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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

A Common Sense Design Manual for Producibility of Hull Foundations

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
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A COMMON SENSE DESIGN MANUAL

FOR PRODUCIBILITY OF HULL FOUNDATIONS

* * *

Prepared by

VIBTECH, Inc.
125 Steamboat Avenue
North Kingstown, RI 02852
(401) 294-1590

Authors

John J. Hopkinson, President
Manish Gupta, Naval Architect/Ocean Engineer
Paul Sefcsik, Mechanical Engineer
Geoff **Rivinius,** Sr. Naval Architect

For

PANEL SP-4
DESIGN/PRODUCTION INTEGRATION

Under the

NATIONAL SHIPBUILDING RESEARCH PROGRAM

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MAY 1996

A COMMON SENSE DESIGN MANUAL
FOR PRODUCIBILITY OF HULL FOUNDATIONS

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EXECUTIVE SUMMARY

The “Common Sense Design Manual for Producibility for Hull Foundations” employs new engineering concepts, guidance and standards to dramatically improve the producibility of foundations. Foundations designed using this manual will significantly reduce construction time and cost. The manual should be used as a tool to profoundly influence engineering and production practice to improve production throughput in a shipyard.

Quoting from an important NSRP project; “Shipyard engineering has the largest single effect and impact on production practice. Planning and material are the next two most important functions which impact production practice”. [1] This manual provides guidance for achieving enhanced producibility for foundations using all three functions. Foundations and outfitting processes exhibit the exhibit potential for improvement since equipment and systems installations are both complex and prevalent throughout the ship.

Foundations as a percentage of hull steel weight are only a small portion of the total ship, but their cost can be up to 10 times higher for their weight than primary ship structure. Therefore, the potential for large savings in foundation construction time and cost is significant. Weight savings for foundations and outfit installations based on the manual’s guidance can be as much as fifty percent (50%) when compared to traditional and conservative designs. Welding size, length and volume can be reduced by over fifty percent (> 50%). Material quantity and cost, foundation manufacture and shipboard installation labor will all be correspondingly reduced.

With proper planning, the sub assembly on-block outfit times and overall ship construction time will be significantly reduced. Potential labor/time/cost savings can be achieved in the following areas:

- Engineering and design labor reduction
- Planning labor reduction
- Material quantity, parts and piece reduction
- Foundation manufacturing labor reduction
- Shipyard handling labor and overhead reduction
- Foundation and outfit installation labor reduction
- Sub assembly outfit and build time reduction
- Reduce overall time and cost for ship construction.

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[1] **"Investigating Methods of Improving Production Throughput in a Shipyard”, Page 2, N.S.R.P. Project SP-8-92-4.**

EXECUTIVE SUMMARY (cont.)

Our industry has demonstrated a persistent resistance to change. Our industrial shipyard culture is locked in tradition and organizational inflexibility that tends to institutionalize design practice. Our internal shipyard procedures instruct the engineer and designer to use previous ship designs as guidance for new construction. As a result most of the shipyard practices in our country, including foundation design, are similar. There seems to be no one or any entity that can or is willing to break the mold. As a result, our engineering and design groups tend to produce the same costly designs ship after ship, program after program. There seems to be no escape from this costly conundrum.

The time is ripe for technology breakthrough ideas. New improved shipyard processes will come from the auto, airline or the computer industry. The guidance manual presented herein is viewed as a first step to emulate more efficient assembly practices used in other industries. A process of continuing improvement should be supported by company executive leadership to ensure that the goal for process improvement is not thwarted by the organization's natural resistance to change.

This manual incorporates designs based on an innovative effort to achieve producibility and construction cost savings in foundations that was started in the early 1980's. This innovative effort led to the development of a family of standard foundation designs based on simple geometries, and quick and easy installation methods. The standardized designs, illustrated in this manual, offer large savings in the time and cost for construction and installation aboard ship. Other guidance provides standard configurations and scantlings for typical mounting methods that can be used for both equipment and systems installations.

The identification of important and relevant processes as they affect foundation producibility and production planning are provided to guide the designer to achieve "production friendly" designs.

Technical requirements, performance criteria and specifications are addressed in the manual. Design and engineering approaches using first principles engineering and testing to validate innovative designs are outlined in the manual to encourage development of a strategy and means to achieve cost effective foundation and outfit design. Design methods are oulined to help guide the designer to select foundations from standardized designs.

ACKNOWLEDGMENT

This project was funded by the National Shipbuilding Research Program, Design/Production Panel (SP-4), chaired by Ronn E. Besselievre of Ingalls Shipbuilding. The SP-4 Panel is one of the Ship Production Committee Panels of the Society of Naval Architects and Marine Engineers, which were established with the purpose of improving U.S. shipbuilding performance.

An extensive survey was conducted on the principles and practices of foundation design and production with several shipyards, and their feedback and recommendations are included in this report. The authors acknowledge and appreciate the interest and participation of the following shipyards: Avondale Shipyards; Bath Iron Work, Ingalls Shipbuilding; McDermott Shipbuilding National Steel & Shipbuilding Company Newport News Shipbuilding.

The authors appreciate the permission to include figure 5.1 from Laurent C. Deschamps of SPAR **Inc.,** MD.

The success of this project was accomplished through the efforts of many VIBTECH staff. The authors would like to extend special thanks to Eric M. Jacobsen; Spencer L. Johnson; Sandra J. Ducharme; Keith C. Morrison and Judson B. Broome for their valuable contribution.

Title A COMMON SENSE DESIGN MANUAL FOR PRODUCIBILITY OF HULL FOUNDATIONS

1.0 PURPOSE

The purpose of this design manual is to provide information and guidance, and outline engineering methodology for optimum design of foundations for either commercial ship or naval combatants, with effectively integrating all design requirements.

