paint
Surface preparation, cents/sq.ft.	26.0	26.0	20.0	20.0
Material, cents/ sq.ft.	12.8	5.6	5.2	6.8
Application, cents/ sq. ft.	6.2	3.1	6.2	9.3
Miscellaneous	5.5	5.5	5.5	5.5
Coating total, cents/sq.ft.	50.5	40.2	36.9	41.6
Coating job cost, $ (885 sq.ft.)	446	356	325	378
Probably service life, years	7	5	3	3
Annualized coating cost, $	64	71	108	126

There are a number of subtle points not immediately obvious from the table. The coating suppliers recommend higher values of useful life for the galvanic primer and coating, but the recommended values were reduced to correspond to the exceptionally severe conditions of use encountered by intermodal containers. Additionally, the spread in service life between the zinc-rich inorganic coating and the zinc-rich primer with a protective epoxy paint was increased to give adequate recognition to the benefit of the epoxy. Actually, the suppliers claim a useful life of seven years for the unprotected coating.

In the comparison of the aluminum paint to the conventional alkyd, the former yields the lower cost job by the figures shown. However, the cost of alkyd by the gallon is less. The higher cost of alkyd is due to the fact that three coats are applied -- one primer and two finish coats. The key to the total number of coats used in preparing job costs in the table is the application cost which is 3.1¢ per square foot per coat.

The decision to use the conventional alkyd paint and primer is based on acceptance by the industry rather than the least cost solution to the problem of protection to corrodible surfaces. The value of $378 was rounded off to $380 and carried into total maintenance cost estimating and thence into life cycle costing. The cost of protecting steel end frame members was estimated by scaling down painting costs in proportion to the amount of surface. The cost is estimated to be $22 for conventional painting. It is interesting to note zinc-rich inorganic coatings are being used on steel end frames by one of the major shipping lines, and they confirm that seven years of excellent protection have been realized.

SECTION 10

LIFE CYCLE COST

Life cycle costs compile all the qualities and operational results into a single measurement -- costs in terms of dollars. Thus the previous sections are drawn together. The investigation in damage led to maintenance costs. Properties of materials and design efficiency have a bearing on cost of investment. As is usually the case, the several constituent elements of cost all have a different degree of influence on the overall cost. Therefore, the sensitivity of the result to variations in all cost elements has been examined. In particular, an analysis of the relationship between a container's tare weight and useable cube and their operating benefit to an operator have been included. Finally, since the several container types under consideration have different ratios of investment to operating costs, the question of discounting has been examined.

10.1 The Cost Model

Life cycle cost in general terms is the cost of acquiring and maintaining a system or equipment item over its useful life span. The concepts used in the analysis of life cycle costs are entirely applicable to the freight containers under examination in this report. For the purpose of this analysis, the cost of acquiring the container was amortized over the useful life span, so that life cycle cost is expressed in total dollars per year of the useful life. Life cycle cost calculations were made on the following basis, which is in effect the cost model:

$$C_t = C_p + C_m$$

where

C_t = Total cost in dollars per year;

C_p = Purchase price divided by the useful life;

C_m = The sum of annual refurbishment costs, annual repair costs, and the cost of the maintenance float.

Amplification of calculation approaches for each of these cost elements is included in the following paragraphs.

10.2 Summary of Results

The results of the cost analysis are presented in Table 10-1. The results indicate a significant cost advantage for FRP/plywood type containers over steel types, with a lesser advantage over aluminum types. When a reasonable range of uncertainty is considered, the cost advantage of FRP/plywood over aluminum appears nominal (see Section 10.5). The use of a 20-year life cycle for costing does not imply any particular value of life expectancy, but rather conforms to established practice. The matter of life expectancy was handled in the most rational way with the fragmentary data available (Section 10.4). The table also shows the "present value" of these costs by applying a discount rate of 10%.

TABLE 10-1

SUMMARY OF COST ANALYSIS

	Aluminum	FRP	Steel
Amortized Purchase Cost	$ 183	$ 204	$ 219
Annual Maintenance Cost	163	88	310
Total Cost Per Year	$ 346	$ 292	$ 529
20-Year Life Cycle Cost	$6908	$5847	$8591
Discounted (10%) 20-Year Cost	$4134	$3648	$4647

Several noteworthy results are immediately apparent in Table 10-1. Despite the lower purchase cost of steel containers, their shorter mean life has the effect of making the annual amortization of purchase cost the highest. Nevertheless, there is less spread in purchase costs than in maintenance costs. It is the latter which dominate the final results. Steel containers suffer high maintenance costs for the dual reasons that they require continuing effort on corrosion prevention and they are damage prone to about the same extent as aluminum units. The FRP/plywood containers are in the low cost preventive maintenance area along with aluminum containers, but they have the advantage in resistance to damage -- and consequently in repair costs.

While the cost results of this study are the result of a comprehensive data collection by means of a field survey -- and are considered by the authors to be fully validated -- it is interesting to compare the results with other reported values. Industry journals contain the additional data presented in Table 10-2. Both of the other sources show the same ranking as that reached in this study.

TABLE 10-2

COMPARISON OF COMPUTED ANNUAL COST
AND ANNUAL COSTS OBTAINED FROM THE LITERATURE

	Computed Annual Cost	REF 10-1	REF 10-2
ALUMINUM			
Amortized Purchase Cost	$183	$235	$232
Annual Maintenance Cost	163	120	108
Total Cost Per Year	$346	$355	$340
STEEL			
Amortized Purchase Cost	$219	$225	$217
Annual Maintenance Cost	310	168	144
Total Cost Per Year	$529	$393	$361
FRP/PLYWOOD			
Amortized Purchase Cost	$204	$265	$260
Annual Maintenance Cost	88	60	48
Total Cost Per Year	$292	$325	$308

REF 10-1 "How To Cut Container Damage" <u>Containerization International,</u> September 1969

REF 10-2 R.D.C. Jones, College of Production Technology, "Design, Construction & Provision of Containers to Meet Customer Needs" 27 February 1969

The recently reported data of Reference 10-3 are identical to those of R.D.C. Jones in Reference 10-2. The values reached for amortization of purchase cost in the referenced studies are higher due to the estimates used for expected life. Specifically, values in Ref 10-1 10-2 of expected life are five years for steel containers versus six years for aluminum and FRP/plywood types. It will be seen in Section 10.4 that the data acquired in the field survey of this study leads to substantially longer estimates of life for aluminum and FRP/plywood. The other source of discrepancy in the table is the implicit estimate in the cost data of the references that steel containers would not be repainted in their total useful life. Again, the field survey data of this study does not conform to the estimates of the references. This can readily be seen by noting the variation in annual maintenance costs for steel containers.

10.3 Initial Price

Initial purchase cost was obtained from several sources. In some cases, the steamship lines disclosed actual purchase price for past acquisitions. Additionally, some lines made available the full range of bids received from manufacturers. The manufacturers are most reluctant to state a purchase price, since their quotations are carefully prepared for each procurement which may have special design features and since transient market conditions have much to do with pricing. For standard 20-foot containers with no special features, the prices at this time cover these ranges.

Aluminum	$1600 - 2800
Steel	900 - 1550
FRP/Plywood	1550 - 2700

These quotations include bids from European manufacturers where bids were significantly lower, especially for steel. Army procurement experience also falls within these ranges. No information is available as to the number of bids at different prices.

There is also considerable indication that the price trend for containers is down, in spite of a steady trend of increases in both labor and materials. The reasons for this downward trend include improved manufacturing methods with experience. Additionally, increasing competition from foreign producers, and a softening of demand have been coupled with an increased production capacity in the domestic industry, thus exerting a downward pressure on prices.

Within the ranges of actual purchase price history and quotations, specific values are selected for further analysis. The selected values are intended to be in the lower part of the range for U.S. purchases and to exclude any extreme values which may not be continuously available:

Aluminum	$1825
Steel	1275
FRP/Plywood	1900

Special design features and strength requirements lead to extra charges -- similar to the way in which many other products have separate prices for basic models and optional items. Some of the more common items and their effect on price are:

Door Mechanisms - The use of four locking bars versus two and the addition of superior anti-racking latches for added strength increases the price.

Door Material - May have thicker core and facing, up to a cost of $60.

Forklift Pockets - The addition of forklift pockets increases the cost by $200 to $400.

Internal Restraint System - Average about $100 extra.

Interior Liners - Increase cost of up to $0.10 for each square foot covered.

Flooring - Increase of thickness in the floor stock might be from a nominal standard of 1 1/8 inch up to 1 1/2 inch and a superior grade may be specified, adding a cost item up to about $30.

Front End Reinforcement - Increased sheet thickness and number of posts may add $30.

Top Corner Protective Plates - These are becoming standard but are not a high cost item in any event.

Cross Members in Lower Frame - The spacing may be decreased, adding additional cross members requiring more material and installation expense.

Panel Stiffeners - The spacing on these members may similarly be specified at reduced intervals adding possibly $30.

Framing Thickness - Special strength requirements can lead to heavier gauge material in end frames, rails and other places which directly converts to cost increase.

10.4 Mean Service Life

The initial price must be prorated over the service life of the unit, thus leading to the important determination of just what might be expected for mean service life. Despite its importance, the matter has received practically no attention in the industry. The tendency to regard a few cases which have survived for very long lifetime periods as indicating the mean service life is erroneous. For example, if attrition during service is neglected and an unfounded very long period is predicted for useful life, then a high cost container might show a falsely low amortization value. From the operator's point of view, there would be a continuing charge for a container which did not exist. Therefore, if the percentage of surviving units is not high, the estimated annual cost of purchase tends to be overstated as compared to its true value.

Mean service life has been estimated on the basis of a distribution of units surviving in service as shown in Figure 10-1. The form of the curve takes into account two general categories of loss: (a) due to the hazards of service, and (b) due to wear out, continued exposure to the elements, and the like. It is possible, of course, to visualize losses due to a combination of factors. For example, a container having experienced years of normal service and exposure, may accumulate loosened rivets, minute corrosion cracking, and seemingly trivial misalignment of primary structural members, and may not be considered as worn out. However, at an advanced point in its life span, it may be subjected to a peak loading condition which it would have survived when new. It then fails in an abrupt way. There could be endless speculative discussion on whether this was a normal wear out.