2.0 GENERAL SCOPE

It is necessary to develop an engineering approach to foundation design that encompasses all the requirements yet results in a practical engineering methodology. The design manual is helpful in formulating the relevant requirements for design and analysis and controlling the engineering content of drawings to ensure that foundations meet

- Structural adequacy
- Vibration limit
- Acoustical level limit
- Producibility criteria
- Weight & Cost effectiveness
- Maintenance requirement

The manual helps in the design process for the foundations, adequate to resist ship's motions acceleration and other environmental loading for all ships and shock accelerations in case of combatants. Equipment function, shipboard environment survivability, and other mission requirements affect the design and engineering factors that must be considered for each foundation installation. Manufacturing techniques, construction and installation requirements must be adjudicated properly to achieve effective foundations. It is essential to identify, integrate and prioritized the requirements as they apply to each foundation. It is important that the guidance be provided to facilitate the engineering drawing schedule and ultimately the ship construction schedule. In order for the guide to be practical, unnecessary engineering and design refinements must be minimized The scope of the engineering design work must be, limited for the following reasons

- The generalized methods (statistical approximations) used to develop shock inputs and engineering methodology used in shock, vibration and noise engineering logically preclude unnecessary and overly sophisticated engineering methodology.

- A generalized seaway and environmental loading used with appropriate safety margin makes detail engineering for every individual foundation unnecessary.

- The engineering and design of foundations must be done in a timely fashion in order to complement the ship construction process which is organized to ensure delivery of the ship on time, with the quality required within estimated costs.

The steadily increasing cost of material and labor on the construction of naval vessels dictates that shipboard foundations be lighter and of simple design. The most costly process in hull structure fabrication is the cutting, fit-up, and welding operations necessary for foundation construction. Foundation designs that minimize cutting, fitting and welding and reduce the requirement for jigs and fixtures will result in a significant reduction of labor man-hours.

3.0 GENERAL APPROACH

The general approach taken in this design manual is to employ a practical and pragmatic approach to foundation design. Use producibility features, weight and cost reductions techniques and follow an integrated engineering and design approach to foundation design.

3.1 Practical and Pragmatic Approach

The foundation design team should understand and be committed to designing lightweight producible foundations (LWPF) and the organizational setup should be structured to achieve LWPF. The underlying idea is to design and fabricate foundations/system installations less costly to manufacture and install. The shipyard engineering, design arid production units should be tasked to implement cost savings designs.

A practical and long-term approach would be to address critical technology, perform design engineering analysis and testing validation, apply innovative producibility and standardization concepts, apply production engineering principles to foundation design, incorporate design methodology which expedites analyses in production mode, improve foundation integration with the hull, accelerate foundation construction installation, and employ technology and innovation for continuous improvement.

3.2 Producibility Initiatives

Production oriented de-sign is an important initiative to be undertaken when implementing ship specifications and a practical constraint of the design. This manual reflects the concept that "producibility initiatives are a way to lower ship production costs by communicating shipyard production considerations to the designer." Through achievement of an understanding of how shipyard construction of lead and/or follow ships will be affected, the designer is guided to select approaches reflecting shipyard optimum construction methods. Implementation of designs which reflect the most cost effective construction methodology will collectively achieve substantial cost savings during ship construction. This approach when consistently applied should result in the development, when appropriate, of the standardization of scantlings for various foundation configurations consistent with equipment weight and geometry.

3.3 Weight and Cost Reduction Initiatives

The development of light weight designs consistent with other requirements is needed in order to help meet ship displacement targets required to satisfy the specific ship's naval architectural limits. From the weight information databases of various class ships its apparent that the foundations are a small percentage of the overall steel weight but the relative cost is very high because the foundation design, fabrication and installation processes are currently not standardized and therefore not process controlled and neither production oriented.

It is important to save weight since weight saving will result in cost saving. There can be a significant potential for cost reduction, if an aggressive policy of foundation weight reduction is pursued combined with a producibility initiative to reduce the labor content of the fabrication and installation of foundations.

3.4 Integrated Engineering and Design Approach

The foundation design manual is developed to place constraints on the engineer and designer to develop typical foundations using an integrated engineering and design methodology. However, an engineering process is never really complete, since improvements can always be made in both production and engineering methodology. It is always desirable to reduce weight, eliminate pieces and reduce welding. It is also important to improve on the foundation engineering methodology, to reduce engineering time and develop new engineering shortcuts. The integrated design approach should be regarded as a starting point upon which subsequent improvement can be made. This procedure should be updated to reflect such improvements and design development.

The design manual provides the engineering design methodology required to achieve adequate foundation designs in a timely reamer. The methodology is broken down into three sections. Technical Approach, Section 8.0 describes the criteria, requirements and specifications; and the design methodology. Producibility and Innovation for Foundations, Section 7.0 gives producibility and cost reduction guidance to facilitate expediting production and to improve standardization in design. Foundation Design Guide for Standard Foundation Types, Section 9.0 provides a series of tables, tips and view-graphs to aid the design process towards standard designs. Appendix A describes the analysis methodology and criteria & specifications used to obtain the design data table values of Section 9.0.

4.0 FOUNDATION DESIGN

The design of ships, ship structures and foundations has followed an evolutionary path, steeped in tradition and qualitative design practices that are collectively known as “principles of good sound ship construction practice”. his practice generally resulted in ships that performed reasonably well for the purpose intended, even though the engineering basis for the performance was not well understood. While this technology has been elaborated on in the general and detail specifications for ships there is no consistent way in which it has been interpreted or applied.