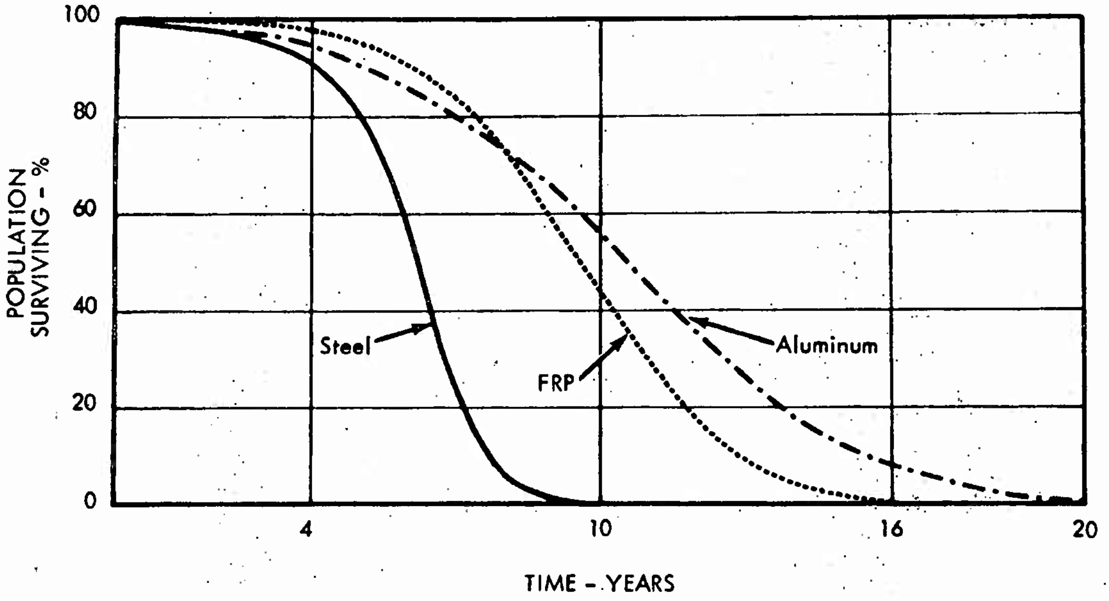


Figure 10-1. Survival Rate for all Container Categories

The construction of the curve is thus a product function containing the following factors:

$$\text{Hazard Function} \quad - R_1(t) = e^{-\lambda/t}$$

$$\text{Wear Out Function} - R_2(t) = \int_{-\infty}^{t} \left(\frac{1}{\sigma\sqrt{2\pi}}\right) e^{\frac{-(t-m)^2}{2\sigma^2}} dt$$

where λ — failure rate (scrapping in this case)

m — mean life on wear out only

σ — standard deviation of wear out failure

These expressions are the well known reliability functions except that in this case the failure criterion is that the container will be scrapped due to the excessive cost of repairs and refurbishment.

Having the form of the curve, it is then required to plot sufficient points to be able to compute the constants which define exactly the full survival population as a function of time. This was done with admittedly fragmentary data. The points on the early part of the curve were estimated on the basis of the damage statistics. At the end of two years, with twelve cargo shipment cycles per year, the average of instances of severe damage (Code 3 as defined in Section 5) will be 5.4% for aluminum containers. At the same time, 102% will have experienced moderate damage. Otherwise stated, on the average all aluminum containers will have been moderately damaged, and an additional one in twenty will have been severely damaged. Obviously, the average values do not apply to all containers -- some will be entirely free from damage and others will have abnormally severe experience. Even neglecting the minor damage altogether, the estimate of 2% scrappage for aluminum and steel and 1% scrappage for FRP/plywood at the end of two years is considered justifiable.

The wear out function is dominant in the later years of the life span. The estimate on the surviving population draws on three kinds of information. Fragmentary pieces were collected during the field survey on the possibility of containers surviving to extremely long periods, for example twelve years for aluminum units. Knowledge of procurement quantities and the total current inventory give clues on losses. Additionally, the analysis of materials and design characteristics is useful. It is on the basis of the latter work that the FRP/plywood curve is plotted to fall off more sharply than the aluminum curve. Specifically, aluminum alloy 5052 as used in sheet stock is rated as more resistant to the elements than the FRP overlay used with plywood. Additionally, the FRP/plywood panels are expected to have, under the overlay, failures due to bending and delamination. Rivet loosening due to hole enlargement is more frequent and serious with FRP/plywood panels.

The final result for mean useful life is obtained by taking the area under the curves for each container type. The values are:

Aluminum	9.97 years
Steel	5.84 "
FRP/plywood	9.33 "

10.5 Maintenance Cost

Details of maintenance information on which maintenance costs are based have been developed in Section 9.5. The maintenance costs considered include the following:

- The cost of repairing damage.
- The cost of periodically painting and otherwise refurbishing containers.
- The cost of an increased inventory to cover containers in the maintenance pipeline (maintenance float).

Repair costs were calculated on a per trip basis since they are more sensitive to damage incurred in the cycle of loading, transporting, and offloading than they are to time. Based on the container damage survey (Table 5-1), the repair costs per trip were calculated to be: Aluminum - $11.48 (weighted average for both aluminum types), Steel - $13.40, and FRP/plywood - $5.91. The primary difference between the three types is the significantly lower rate of damage for FRP. The number of trips per year varied widely between operators, depending primarily on the trade route. A representative composite of all operator experience is estimated to be 12 trips per year. Therefore, the estimated annual repair costs are: Aluminum - $138, Steel - $161, and FRP/plywood - $71.

Painting and refurbishing is a major cost for steel containers, requiring complete surface preparation and repainting. For steel, this cost is estimated at $380 and required every three years on the average. It was shown in Section 9 that superior coatings at a high cost would provide enough increase in their life to reduce paint costs on an annual basis. The figure used in cost analysis corresponds to a conventional job, as generally performed in the industry. For FRP and aluminum, most of which have some steel framing members, only the end frames must be periodically painted, at an estimated cost of $22. This is also estimated to have a three-year renewal period. Thus, the annual costs for painting and refurbishment are: Aluminum - $7, Steel - $127, and FRP/plywood - $7.

The operators generally agree on a requirement for an inventory 10% higher than operational requirements to cover containers in the process of repair and maintenance. Since the repair rate for FRP/plywood is half that of aluminum and steel, 5% is the estimated float requirement for FRP/plywood. Maintenance float costs are therefore:

TABLE 10-3

MAINTENANCE FLOAT COSTS

	Aluminum	Steel	FRP/Plywood
Amortized Initial Cost	$183	$219	$204
% Float Required	10%	10%	5%
Maintenance Float Annual Cost	$18	$ 22	$ 10

10.6 Cost Uncertainty

Each cost element in the cost model has a range of possible values. It must be realized that even when all reasonable measures are taken to obtain valid data and observations, and to process such data in a correct and rigorous manner, there still remains some degree of approximation in the final results. The analysis of uncertainty in this kind of situation has been performed by Rand Corporation workers (see, for example, Reference 10-4). The techniques of this reference are cumbersome and time consuming to the extent that they could not be employed within the scope of the current study. However, the typical form of the uncertainty distribution presented in Reference 10-4 has been used to plot a possible distribution of uncertainty for the container cost analysis (see Figure 10-2).

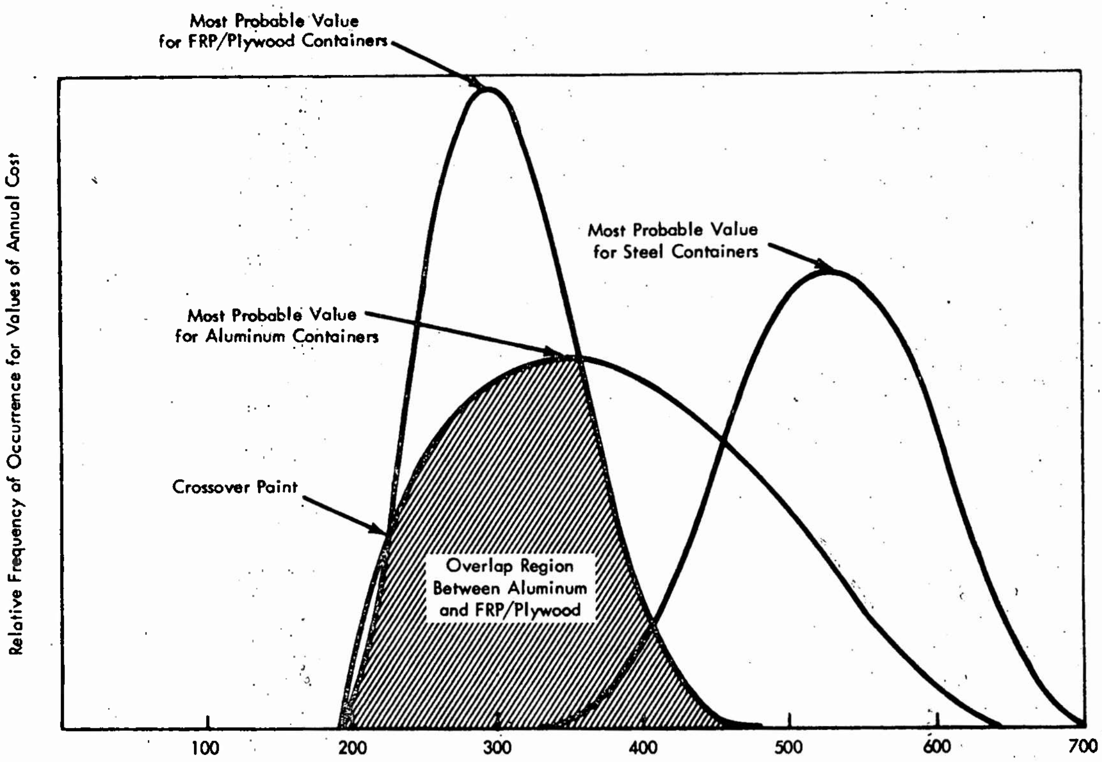


Figure 10-2. Uncertainty Limits Showing Overlap of Possible Cost Ranges

The limit values for each cost element are contained in Table 10-4. In some cases the extremes can be justified by