Traditional foundation designs are characterized by robust scantlings with substantial reinforcements that are costly and require significant time to manufacture and install. These designs have had a tendency to be based on past practice since there has been little guidance or information provided on acceptable alternative design approaches. The cost per unit weight of foundations in naval surface ships is approximately ten times greater than the cost of primary hull structure. The time required for foundation construction and installation process significantly affects the overall construction schedule. Traditional design practice and conservative interpretation of the ships specifications has tended to inhibit changes to improve foundation design to be more cost effective.

With the advent of more rational and cost effective means to analyze and test the performance of ships structures and foundations, significant cost reductions can be achieved while maintaining reliable and safe performance of both ship structure and foundations. Cost and schedule benefit can be achieved for both commercial ships and naval vessels, although the foundations for naval vessels have more stringent performance requirements. However, both commercial and naval vessel foundation designs will benefit greatly by subjecting foundation designs to testing as well as analysis, since the analysis methods employed are very conservative and don’t either, reflect the dynamic loads imposed on the foundations or accurately portray the response mechanisms that inherently exist in the ship and foundation structure.

4.1 Traditional Design Practice

The traditional relationship which has been established between the drafting and engineering design functions for foundations has proven to be very inefficient. This approach is likely the result of a lack of visibility and appreciation for the adverse impact foundation design has had and continues to have on the cost of ship construction. Although foundations represent only about 10% of the steel weight of Navy ships, they represent 50% of the steel construction costs. While foundations in commericial ships represent a smaller portion of steel weight, their absolute numbers remain significant.

Traditionally, draftsmen were tasked with the design of foundations. These draftsmen/designers invested many man-hours in drawing foundations based on previous designs. This sequential design process developed from the "apprenticeship" heritage of shipbuilding, when designers/draftsmen had years of production experience prior to being tasked with developing a design. This Sequential design paradigm worked well for many years, particularly for commercial ships, as long as designers had the knowledge to perform the job.

As requirements became increasingly more complex and the shipbuilding industry became more competitive, with margins on labor hours and throughput determining the winners and losers in a poor economic climate, it has become important to develop efficient and cost effective designs. The sequential design process is not suited to effective systems engineering which requires the integration and synergy of many fields and requirements. The designs which these draftsmen based their work on did not incorporate new knowledge and technology regarding producibility. Engineers played a small part, merely approving designs with minimum changes, since any change would require drawings to be redone and confusion would ensue. Engineers were largely regarded as necessary to satisfy a legal requirement, rather than needed as an integral part of the design process, even though the time had come when systems needed to be engineered rather than merely drawn up. As a result, optimum scantlings and producibility concepts were never introduced into this costly group of ship structure,' although overtime considerable attention was being given to primary hull structure due to its *greater visibility* (failures during and immediately following World War II) and strides in hull design for greater performance. This draftsmen-driven design approach is still prevalent in the design community today, and producibility as a driving consideration is not yet fully entrenched in our industry's corporate culture. The results of this design approach are heavy, over-designed foundations which are very expensive to construct.

The roles of the drafting and engineering functions in the sequential design regime can be summarized as follows:

DESIGNER'S ROLE

- Draftsmen developed a systems integrated foundation design and final drawing
- Draftsmen extrapolated new designs from similar previous ship designs with a best guess at scantlings

ENGINEERS ROLE

- Engineers validated scantlings developed by draftsmen
- No requirement to stress optimize foundations
- Engineers approved designs with minimal scantling changes, since drawings and budget were almost expended
- Engineers "rubber stamped" those designs which met specifications even if grossly over designed.

Figure 4.1 illustrates the traditional sequential approach. This is symptomatic of the traditional sequential design and engineering approach to the overall ship design, and is not limited to foundations alone. In this traditional sequential engineering model, by the time engineering reviews and calculations are made, it is often too late to provide feedback to those functions that are responsible for locking in decisions which drive the construction costs. Production planners are relegated to developing plans for building that which has already been designed. Feedback from these producibility experts is rarely incorporated into the design. This system had worked during the earlier days of ship design and construction, when those responsible for the design were experienced and accomplished shipwrights, knowledgeable in ship production, with few stringent requirements to consider. Today, to large extent, a few key decisions made "in a vacuum" early on in the project lock in nearly all future costs.

Recognizing that the shipyard is generally not in control of wage rates and material costs, but is in control of labor hours and throughput rate, there is an incentive to incorporate producibility and build strategy considerations early into the design phase. With properly sequenced engineering and drafting efforts significant Mwprovements in design to cost of foundations can be made with more efficient use of budgeted design/engineering time and cost.

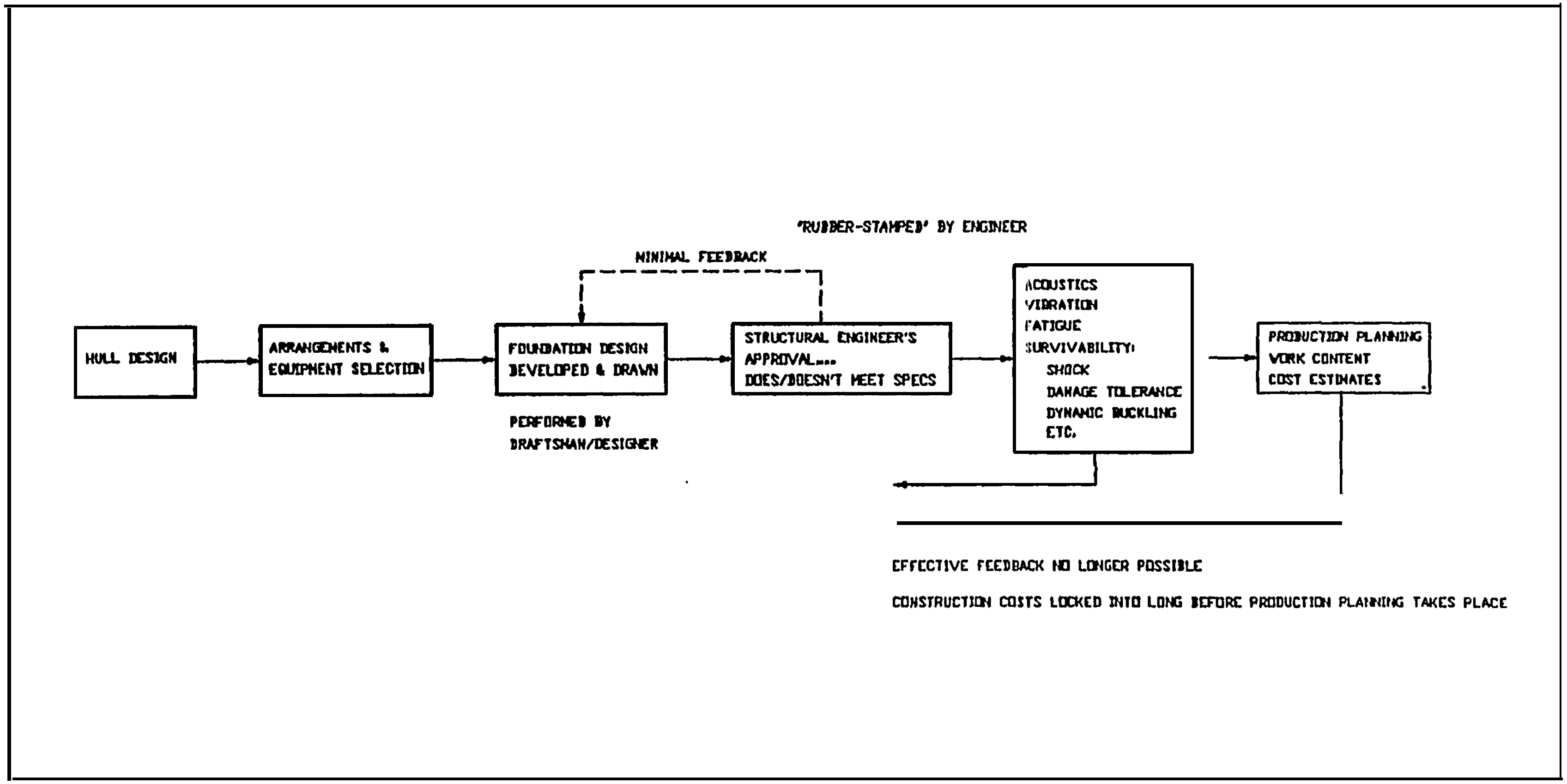


FIGURE 4.1 - SEQUENTIAL DESIGN OF FOUNDATIONS

4.2 Progressive Design Practice

The function of drafting, design and engineering must take on anew relationship if producibility and build strategy considerations are to be incorporated early in the initial ship design phases.

This new relationship requires the following:

- Draftsmen first develop sketches identifying systems environment and foundation development constraints.
- Experienced and well trained designers and engineers, with the aid of expert systems such as foundation data bases and extensive producibility guidelines, develop producibility oriented foundation concepts within the foundation environment space.
- Engineers fully develop foundation designs governed by the relevant criteria, such as shock, vibration, ship environment loading and fatigue.
- Draftsmen develop final drawings once engineering definition of foundation scantlings and producibility considerations/build strategies are complete.

This reordering of design functions, which can be referred to as a parallel design or concurrent engineering permits the major drafting effort to be expended after the optimum foundation design has been achieved, maximizes producibility and minimizes any major backfix efforts. In this process, engineering drives the design, constantly providing feedback and lessons learned to the expert systems. which serve as a knowledge base. In this way, the ship design team will continuously improve its design processes and products. The parallel approach to engineering is one of the keys to achieving the goal of parallel construction, significantly reducing time to delivery.

A vast quantity of data regarding equipment and foundation dimensions, scantlings and weights exists for a variety of ships and applications. Experience with and ability to utilize these statistics has permitted the development of a system for characterizing foundations into standard types. A library of standard baseline designs has been developed, which incorporate design principles for low cost and light weight structural systems that can be engineered for a variety of applications. By performing parametric analysis, in which key variables are varied to determine a design’s sensitivity to these variables, a baseline design can be applied to an entire class of situations rather than a single application. Armed With this information essentially an expert system for foundation design, structural engineers may integrate the available information, refine and optimize the deign and constantly feed new knowledge and lessons learned back into the expert system. After a final, optimum, design has been established, the drawings can be made and work packages developed. Figure 4.2 illustrates the notional Parallel Design approach which facilitates producibility and provides the shipyard with a more rigorous means of estimating costs and work content through the consistent application of known processes, procedures and systems in an efficient and cost efficient manner.