TABLE 10-4

CALCULATION OF EXTREME RANGES OF TOTAL ANNUAL COST

	ALUMINUM		STEEL		FRP/PLYWOOD		
	Low	High	Low	High	Low	High	Remarks
1. Purchase Price	1600	2800	900	1550	1550	2700	Range of operator estimates
2. Mean Useful Life	14.89	7.35	7.4	5	11.74	6.92	1 σ range (Figure 10-1)
3. Amortized Price (Line 1÷Line 2)	107	381	122	310	132	390	
4. Painting (Amortized)	6	9	602	152	6	9	± 20% variation
5. Repair Cost/Trip	6.08	16.21	8.95	16.90	4.59	6.58	See Table 9-5
6. Number Trips	12	12	12	12	12	12	Variance inappropriate
7. Repair Cost/Year (Line 5 x Line 6)	73	195	107	203	55	79	
8. Maintenance Float Factor	.05	.15	.05	.15	.025	.075	± 50% variation
9. Amortized Maintenance Float (Line 8 x Line 3)	5	57	6	47	3	29	
10. Annual Cost (Lines 3, 4, 7, 9)	192	642	337	711	196	507	

collected data, for example the purchase price -- where it should be noted that the low values are prices being quoted by European sources. In other cases, the extreme values are estimated in terms of a percentage above and below the estimated value of the cost element, for example the cost of painting.

There is very substantial overlap in the regions of uncertainty for aluminum and FRP/plywood. This, of course, opens up a final selection more to the judgment of a decision maker. And, this indeed does happen. The steamship lines which have the most highly mechanized facilities at their port terminals, and thus provide a more protective handling environment, have container fleets exclusively of the aluminum type. Furthermore, at a time when a number of steamship lines are switching over to FRP/plywood, these important segments of the containerized freight transportation industry have not indicated any intention to change.

Close examination of Table 10-4 explains and justifies such a position. Note in Line 7 that the low values of annual repair cost for aluminum and FRP/plywood are only $18 apart. Note also that on Line 3 for the low values of amortized purchase price aluminum more than makes up for the disadvantage. Furthermore, the probability of getting out to the extreme value of mean useful life may be better for aluminum than for FRP/plywood for the very same reasons which led to the longer life for aluminum -- essentially its superior weather resistance as previously discussed. Note also on the table that if no judgments are made on the probability of getting to the lower values of the cost elements and they are all accepted as feasible of attainment, the advantage of least annual cost rests with aluminum as may be seen on Line 10. The difference is very small, being only $4.

However, if we had excluded European quotations from the purchase price estimate, the position of aluminum vis-a-vis FRP/plywood becomes much stronger. Note on Line 1 that there is a $50 advantage to FRP/plywood which inverts the first cost situation of the "most probable costs" (see Section 10.3) where aluminum is found to have a purchase price of $1825 versus $1900 for FRP/plywood). The explanation for the inversion is straightforward. While European costs for labor are less than domestic costs, the difference for materials is not as great. Furthermore, aluminum runs counter to this trend, being about 25% more expensive in Europe. In addition, when purchase price goes up the result favors aluminum whether there is any crossover or not. The differential shown on Line 10 of Table 10-4 favoring aluminum simply becomes greater. It is obvious that the controlling factor on purchase price at the low end of the uncertainty range is the mean useful life -- which is in favor of aluminum.

10.7 Sensitivity Analysis

The variation in total annual unit costs due to variations in the individual cost elements has been examined. These are in effect the partial derivatives of total cost -- that is to say that only one change at a time is made and all other factors are held constant. Variations were performed for these elements.

- Purchase price
- Mean useful life
- Repair cost per cargo shipment cycle
- Number of cargo shipment cycles per year
- Cost of preventive maintenance (painting)
- Maintenance float factor

The results of the analysis are shown in graphical form in Figures 10-3 through 10-8. In general, variations were taken up to 50% above and below the best estimate of the element under examination. A typical example illustrates the use of these results.

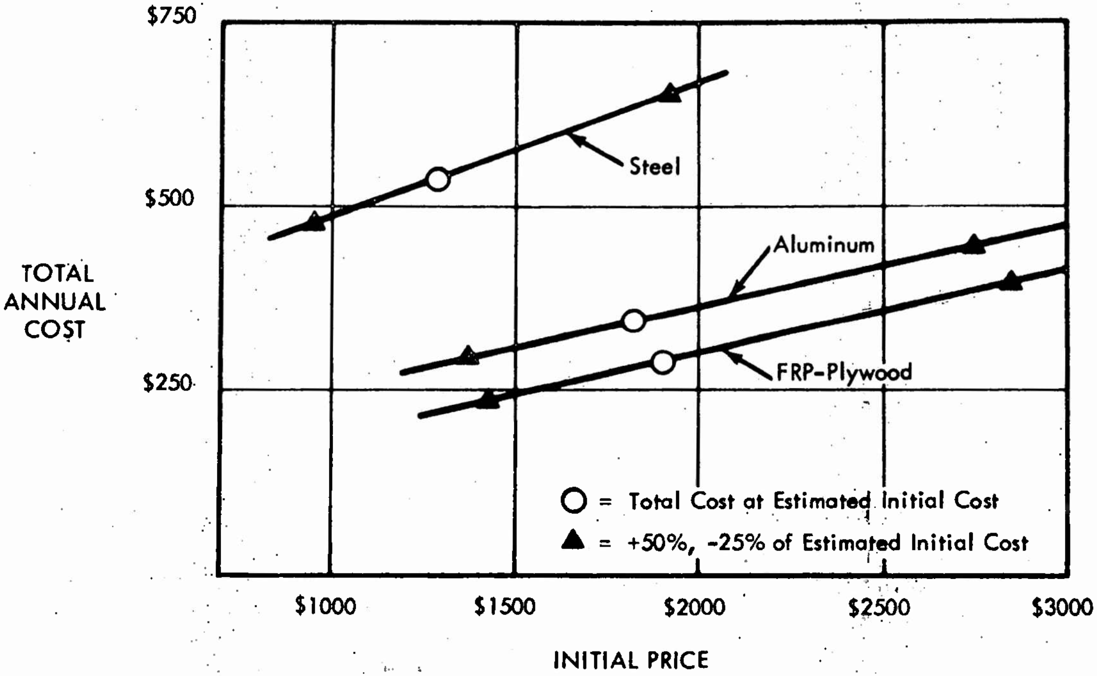


Figure 10-3. Effect of Variation in Initial Price on Total Cost

Suppose that a new design is produced by a container manufacturer specializing in aluminum units. Suppose also that the manufacturer demonstrates that the improved resistance to damage of the new design

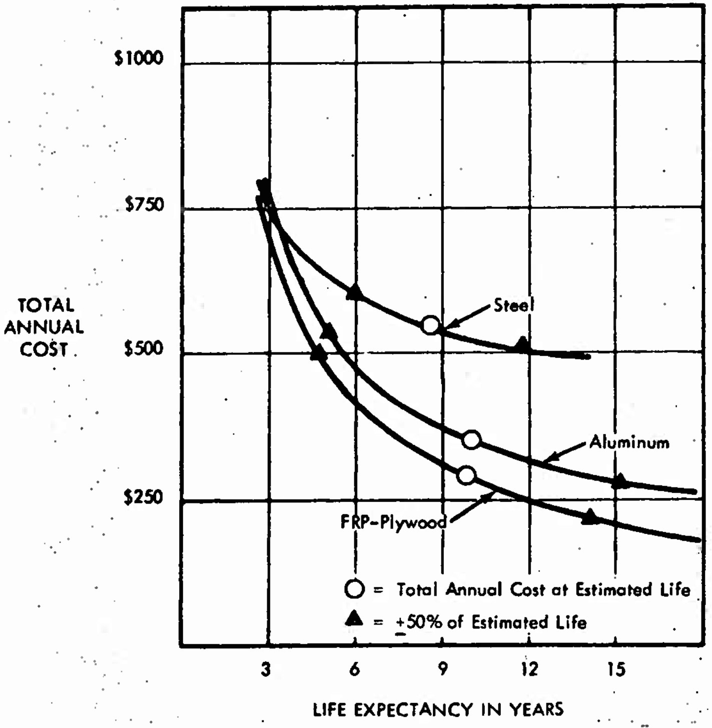


Figure 10-4. Effect of Variation of Expected Life on Total Cost

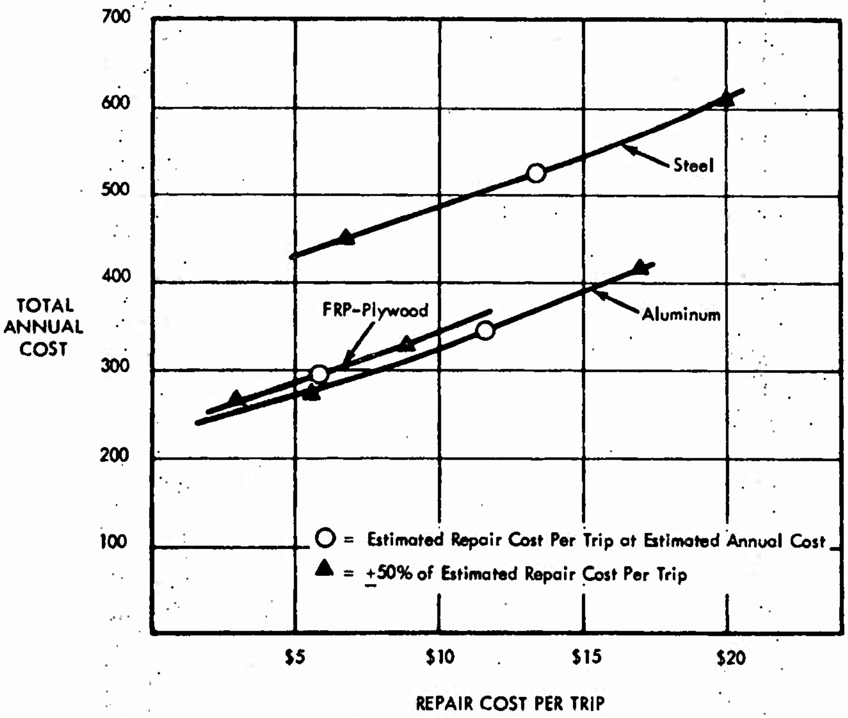


Figure 10-5. Effect of Variation in Repair Cost per Trip on Total Annual Cost

will lower maintenance costs by 40%. The new design carries an increase or purchase price in the amount of $500. The annual cost increment for amortization of purchase price goes up $65 and the new annual unit cost becomes $400, obtained by reading off of Figure 10-3. Then, the benefit from the reduced annual maintenance cost can be found on Figure 10-5, which shows a reduction of $55. In this case, the reduction from lower maintenance does not equal the increase due to the new purchase price when both are carried through to total annual unit cost and, therefore, the new design would have to be ranked unfavorably with existing designs.