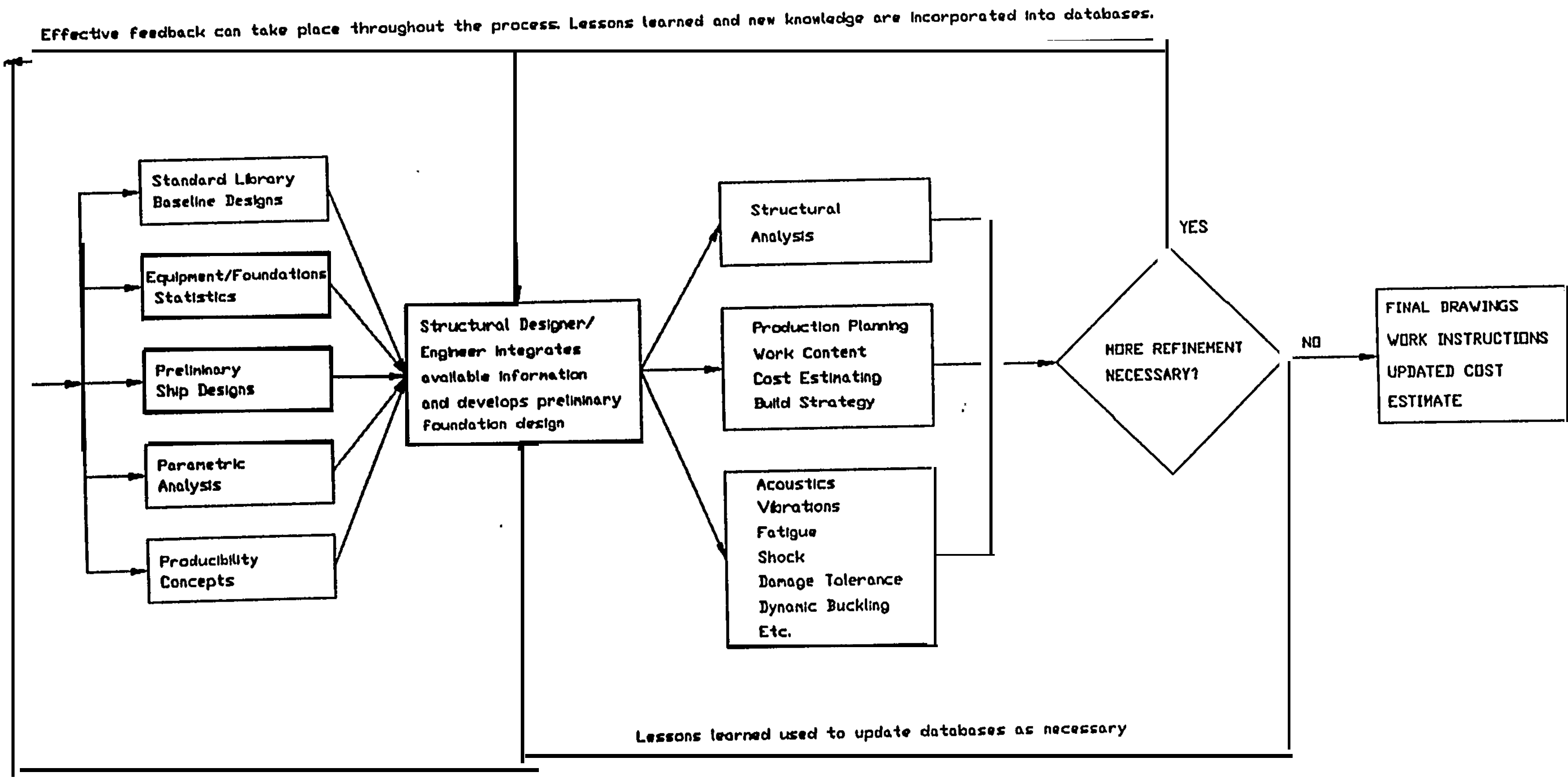


FIGURE 4.2 - PARALLEL FOUNDATION DESIGN APPROACH

5.0 PRODUCTION PROCESS

Production processes employed in the United States vary significantly from shipyard to shipyard, especially between those engaged in Naval work and those engaged in commercial work. A simple characterization of shipyard production processes employed would not do justice. Tradition, workload, capitalization, and business focus affect each shipyard's market position and business strategy and hence their strategy and means of production.

Ship building has evolved from construction of hull steel and outfitting by ship fitters and skilled craftsmen on the building ways to modular construction where units are fabricated from sub-assemblies and joined together in a graving dock or launching ways. The traditional sub-assemblies are outfitted to the maximum extent practicable before the units are fitted to a main erection block. On block work completes the outfitting during block erection prior to launch.

Competitive shipbuilding is fostered by ensuring that designers and engineers are aware of the primary shipyard work centers and how they are related in an integrated shipbuilding production process. Design and engineering can then be more effective in ensuring that foundation, equipment and outfit items are manufactured, installed, and pre-outfitted, in the ship in the right sequence and time in order to lower overall ship construction costs and reduce the ship construction schedule. Nevertheless, there are many constraints which may tend to inhibit pre-outfitting, such as lack of timely design information, that will require such items to be installed later in the zone outfit stage of construction. The shipyard administration must do everything possible to change methods of ship construction that result in a high ratio of labor to material costs in order to be globally competitive.

5.1 Primary Work Centers

Primary work centers involving the foundation drafting, design, engineering, fabrication and installation process includes the following Purchasing (equipment and materials); Engineering and Design (procurement specifications); Planning; Stores; Steel Fabrication shop (foundations); Panel line Sub-assembly and Blast and Paint. Of course other work centers such as information services, quality control and the shipyard administration have a direct effect on the efficiency of the operation of which foundation design, fabrication and installation is a part.

Figure 5.1 provides an illustration of the primary shipyard work centers that comprise a concept of an integrated shipbuilding production process that embodies sub-assembly and erection techniques currently used in U.S. shipyards. Figure 5.1 illustrates the processes involved in both pre-outfitted hull unit construction and zone outfit.