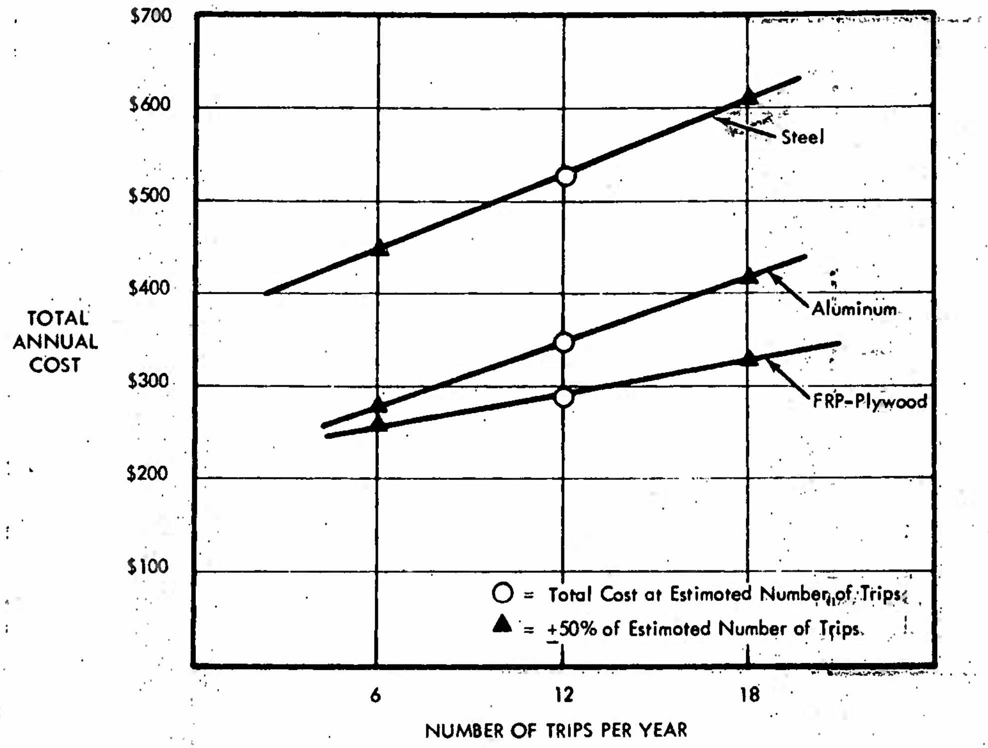


Figure 10-6. Effect of Variation in Number of Trips on Total Cost.

The question arises as to whether the final results are sensitive to any changes in inputs which would alter the relative ranking of the several container types. (Note should be made that sensitivity analysis treats variations in the most probable cost elements and should be distinguished from the previous section in which the lower values in the range of uncertainty were examined -- to the benefit of aluminum.) Since the FRP/plywood category was found to be the least costly on a full life cycle basis (Table 10-1) and its advantage is in annual maintenance cost, this will be considered first. Using the sensitivity figures in a way similar to the example

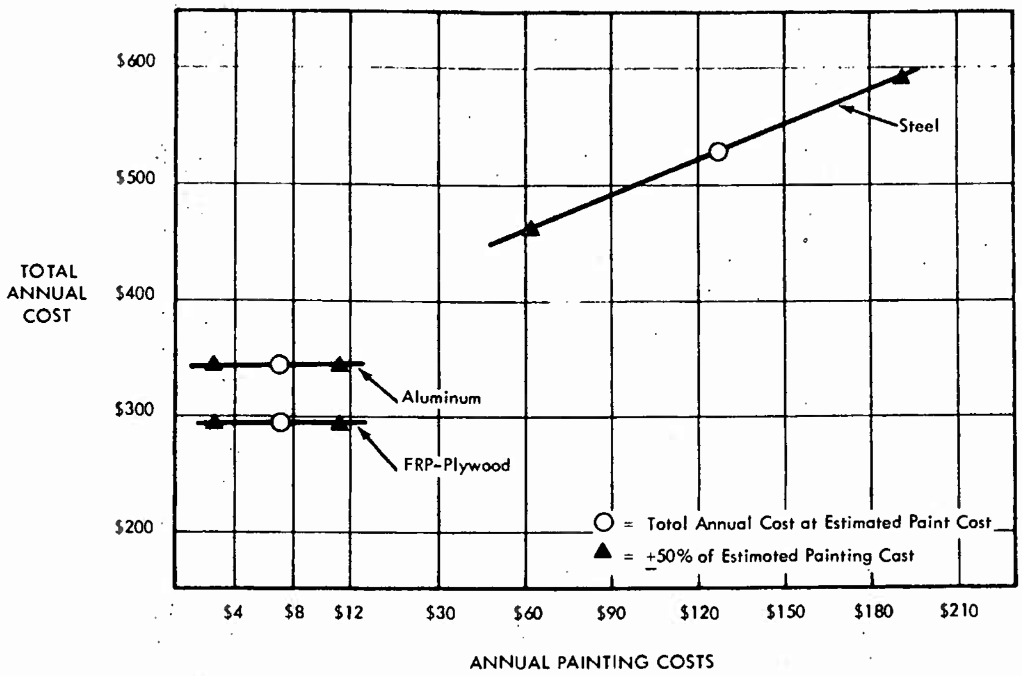


Figure 10-7. Effect of Variation in Paint Cost on Total Cost

above, it can be found that a reduction of 30% in maintenance cost lowers the total annual unit cost of aluminum containers to that estimated for FRP/plywood. However, a substantial decrease in both damage rates and repair costs for aluminum containers is required to bring maintenance cost down by 30%. The decrease was judged to be beyond the boundaries of a reasonable error band for the data.

A second possibility of variation of an element of cost exists where the change of final ranking between aluminum and FRP/plywood might result. It is the increment of purchase price to be amortized annually. There is more potential for variation in the useful life span than in purchase price. A decrease in the estimated useful life of 25% (from 9.33 down to 7.0 years) increases the total cost of FRP/plywood beyond that estimated for aluminum containers. It should be recalled that a mean life of seven years does not exclude the possibility of many units surviving long beyond that life span. At this time FRP/plywood containers are relatively new and their life estimate is unquestionably less validated than the estimates for the other types. Thus, there is a possibility that the true value lower than the estimated value in this analysis would bring aluminun and FRP/plywood containers closer in total annual unit costs or even cause a cross-over.

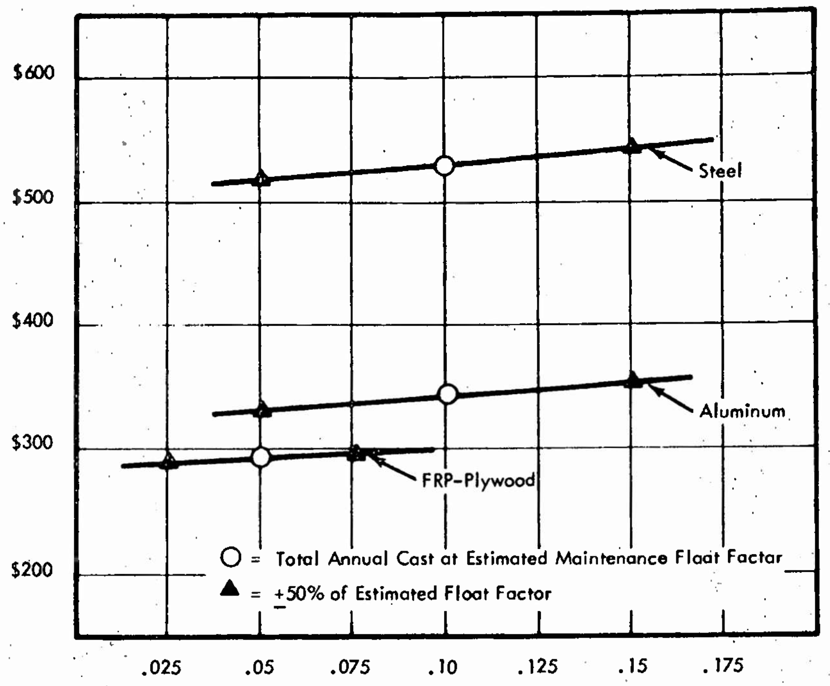


Figure 10-8. Effect of Variation of Float Factor on Total Cost

Whether or not steel containers could become competitive on the basis of total annual unit costs can be similarly studied. The curves of this sensitivity analysis include Figure 10-7 which shows the effect of variation in painting cost on total cost. A $25 reduction in paint job cost reduces the total annual unit costs down from $524 to only about $495, a long way from the competitive area of $300 - $350. Furthermore, it is possible that without first rate protection to the corrodible surface of a steel container that its useful life would be shortened and no gains would be achieved. The possibilities of bringing steel containers into a more competitive position with respect to aluminum and FRP/plywood are not attractive through any reasonable variations that have been attempted. (Section 6, in its discussion on steel as a candidate material of construction, considers alternative alloys which have inherently higher corrosion resistance and are, therefore, less demanding on surface protection than is plain carbon steel.)

10.8 Impact of Cube and Tare Weight Variation

Thus far all costs of the operation of a unit in a container fleet have been limited to the container proper while the freight transportation function has had no effect on the results. There are, however, important interactions between technical characteristics, operational characteristics, and the cost results which accrue to operators. Any number of examples could be quickly noted. In the case of steel containers, which are popularly regarded as strongest and most damage resistant, the incidence of damage and level of repair costs turned out to be equal to those for aluminum. The explanation is found in the fact that steel containers are not much heavier than the others and, therefore, the cost advantage for steel, as a structural material, in terms of least cost for unit strength is mitigated by its disadvantage in strength to weight ratio. If the operators had not desired a low tare weight container, steel's position could be improved somewhat. Similarly, aluminum and FRP/plywood containers could be more damage resistant if there was no tare weight constraint on design.

The question, therefore, arises as to what premium or penalty operators can trade off in total annual unit costs against some effect on their operating results. Useful internal cube has been found to be a stronger influence on operating results and it will be covered first. The range of variation in both cube and tare weight was previously noted in Section 7 (Table 7-1).

10.8.1 Revenue Per Unit of Cube Per Trip

The variations in interior cube directly affect the revenue producing capability of a container. Variations considering all types range over the spread of 1090 - 1130 cubic feet. In order to determine the dollar value of a unit of container cargo carrying space, representative cargo information presented in Section 4 are used. The essential characteristics are repeated below:

Total containerized cargo of Trade Route, L.T.	823,000
Cube of cargo, cubic feet	91,000,000
Available container cube	117,000,000
Container utilization, weighted average, percent	80
Average cargo density, pounds per cubic foot	20

For purposes of this analysis, container shipments in standard 20-foot containers were assumed to be 90% cube limited, and 10% weight limited based on ship operator reports for 20-foot units. In addition, a shipping charge (door-to-door) for the cargo was assumed to be $40 per measurement ton (40 co.ft.) divided equally between the sea and road transport segments. The Ernst and Ernst Report previously mentioned (Reference 3-3) related that the total shipping cost on the North Atlantic from the U.S. East Coast was approximately $20/MT. This cost was doubled to get the total cost per trip ($40/MT). The equal charge for the road transport segment was based on Figure 3-2, which shows that the pick-up costs for Matson Lines is about one-sixth of the total freight costs. Since their road transport distances in Hawaii and the U.S. West Coast are short compared to the U.S. East Coast - Northern Europe segments, the road transport costs were multiplied by a factor of five, resulting in the equal proportion of transport costs.

Using the aforementioned information, the revenue per cubic foot per trip (R_c) was calculated to be:

$$R_c = \frac{(\$40/MT/trip) \times (.8 \text{ utilization} \times .9 \text{ cube limited})}{(40 \text{ cu.ft}/MT)} = \$0.72/\text{cu.ft/trip}$$

It may be immediately noted that a change of 10 cubic feet under the circumstances of the analysis case represents an amount of revenue ($7.20) that is of the same order of magnitude as the maintenance cost for the container, which is obviously an important element in the total life cycle. The limits in container cube span a range of 40 cubic feet. This represents an annual revenue producing capability of:

$$R_c = (\$0.72/\text{cu.ft/trip}) \times (40 \text{ cu.ft.}) \times (12 \text{ trips/yr}) = \$345/\text{yr}.$$

This is a very significant dollar amount since it approximates the total annual unit costs for containers.

To appreciate the amount of cube difference from one design to another, consider the following. A wall thickness reduction of 1/2 inch (off the inside) from the two side walls, nominally 20 ft x 8 ft, gains 13.3 cu.ft. If the wall thickness reduction is extended to the roof and front end, an additional 9.3 cu.ft. is added for a total gain of 22.6 cu.ft.

The benefits which appear to be available to an operator do not apply universally but are a consequence of the 90% value for cube-limited cargoes in 20-ft. containers. Many lines are increasing the proportion of 40-ft. containers in their fleet. The larger units have about double the cube but only a 50% greater capacity by weight as compared to the 20-ft. units. Note should also be taken of the trend to a container height of 8 ft.-6 in., which has one obvious purpose of gaining cube. Note also the characteristics of the Sea Land containers which have a weight carrying capacity of 45,000 lbs., about 1.12 times the nominal value for a standard 20-ft. unit but have a cube of 2088 cu.ft., which is about 1.90 times the nominal cube of the standard.

In summary, the benefits of a gain in cube to a transportation operator are substantial for the case of standard 20-ft. containers. The dollar value could easily be as large as the sum devoted to maintenance. This result is predicated on cargoes being 90% cube-limited. The situation changes radically when larger containers are considered, since the probability of cargoes being weight-limited goes up sharply and extra cube is unlikely to be worth much.

10.8.2 Revenue Per Tare Weight Unit Per Trip

Variations in tare weight span an even larger range than cube -- the nominal limits being 3200 to 5000 pounds. Using the same cargo data as before, the cost per pound per trip (R_w) is calculated to be:

cost/100 lb.

$$R_{wt} = (\$0.004/\text{lb/trip}) \times (100 \text{ lbs}) \times (12 \text{ trips}) = \$4.80/\text{yr}.$$

Tare weights appear to be settling down into a range of 3400 - 3700 pounds, that is to say that a 300 pound variation is available to work with. This corresponds to a range of $14.40 per year in available revenue. While the dollar amount is a significant fraction of the annual cost of a container, weight savings in this case do not represent as valuable a benefit as an increase in internal cubic capacity. Because of the nature of the calculations, the dollar value ratio is 9 to 1 in favor of internal cube. This is given by:

300lb x $4.80/100lb-yr

$$\frac{R_c}{R_{wt}} = \frac{\$0.720/\text{cu.ft/trip}}{\$0.004/\text{lb/trip}} \times \frac{1}{20 \text{ lbs/cu.ft.}} = \frac{\$0.72/\text{cu.ft/trip}}{\$0.08/\text{cu.ft/trip}} = 9$$

Thus, if the ratio of cube-limited to weight-limited shipments decreased, so would the dollar value ratio. This, of course, is exactly what happens when 40 ft. containers are used in place of 20 ft. containers. Thus, weight saving can be expected to play a more dominant role for 40 ft. containers while cube savings is more important for 20 ft. containers.

10.9 Present Value of Life Cycle Costs

Since the three primary categories of containers have been shown to have varying distribution of cash outlay over their full life cycle, particularly the lower purchase price for steel, it is useful to examine the present value of costs. The present value concept recognizes that the value of money is relative to time. Thus, a commercial operator in considering two candidate systems, will assign some preference to the one which postpones its demands for cash outlay. Presumably, he will be able to deploy the unused but available assets in a profitable manner while they are not required. The earning power of the money during the interval is the amount of the benefit. Conversely, if an expense must be met at some future time and the money can be used productively until that time, the amount allocated at the present time for the purpose could be less than the required amount -- with the difference to be earned in the time interval. Hence the term present value. Note also that the present value of a cost is less than the actual cost and that decrement is dependent on the rate of return earned in the interval.

The assumed rate of return is referred to also as the discount rate. The results presented in the summary of cost analysis (Table 10-1) shows the effect of a 10% discount rate. Note that the steel containers are most affected by discounting, but that a 10% rate has not changed the relative ranking of the three container types. The emphasis on a 10% discount rate appears in this study on the basis of currently popular useage in Department of Defense analyses. In effect, with a 10% discount rate, every dollar that will be spent one year from now has a present value of $0.91 and it will be able to procure a full dollar of value at the time of spending. The implications of using other rates have been included in the analysis.

10.9.1 Cost Stream and Cumulative Costs

The analysis was performed for a 20-year period. First the cost elements were organized into a cost stream according to when they occur (for example, painting every three years, procurement of new containers at the end of their mean useful life, and so on). For steel and FRP/plywood containers, a credit was computed in the 20th year for the amount of life remaining. For each year, all cost elements were summed for a total cost for that year. The resultant cost streams are presented in Table 10-5. The present value of these cost streams was then computed, including cumulative cost and cumulative present value for each year. These computations are presented in Table 10-6. The cumulative cost and cumulative present value in the 20th year are the total 20 year life cycle cost and present value of these expenditures.

10.9.2 Discount Rate Variation

The use of a discount rate of 10% was chosen as customary for Department of Defense analyses. However, since this is an examination of costs in a commercial environment, consideration of other discount rates is indicated.

It is generally assumed that the return on capital in the commercial sector is higher than the cost of financing in public expenditures. Some data are available to support this assumption.