PRIMARY SHIPYARD WORK CENTERS

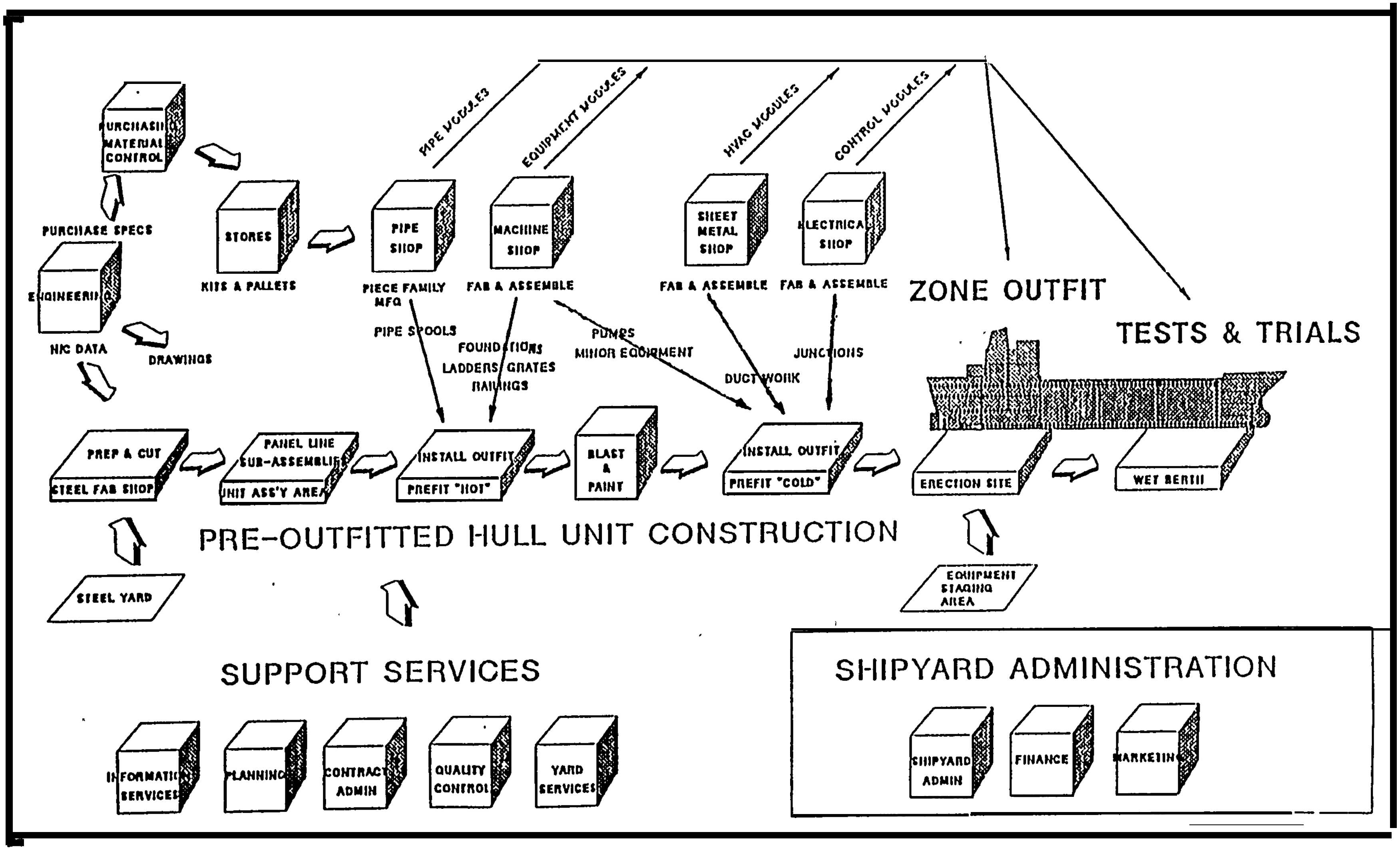


Figure 5.1: Integrated Shipbuilding Production Process (with permission to publish from SPAR Inc., MD)

Pre-outfitting is the installation of non-structural items (including foundations) during all production stages up to erection. Such work on the post-erection period is called outfitting. In general, early pre-outfitting lowers cost. Of importance is the split out of work during the "hot" prefit stage compared to the "cold" prefit stage of construction. Where completely finished products can be installed subsequent to "blast and paint", significant cost savings can be achieved by avoiding rework, painting and repainting of affected items.

5.2 Zone Outfit

Build strategies using modular hull construction methods will reduce shipyard costs with properly developed zone outfitting methods. As indicated in Section 5.1, pre-outfitting of units will generally result in lower costs. However, where pre-outfitting can not be achieved, then cost effective means for accomplishing zone outfit must be developed. Constraints that affect the amount of pre-outfittng include

- Lack of timely design information (lead ship)
- Erection weight
- Installation and trade sequences
- Protection of certain equipment from damage during construction
- Systems crossing unit boundaries
- Technological state-of-the-art, such as special coatings

General guidance for the design of ship systems and components, (or foundations) in way of unit or subunit breaks is as follows:

1) Avoid system runs in way of unit/sub-unit breaks
2) Minimize system runs crossing the unit/sub-unit breaks
3) Avoid placing equipment (hence foundations) straddling unit breaks
4) Avoid placing bulkheads at the unit/sub-unit breaks
5) Avoid supporting systems from two different units or sub-units
6) When systems run close to unit breaks leave room to allow access for welding and other fabrication techniques
7) Pay attention to horizontal breaks as well as vertical breaks

On block work after sub-assembly and assemblies have been joined together in erection units requires welding and other trade work that will potentially damage work previously done: Consequently, foundation designs that minimize the amount of rework necessary will significantly reduce construction costs.

5.3 Pre-outfit Hull Construction

Traditional methods of ship construction and outfitting result in a high ratio of labor costs to material costs. Pre-assembly and pre-outfitting in a shop under ideal conditions of temperatures, lighting, and access will reduce labor costs drastically. Not only are structural costs reduced, but outfitting costs, which represents a much greater percentage of total cost, are also reduced substantially.

As a general principle, the earlier a job can be performed in the production plan, the cheaper it will be. The cost ratios at various stages of production have been estimated to be as follows:

• Fabrication	1
• Unit Assembly	5
• Building Ways (zone outfit)	10
• Post Launch	20

Obviously, pre-outfitting pays off, however there are many constraints that preclude pre-outfitting as discussed in section 5.2. The designer can have a favorable influence on many such constraints as described hereafter. Basically, attention to two basic design requirements will support cost reduction.