TABLE 10-5

COST STREAM DATA FOR ALL CONTAINER TYPES

Year	Purchase Price	Maintenance Float	Paint	Repair	Total
ALUMINUM					
1	1825	183		138	2146
2				138	138
3			22	138	160
4				138	138
5				138	138
6			22	138	160
7				138	138
8				138	138
9			22	138	160
10				138	138
11	1825	183		138	2146
12			22	138	160
13				138	138
14				138	138
15			22	138	160
16				138	138
17				138	138
18			22	138	160
19				138	138
20				138	138
STEEL					
1	1275	128		161	1564
2				161	161
3			127	161	288
4				161	161
5				161	161
6	1275	128	127	161	1564
7				161	161
8				161	161
9			127	161	288
10				161	161
11				161	161
12	1275	128	127	161	1564
13				161	161
14				161	161
15			127	161	288
16				161	161
17				161	161
18	1275	128	127	161	1564
19				161	161
20	-570	-57		161	-466
FRP/PLYWOOD					
1	1900	95		71	2066
2				71	71
3			22	71	93
4				71	71
5				71	71
6			22	71	93
7				71	71
8				71	71
9			22	71	93
10	1900	95		71	2066
11				71	71
12			22	71	93
13				71	71
14				71	71
15			22	71	93
16				71	71
17				71	71
18			22	71	93
19	1900	95		71	2066
20	-1610	-80		71	-1619

TABLE 10-6

CUMULATIVE COSTS AND PRESENT VALUES (DISCOUNT RATE IS 10%)

ALUMINUM

PERIOD	COST	COST CUM	FACTOR	PRSNT VALU	CUM
1	2146.	2146.	1.00000	2146.	2146.
2	138.	2284.	.90909	125.	2271.
3	160.	2444.	.82645	132.	2404.
4	138.	2582.	.75132	104.	2507.
5	138.	2720.	.68302	94.	2602.
6	160.	2880.	.62092	99.	2701.
7	138.	3018.	.56448	78.	2779.
8	138.	3156.	.51316	71.	2850.
9	160.	3316.	.46651	75.	2924.
10	138.	3454.	.42410	59.	2983.
11	2146.	5600.	.38555	827.	3810.
12	160.	5760.	.35050	56.	3866.
13	138.	5898.	.31863	44.	3910.
14	138.	6036.	.28967	40.	3950.
15	160.	6196.	.26333	42.	3992.
16	138.	6334.	.23940	33.	4025.
17	138.	6472.	.21763	30.	4055.
18	160.	6632.	.19785	32.	4087.
19	138.	6770.	.17986	25.	4112.
20	138.	6908.	.16351	23.	4134.

STEEL

PERIOD	COST	COST CUM	FACTOR	PRSNT VALU	CUM
1	1564.	1564.	1.00000	1564.	1564.
2	161.	1725.	.90909	146.	1710.
3	288.	2013.	.82645	238.	1948.
4	161.	2174.	.75132	121.	2069.
5	161.	2335.	.68302	110.	2179.
6	1564.	3899.	.62092	971.	3150.
7	161.	4060.	.56448	91.	3241.
8	161.	4221.	.51316	83.	3324.
9	288.	4509.	.46651	134.	3458.
10	161.	4670.	.42410	68.	3527.
11	161.	4831.	.38555	62.	3589.
12	1564.	6395.	.35050	548.	4137.
13	161.	6556.	.31863	51.	4188.
14	161.	6717.	.28967	47.	4235.
15	288.	7005.	.26333	76.	4311.
16	161.	7166.	.23940	39.	4349.
17	161.	7327.	.21763	35.	4384.
18	1564.	8891.	.19785	309.	4694.
19	161.	9052.	.17986	29.	4723.
20	-461.	8591.	.16351	-75.	4647.

FRP

PERIOD	COST	COST CUM	FACTOR	PRSNT VALU	CUM
1	2066.	2066.	1.00000	2066.	2066.
2	71.	2137.	.90909	65.	2131.
3	93.	2230.	.82645	77.	2207.
4	71.	2301.	.75132	53.	2261.
5	71.	2372.	.68302	48.	2309.
6	93.	2465.	.62092	58.	2367.
7	71.	2536.	.56448	40.	2407.
8	71.	2607.	.51316	36.	2443.
9	93.	2700.	.46651	43.	2487.
10	2066.	4766.	.42410	876.	3363.
11	71.	4837.	.38555	27.	3390.
12	93.	4930.	.35050	33.	3423.
13	71.	5001.	.31863	23.	3446.
14	71.	5072.	.28967	21.	3466.
15	93.	5165.	.26333	24.	3491.
16	71.	5236.	.23940	17.	3508.
17	71.	5307.	.21763	15.	3523.
18	93.	5400.	.19785	18.	3542.
19	2066.	7466.	.17986	372.	3913.
20	-1619.	5847.	.16351	-265.	3648.

Returns on equity capital for a 5-year period are reported in Reference 10-1. Of the leading 500 industrial corporations, 73 have averaged better than 20% annual return on equity. On the other hand, the average return for all industry for the years 1965 to 1969 ranges only from 11.5% to 13% (Reference 10-2). No specific data on the shipping industry are readily available, but it is presumed it would be low due to high investment costs and low profit margins.

To examine the implication of variation in discount rates, the present value of 20-year life cycle cost was computed at 20% and 30%. The resultant curves showing the influence of discount rates are shown in Figure 10-9. Note on the figure that the case for steel containers is better at higher discount rates. There are cross-overs at 23% (with aluminum) and at 36% (with FRP/plywood). Although it is considered unlikely that any shipping operation is realizing return on capital over the 25% level necessary to make steel containers preferred on a present cost basis, special situations may arise. For example, the initial investment in containers must be financed out of available working capital, while maintenance costs are financed out of revenues. Therefore, the lower cost steel container may be indicated, even though it costs more in the long run, in situations when capital is in short supply.

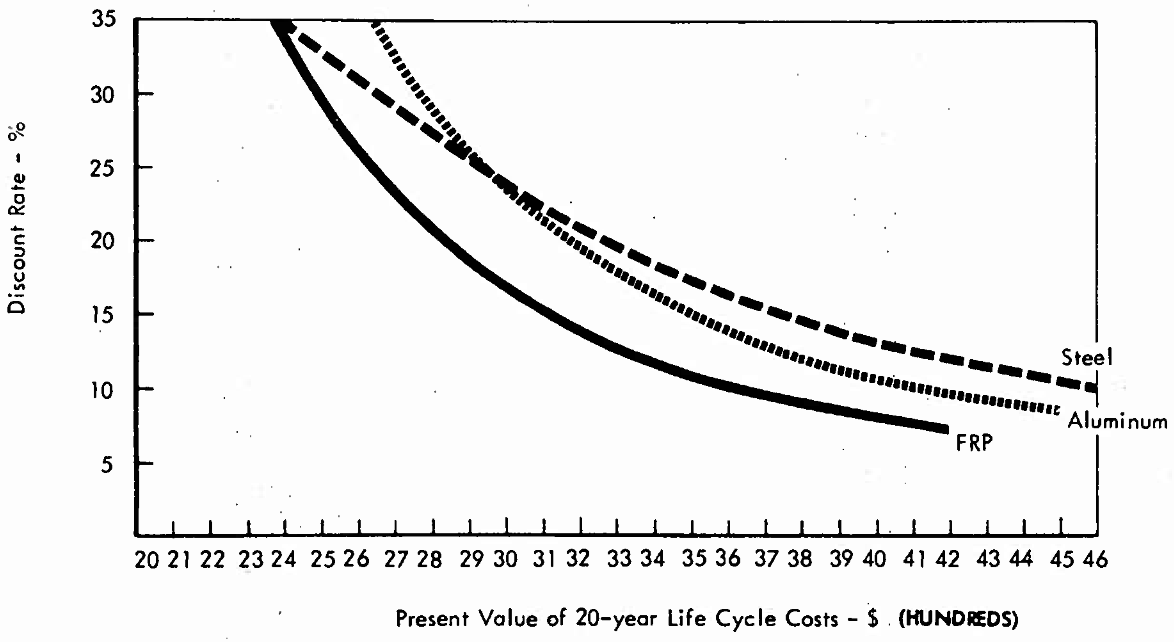


Figure 10-9. The Influence of Discount Rate on Present Value of Life Cycle Costs

SECTION 11

CONCLUSIONS AND RECOMMENDATIONS

Through the various sections of the investigation up to this point, numerous discrete conclusions were recorded as they relate to individual topics. This section integrates the conclusions in a coherent way. It has been gratifying to the investigators to reach a position where the seemingly contradictory information obtained from transportation companies has been reconciled. Additionally, in the matters where independent analysis could be performed, it has been determined that there are rational foundations for most of the intuitive positions held in the industry. However, analysis has also led to a few conclusions which bring into question some industry tenets.

11.1 Primary Conclusions on the State-of-the-Art

11.1.1 Preference for FRP/Plywood Paneled Container

One of the main issues encountered in the field has been on whether a change over from the more traditional aluminum paneled containers to the newer FRP/plywood containers is warranted. Most of the steamship lines are in the process of adopting an FRP/plywood design. They believe that the FRP/plywood container will prove more damage resistant and consequently provide an operator with a lower maintenance cost and a saving on full life cycle costs.

There is also an opposite opinion held in the industry. Several of the major containership lines -- having the most elaborate handling facilities -- believe they are well advised to stand by their original selection of aluminum containers. They believe their maintenance costs are tolerable at present levels and do not want to sacrifice the tare weight saving they enjoy with aluminum paneled containers.

It should be noted that those lines reporting the preference for FRP/plywood are primarily users of standard twenty-foot size containers. The average occurrence of cube-limited cargoes with standard twenty-foot containers is about 90%. Thus, the weight penalty associated with FRP/plywood containers is less important and clearly is not worth as much to such operators as the cube gain. Those operators standing by their preference for aluminum use dimensionally non-standard containers which have a higher ratio of cube to the cargo weight load than do standard size containers. Accordingly, their occurrence of cube-limited cargoes comes down and weight-limited cargoes goes up, and greater emphasis on minimum weight design is to be expected.

11.1.2 Confirmation by Life Cycle Cost Analysis

Analysis of cost confirms, for the most probable values of all cost elements, that FRP/plywood containers have an advantage. The main variation is in maintenance costs and that is where the FRP/plywood advantage originates. The maintenance data costs were derived from two independent approaches which produced remarkably well correlated results. In one case, the steamship lines supplied aggregate annual maintenance costs. Then, using the known distribution of their container population among the several types, a statistical analysis showed the maintenance cost for each type. In the second approach, a damage survey of 10,000 container movements through the Port of New York produced a breakdown of damage by container type, relative severity of damage, and type of handling facilities. Then, using job cost estimates and probable annual useage, annual repair costs were determined. The addition of preventive maintenance cost enabled the determination of total annual maintenance cost.

It is also clear that steel containers -- as presently designed for the market -- show up more poorly on total life cycle costs than the other types. Their purchase price is lower than the other types, but their useful life is substantially less. Thus, the annual cost for amortization of the investment for steel containers is slightly above the other types. In the matter of maintenance costs, steel containers suffer from the necessity for repainting which comes close to the cost of damage repair, which in turn is about the same order of magnitude as that for aluminum.

11.1.3 The Range of Cost Uncertainty

Since the range of total life cycle costs is fairly broad, it should be noted that the above conclusions on ranking of the several container types may change under certain conditions. Despite the 20% advantage in FRP/plywood annual costs over aluminum at the most probable value of annual costs, the full range of possible costs results shows a substantial overlap between the two. At the low end of the range the two cost bands closely converge and then cross over, making aluminum the preferred choice on total costs. (Cost uncertainty includes cost variation due both to unknowns such as errors in the data, and known causes of variations such as differences in environmental conditions.) Since the lines which continue to prefer aluminum containers are the major container operators and undoubtedly operate in the lower region of costs, the analysis validates the empirical finding.

The cost overlap of steel containers with the other two types is not regarded as significant. It is difficult to conjecture a set of circumstances which would make steel containers -- as presently constructed -- the preferred choice. However, this situation could change with a different attitude about selection of alloys and design approach. In particular, the advantage of steel in its low purchase price, since it does not carry through to annual costs, would be partly sacrificed, mainly to higher quality alloy selection.

11.1.4 The Overall Influence of Material Selection

The superior damage resistance of FRP/plywood containers over the aluminum type cannot be attributed to an inherent superiority of the one material over the other. In fact, hardened aluminum alloys have the best balance of properties and must accordingly be ranked as the most suitable material of construction. Aluminum alloys have a good level of cost/strength, and are clearly ahead on strength/weight. Their resistance to corrosion is among the best. In their hardened state, their workability is limited and this has an obviously constraining effect on design. Welding reduces the strength increase of hardening. The particular alloy in wide use as panel sheet stock, 5052-H38, is the least attractive of the structural grades of aluminum on the basis of all the performance parameters except corrosion resistance, where it is superior.

Fiberglass reinforced plastics are difficult to rank due to the numerous variations in type, directionality, and quantity of glass fibers and to the further anisotropy that results when it is in a composite sandwich with a core of plywood. In general, the reinforced plastics are comparable to, but slightly behind the structural grades of aluminum on a strength/weight basis, and far behind on cost/strength. Resistance to corrosion is comparable to aluminum alloys in general, being possibly a shade behind alloy 5052. However, when in a composite sandwich with a plywood core, the Douglas Fir characteristics dominate to bring the cost/strength down to the level of aluminum. However, the strength/weight parameter suffers at the same time. The parameters used in the comparative ranking have a bias in favor of FRP/plywood since they give full credit to the strength in the plywood core when it cannot be fully utilized at the centroid of a section in bending.

Carbon steels are in an excellent position on the basis of the performance parameters. They have a superior cost/strength rating (by a factor of 2.5 - 3 as compared to aluminum alloys) which could more than offset their deficiency in strength/weight. However, the weakness in corrosion resistance mitigates the otherwise strong position. The data on materials properties reinforces the findings on damage resistance stated previously. That is to say, a steel container should have more than twice the weight of an aluminum container (for the non-common members) if it is to exceed the strength of an aluminum container. However, the steel containers being supplied to the market currently do not carry such a large weight penalty.

Corrosion resisting steels such as COR-TEN and the fully stainless groups have been given only minimal consideration by the domestic container manufacturing industry. COR-TEN in particular has an improved strength/weight position over mild steel and no cost penalty. Further investigation is, therefore, warranted on the extent to which its superior corrosion resistance will lengthen the life of a steel container and reduce painting costs. In the case of one particular design, muffler-grade stainless is being used in end frames of aluminum paneled containers to assure that the life of all members is equally long.

11.1.5 The Overall Influence of Design Approach

There seems to be a paradox in that the FRP/plywood containers have an advantage in total life cycle costs (closely) over aluminum and (decisively) over steel while the rankings on the basis of materials properties do not correspond. The explanation can be found when design efficiency is analyzed. The criterion for panel design is the ability to resist the pressure loading uniformly applied normal to the surface of the panel as specified in standardization documents. The typical stiffened sheet construction of an aluminum panel has a fairly deep section and is relatively efficient compared to an FRP/plywood panel. The immediate consequence of this is that a typical aluminum panel construction is about 1.8 lbs/sq.ft. while an FRP/plywood panel runs to about 3.2 lbs/sq.ft. Thus, the seemingly superior structural efficiency of the aluminum panel in meeting a standard design requirement would appear to reinforce the superiority of aluminum as a material choice.

Efficiency in meeting the standard design requirement does not, unfortunately, lead to the most damage resistant panel. Damage is more likely to be caused by high intensity impulsive loads which occur in routine handling and rough service than by a uniform pressure acting on the full panel surface. The FRP/plywood composite sandwich has higher mass and resilience (greater deflection under unit load to cushion impulsive loads) which combine with its thickness, UTS and surface hardness to provide excellent resistance to high intensity, localized loadings that actually occur in service.

By contrast, the stiffened aluminum panels fabricated of thin sheet stock (generally 0.062 inches) and hat-section posts (spaced at a distance of 18 - 24 inches apart) are prone to tearing of the thin sheet material and bending and breaking of the posts. It may also be noted that superior structural efficiency of aluminum stiffened sheet panels leads to deeper sections which have the effect of subtracting from the useful cube of a container. Thus, a design having the least tare weight can generally be expected to lose cube.

Steel panels offer advantages over the other two basic types from the point of view of structural efficiency. The material lends itself to a wide variety of corrugation patterns which can be designed to dispose of the structural material in a balanced way on each side of the centroid of the section under bending. The use of hardened aluminum sheets precludes efficient corrugations. Similarly, there are inherent inefficiencies in FRP/plywood panels due to the lack of greater spread on modulus between the two materials. With the modulus of FRP only about two times as great as that for Douglas Fir plywood and the strengths in the ratio of about five to one, an obvious mismatch exists. The consequence of this situation is that if the strength of the FRP face material is to be fully utilized, the risk of failure in the plywood core just under the interface is very high.

11.2 Conclusions on Utilization and Environment

11.2.1 Transfer Operations

The main conclusion to be drawn from the examination of utilization and environment is that individually and taken together, they are severe. Some containers may be involved in as many as 18 cargo shipment cycles per year and the average number is about 12. A cargo shipment cycle requires that the container, loaded with its cargo, be transferred to and from transportation media and through staging operations. The number of transfers per shipment cycle is in the range of 2 - 10.

Hazards are present during all these transfer operations and the consequence is that a high damage rate is experienced by the operators. The operators are of the general attitude that forklift handling at the bottom either by built-in forklift pockets or from underneath is the most severe handling operation. Handling equipments engaging the container at the top corner fittings either in a straddle mode or by side-carry are preferred, but many forklifts remain in operation.

11.2.2 Chassis Operations

The industry is aware of the benefits to be gained by prompt coupling of a container to a chassis as the container comes off a ship and subsequently operating them as a unit. This minimizes the number of times a container must be engaged by handling equipment to perform a transfer. However, the additional chassis required for this kind of operation is a major capital investment -- beyond the immediate resources of most of the steamship lines. Additionally, the limited space at most of the port terminals requires that containers be stacked while waiting to be loaded aboard ship or to be forwarded to an inland destination. The chassis mode of operation precludes stacking and, therefore, consumes yard space which is often not available. There does not appear to be any justification to expect that a chassis mode of yard handling will prevail in the foreseeable future -- say at least five years ahead.

11.2.3 Transportation

All the modes of transportation contain hazards which lead to damage of both the container and its cargo. The environment aboard ship includes severe motions and leads to damage when the ship encounters heavy weather. The exposures faced by containers stowed on the weather deck (which may be as many as 25% of the shipload) are even more severe than the general situation aboard ship. A patented buttress system is used by one line to improve the restraint of exposed containers, but again, the investment required to install such a system precludes its general adoption. Another line has developed a new containership design which increases the height of below deck stacks and essentially eliminates weatherdeck stowage. However, large-scale use of such designs is in the distant future. The entry of containers into ships' cells is frequently accompanied by bumping and rubbing.

Railroad cars introduce a new set of hazards. Humping operations at rail yards inevitably lead to heavy loads on either end of the container, affecting both the container and its cargo. It is widely known that limitations on impact velocity during humping of rail cars are practically unenforceable. In addition, the cushioning benefit of modern draft gear is not assured since many cars are not so equipped.

Highway operations include major accidents and the much more frequent occurrence of minor contacts between the container and a variety of obstructions. The former are mainly roll-overs and impacts due to inadequate overhead clearance (so-called low-bridging). The latter include various low velocity sidewise collisions with other vehicles in crowded quarters and with other impediments to traffic flow. Steamship operators have no formal records on this segment of the operating cycle since the highway common carrier has the responsibility for the safety of the container and its cargo during over-the-road transport.

11.2.4 Specifications and Standards

The documents of the ISO (International Standardization Organization) and the ANSI (American National Standardization Institute) cover not only dimensional standardization, but also standardized load resistance capability. The transportation companies report without exception, that the standards are adequate, especially in the latter regard. However, the actions of the transportation companies do not support a position that the standards alone provide a basis for the structural design of containers. What happens in actual practice is that the operators quote the standard loading conditions when issuing a procurement specification, but then add specific design requirements for the purpose of improving damage resistance.

Notwithstanding the lengthy deliberations of the MH-5 Committee of the ANSI, and the additional design features required by the operators, damage experience is at a very high level. The values of the loading conditions covered by the standards are only a starting point. They cannot be considered a specification of the operating environment. Furthermore, the actual values appearing in the standards represent a compromise value reached in the committee action. There are diverse objectives among the points of view held by the various committee members.

11.3 Conclusions on Damage Experience

11.3.1 Average Rate of Normal Damage

The primary conclusion on the subject of damage is that it must be rated as a serious problem. A damage survey based on the observation of 10,701 containers divided evenly between containers being loaded and discharged showed a damage rate of 14.5%. The important point about this statistic is that the proportion of containers suffering damage is rated as representative of service conditions as actually experienced -- on the average. If ships coming in from a voyage which encountered abnormally heavy seas had been surveyed, the damage rate would have been much higher and the average amount of the damage (in terms of cost to repair) would also have been substantially up. Since rough voyages do occur, the results presented in this report must be considered as conservative -- that is, on the low side of the long term average.