- Careful attention to installation sequences

- Proper treatment of through ship systems (and components) at erection unit boundaries

Table 5.2 shows, for each stage of construction, the types of pre-outfit activity to be expected.

TABLE 5.2

Pre-outfitting and Outfitting Activities

CONSTRUCTIONSTAGE	PRE-OUTFITTING	ROUGHCOSTFACTOR
Fabrication	Cut and pre-coat all Steel, Aluminum Pre-outfit	1
Sub Assy	Pipe & Vent Duct Spools, Misc. Headers & Clips, Foundation Method Mounting	2
Panel Assy	Ladder Clips, Pipe Supports, some Piping Pipe & Vent Spools in Panels, Headers, Cable Penetrations, Foundation Methods/ Standards Installation	2
Unit Assy & Post Assy Storage	Piping, Ladders, Vent Ducts, Foundations, Cableways & Local Wiring, Pumps & similar Machinery, Doors, Ports, Railings, Deck Fittings, Masts, and certain living and electronic spaces	5
Ways Work	Major Machinery (Big Lifts) Propulsion Shafting	10
Post-Erection (Outfitting)	Furniture, certain Electronics Equipment, Continuous through Ship Systems such as Degaussing	N.A.
Post-Launch	Final Onboard Stores and Final Tests with any Pick-up Necessary	20

In order to properly develop foundation designs that are amenable to construction, draftspersons, designers and engineers should concern themselves with production practices and manufacturing techniques employed at the shipyard. Innovation in design and manufacturing can be achieved through understanding the capabilities and limitations of the manufacturing processes.

Certain shipyard practices need to be understood to effect best shop and ship methods. For example, casualty power cables need to be called-out separately to allow them to be made up as a separate job in the electric shop. On board ship, the design of piping runs and piping hangers should take into account the amount of pre-outfitting done in the unit assembly. Other techniques need to be understood as critical in a modem yard:

- Welding, both structural and for attachments
- Straightening
- Hydro and air testing of tanks and compartments
- Surface preparation (e.g., sandblasting)
- Painting and coating
- Sheathing or insulating - sequence for installation
- Installation of ducting, piping, cable, design of hangers
- Installation of machinery and electrical equipment
- Protection of equipment during erection
- Testing of erection joints
- Testing of Systems (e.g., ventilation flows)
- Preparation and preservation of erection joints

While all these techniques are not necessary to the development of foundation designs, the awareness of these techniques will facilitate the installation of equipment and system components. All equipments and system components are outfit items that need to be securely mounted to the ship and as such can in a general way criteria for foundation design can apply to both equipment and system installations.

6.0 PRODUCIBILITY PRINCIPLES FOR SHIP CONSTRUCTION

The producibility design objective is to quantify the design performance requirements and to satisfy the requirements with an economical design solution. In order to achieve these goals consistent with other ship design requirements the following objectives are cited

- Ensure that ships as designed can be built with speed and economy
- Ensure that excessive sophistication is not built in
- Ensure that producibility is given due consideration throughout the ship building program
- Ensure that the staff are familiar with the ship producibility design intent.

Implementation of designs which reflect the most cost effective construction methodology will collectively achieve substantial cost savings during follow ship construction. Through achievement of an understanding of how construction of lead and follow ships will be affected, the designer is guided to select approaches reflecting optimum construction methods.

Change in Ship Construction: Shipbuilding is changing. New ship construction is no longer a matter of bringing materials to the ways for erection. No longer can a shipyard remain competitive by completely outfitting a hull floating in water. No longer can the skills of a shipwright be depended upon to have been handed down from father to son through long apprenticeship. However, even with the advent of modern techniques for modular hull construction, vestiges of shipwright practices influence the construction of ships. Design practices developed to suit traditional outfitting survive in the outfitting practices utilized in modular construction. Labor intensive practices indulged by necessity when ships were constructed on the ways, must be changed to be compatible with modular construction techniques. Design solutions to reduce the high cost of outfitting are achievable through application of engineering first principles and testing to validate lower cost designs.

Manufacturing and Ship Assembly The shipyard has evolved to becoming more of a manufacturing activity and an assembly plant combined. As reducing costs to become world competitive becomes more imperative, shipyards will have to evolve their assembly processes to become more effective.

Work in shipyards has been simplified by breaking it down to fit into prescribed stages of construction. These stages are separated into different divisions at different yards. The objective is the same however, to simplify the workers job and to eliminate unnecessary movement of materials. Typical stages of construction are:

- Fabrication
- Subassembly
- Panel Assembly
- Unit Assembly
- Erection
- Launching
- Final Overboard

Preoutfitting is done prior to erection, outfitting is done after erection. Erection consists of putting large assemblies (units) into their final position as part of the ship.

Material Flow: In parallel with the construction stages, are the stages of material flow. The materials are received, sorted, stored, processed, kitted or subassembled, and installed. Material flow has evolved significantly from that used when building ships on the ways. In traditional ship construction materials were transported piece by piece to the construction site aboard ship. Modern subassembly practice with pre-outfitting has reduced the amount of material handling and ship fitting. However such work is still accomplished in manners reminiscent of traditional ship building practice. Material flow techniques need to evolve to support assembly line manufacturing in order to outperform our world class competitors.

Producibility principles must start with the idea of improving our ships and our shipyards.

- Upgrade our shipyards by setting up combinations of places for men, materials and machines that will produce improved ships for less expenditures of man-hours and dollars.

- Keep ships simple, but refined enough to accomplish their basic mission.

- Design ships to fit the production processes, as well as their ultimate use.

Producibility in principle, starts with the idea that production techniques that arise from sound production planning principles must be reflected in design to be used effectively.