11.3.2 Effect of the Handling Environment

The industry as a whole appreciates the benefits in damage reduction that accrue to fully mechanized handling systems and true containerships. The survey results confirm the generally held attitudes. In the case of the best systems, the damage rate is 10.2%. This rate increases to 16.5% for conversion type containerships generally mounting deck gantry cranes. The rate further increases to 19.3% for partially converted ships using a conventional hook cycle to transfer containers aboard ship and to perform the discharge operation. These rates are averages covering all container types.

It should be realized that the superior handling systems are not necessarily justified solely on the basis of the damage rate of containers. The faster acting handling gear enables ships to turn around in the minimum time -- which contributes to ship productivity. Additionally, protection of the cargo is worth even more than the container damage reduction.

11.3.3 Variation in Damage to Container Types

The results of the damage survey confirm that FRP/plywood containers are superior to the other types in damage resistance. The superiority is demonstrated in all handling systems and all ship types whether they are full containerships designed as such or whether the ship is a partial conversion. The margin is sufficiently great to avoid any doubt as to its validity. Furthermore, when the damage survey results are extended to maintenance costs for each container type, they correlate closely with maintenance costs derived from completely independent data. There is very little difference in damage resistance to be found between aluminum and steel types. While this conclusion is not consistent with the widely held position that steel containers are stronger, it is validated by the analysis of materials properties and design.

11.4 Conclusions on Preferred Materials

Despite the difficulty of direct comparisons between materials which have gross dissimilarities, aluminum alloys show a superiority as the preferred material. The properties of aluminum are the best combination of strength, lightness, cost, and corrosion resistance. The workability of the material is a limitation to its incorporation into efficient designs, but this deficiency could be overcome with the evolution of new design approaches and fabrication techniques.

FRP/plywood is limited to panel applications at the present time and is reasonably well suited for the purpose. The composite sandwich has an inherent inefficiency in that face and core members are not well matched and the strength of the face cannot be fully used without overstressing the core. The superior service performance of container panels derives as much from the structural inefficiency of the sandwich as from the appropriateness of the properties of the material. This may be stated in other terms to better illustrate the point. If other materials were fabricated into equal weight panels (3.2 lbs/sq.ft.) their service performance should be substantially improved).

The family of composite sandwich materials offers many attractive possibilities. Weight savings in the core are feasible with foamed plastics and other options while retaining the FRP face. Additionally, there are opportunities for cost savings. Wood also has attractive properties and with a different face material may lead to an efficient panel sandwich construction.

Steel is not altogether uncompetitive despite the poor ranking of presently designed steel containers. Even with alloys having better strength/weight ratios, improved inherent corrosion resistance, and superior protective coating, an edge will still be possible over the other types in purchase price. The essential problem in applying steel is to recognize the necessity to improve the useful life and to reduce the recurrent maintenance effort for corrosion prevention. It must also be recognized that the strength/weight ratio of steel will lead to a weight burden when damage resistance is equal to that of the other types.

11.5 Conclusions on Design Approach

The design approaches of the present state-of-the-art offer many opportunities for the continuing evolution of improvements. It must be recognized that a systematic approach to design involves the formulation of design requirements in a rational way. The standardizing documents provide only a minimum start on this matter and are not to be confused with design requirements.

From the structural point of view, both aluminum and FRP/plywood panels have design inefficiencies which could be rectified. Aluminum stiffened panel fabrication, on the present sheet and post approach, results in an extremely poor distribution of peak stresses. While bending cases have inherently non-uniform stress distribution, the problem is accentuated when the outer fibers of the post are more than three times the distance from the section centroid as the sheet material -- which has the bulk of the material. The formability of steel enables the fabrication of panels which have a balanced corrugation pattern about the centroid.

The greatest opportunity for weight saving by design improvement appears to be in the bottom structure presently used by the industry. In transferring the dead weight load of the cargo, say during hoisting, there are three distinct steps -- and redundancy of structural function. The load acts on longitudinal floor boards which transfer the load to side rails, thence to the end frames. An integrated bottom structure could eliminate this redundant action while at the same time capturing some useful cube. Even without a comprehensive redesign, the question of flooring could be examined. Hardwood flooring weighing about 600 pounds appears to be dictated primarily by the need to nail in shoring for accommodating concentrated cargo loads. A cargo restraint system which efficiently puts the loading into the primary structure would contribute to the weight saving. In any case, limited sections of hardwood for use in shoring and dunnaging the cargo of a container could be emplaced throughout an efficient bottom structure to serve the purpose at a substantial weight saving over present bottom designs.

Integration of all structural members into a more unified structure would lead to weight saving and improved damage resistance. The matter of the various bottom members is only one case in point. The possibility exists that designs could be evolved which integrate all panels and rails to provide the total box (considered to be a built-up girder) with adequate bending resistance while at the same time allowing the panels enough weight to resist handling abuse. At the present time there is one example of structural integration -- end structures -- which could be even further exploited. The end doors must be designed to resist pressure type end loads. At the same time, when secured to the end frame with adequate latching hardware, they contribute to the frame's ability to resist racking loads. The panels and edge joining members could make a further contribution.

All sections of structural members are of uniform section when invariably they are not stressed uniformly. There are obvious fabrication advantages to uniform sections. However, if a design were to be evolved which fully integrated all members into a composite structure, there might be an application for non-uniform sections of some members with a further weight saving potential.

11.6 Recommendations

Research and development activity in the industry has been primarily directed to solving problems on the level of design detail. Typical examples include the application of new sealing compounds for watertight joints or as a barrier between dissimilar materials, hardware improvements, and fabrication techniques which will control manufacturing costs. The case of the new aluminum plate design container represents a major development project, but it is an exception to the general situation observed. Accordingly, it is recommended that the continuing research and development programs at USAMERDC include attention to some of the major opportunities to improve the technical and operational characteristics of reuseable shipping containers identified in the conclusions.

11.6.1 Service Duty and Design Criteria

A study task is recommended which would lead to definitive profiles of service duty. The foundations have been established in the present study but the work needs to be expanded and perfected. The MH-5 Committee of the ANSI cannot be expected to carry its work into a detailed description of service since by its very nature as a committee it could not reach a concensus position among its constituents who all have different operations. The purpose would be to provide the substantive inputs to a set of design criteria. The natural environment needs to be stated in such a way that it can influence design requirements. This effort should include specific test requirements which would provide a realistic simulation of actual handling and transportation loads. Additionally, there is a need to develop test procedures for accelerating the effects of service duty and thereby enable the expedited test and evaluation of prototypes.

11.6.2 Design Optimization

An effort is required which will initiate design studies without the constraints and inhibiting influence of current designs or fabricating facilities of the manufacturers. This could be in two distinct phases which might overlap timewise or even be concurrent. One phase of this work would examine optimum design on the subassembly level and could achieve partial integration of structures. Topics of particular interest would include the integration of bottom structure to include longitudinal bending resistance, coupling of the side members and suitable surfaces on the interior and exterior (to facilitate contingency use as an air transportable container). Panels obviously are another item for this phase. The data coming from the MERDC test project on panel specimens should be another source of guidance in this effort. The results from this phase of work would lead to prototype designs of relatively low risk and early availability for test and evaluation.

Prototypes which might evolve from the subassembly development phase can be envisioned. Several panel types are obvious candidates. A framework which would provide a test bed for alternative candidate panels could be constructed. If double-wall roll bonded aluminum panels can be developed on a compatible time scale, they should be included. Corrugated aluminum panels should be investigated even if a reduction in hardness (and strength) is required to perform the forming operation. In any event, minimum panel weight for aluminum panels is not recommended as an objective. In fact, candidate aluminum panels in the range of 2.5 - 3.0 lbs/sq.ft. should be considered in the effort to improve damage resistance of aluminum panels. Panel alternatives should include variations in thickness in the range of 0.80 - 1.30 inches. Prototype containers might include two different panel designs, one on each side, to enable comparative performance data to be accumulated with the least amount of test and evaluation effort.

Candidate panels in the steel category should concentrate on improved corrosion resistance. Corrugated panels of COR-TEN and structural grade stainless steel are recommended. The thickness range recommended for aluminum should be slightly increased, say from 1.20 - 1.50 inches, to avoid an extreme weight penalty.

Composite sandwich panels should be included. In the FRP/plywood category, an effort is warranted to increase the modulus of the face material with minimum cost and weight penalty. Alternative patterns of glass reinforcement should be considered. Core material other than plywood is an interesting possibility as a candidate, but since it will lead to higher cost containers it might be sacrificed from the development program if funding limitations are severe. Metal face composites should be included with both aluminum and steel.

Weight saving design alternatives of container bottom structure need further investigation. This could also proceed from present design approaches in steps to produce several prototypes of various risk levels.

The second phase of the design optimization study should seek a fully integrated structure which would have maximum improvements over current designs in all its characteristics. Targets could be established in categories of damage resistance, useful interior cube, and tare weight. Of course, if this work is initiated prior to the completion of the service duty description and design criteria, there might be adjustments in the targets as work proceeded.

11.6.3 Operational Flexibility Features

Doctrine on the use of reuseable shipping containers by the Army in the field is being evolved progressively. At this time some general objectives are envisioned, such as ease and speed of unloading. Selective unloading and access to all the contents of a container when it is used as a warehouse type of structure may become a requirement. It must be determined how these kind of operational flexibility features affect the selection of structural design approaches. If it develops that additional doors, perhaps side opening doors, add excessive structural complexity and weight, there may be preferred alternatives such as top opening arrangements. Indeed, top openers may have a general advantage to Army units in the field since cargo may be unloaded to trucks much more quickly with overhead cranes than by conventional warehouse lift trucks. Top loading standard containers would be compatible with half height containers which are inherently top loading. Other operational features might be considered such as the most efficient internal restraints for standard military unit loads. Provisions in container design to enable small displacements with field expedient methods is a typical example of other operational flexibility features that could be considered.

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