Certain fundamental principles, or first principles of production lead to production techniques that must be considered by the designer in order to achieve optimum results. Producibility for foundations no less than other disciplines, involves the application of production planning principles; especially:

ACCESS
TRADE SEQUENCE
ONE-TIME SKILL APPLICATION
INSIDE WORK
DOWN HAND WORK
SHOP PACKAGES

Such principles lead logically to production techniques, design considerations and ultimately to the desired improved results in production that will lead shipyards to world class productivity. See Figure 6.1. For example, all the above principles are served by the techniques of unit construction and pre-outfitting; however, unit boundaries must be observed and maintained by designers, both in structure, foundations for equipment and in through-ship systems design. These principles were outlined in the Producibility Assurance Manual developed for the Patrol Frigate Program.

INTRODUCTION TO PRODUCIBILITY INNOVATION

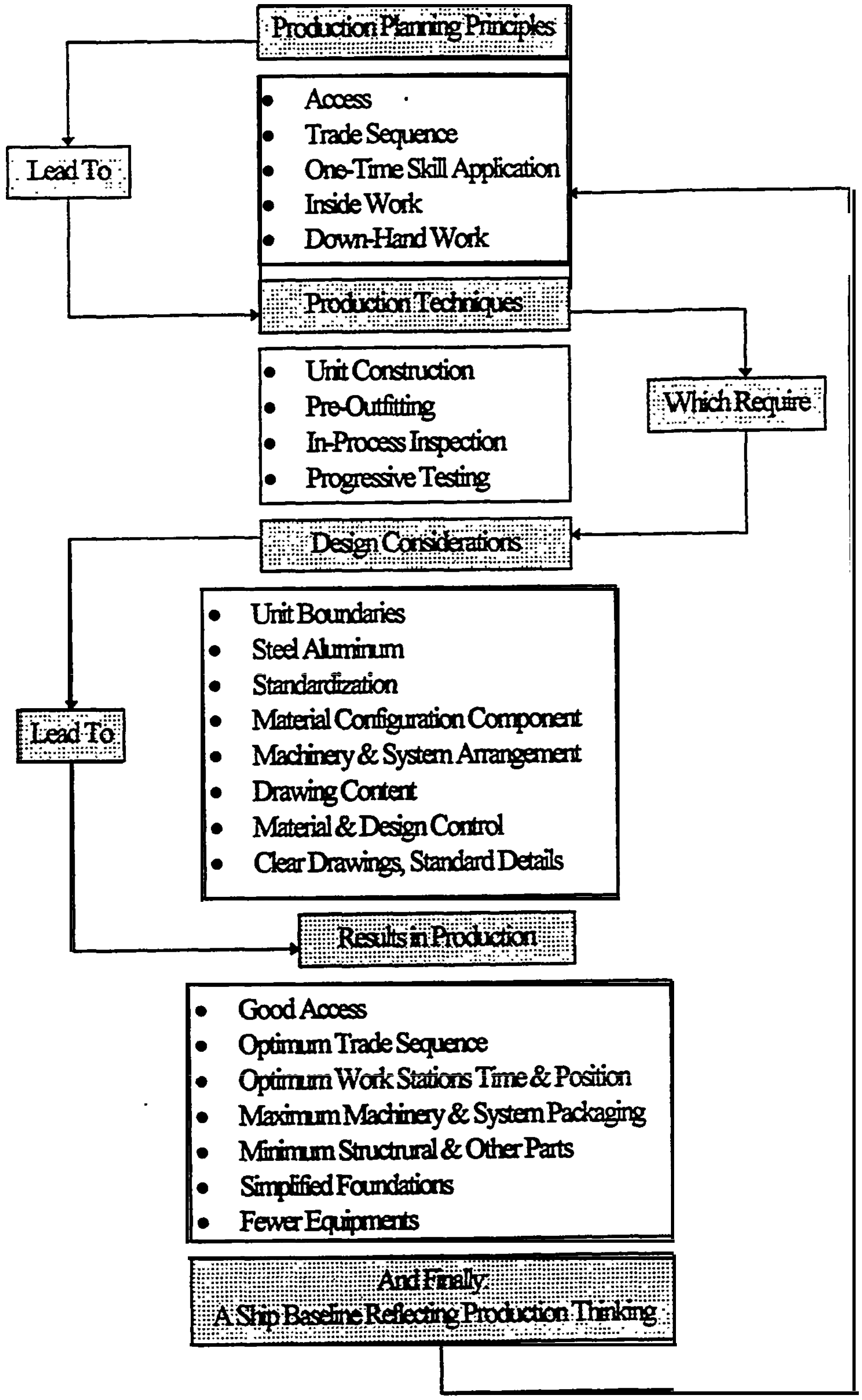


Figure 6.1

6.1 **Production** Principles

Figure 6.1 illustrates how production planning principles relate to production technologies which require design considerations that lead to positive results in production. Since these principles are essential to efficient and cost effective foundation development they are discussed in some detail in this section and sections 6.2,6.3 and 6.4.

ACCESS: In addition to providing access for maintenance, the designer must keep errection and the installation sequence in mind. Equipment must have easy access for loading, systems must be easily installed, and access for welding must be allowed.

Example Local cables will be pre-installed in each erection unit before through ship cables; therefore when these cables are located in cable-ways they must be positioned closest to the overhead, bulkhead, or deck so as not to interfere with the pulling of the through-ship cables.

Example: Foundation installations for groups of equipment in tight areas must be designed with access in mind to achieve easy foundation installation.

Design Information Erection Sequence
Outfitting Sequences
Minimum Welding Clearances

TRADE SEQUENCE: The necessity for several trades to work the same area simultaneously results in restricted access and delays.

Example: Traditional destroyer design forces four trades to follow one another with about equal effort in all fan rooms. Ship system design can minimize congestion in fan rooms and allows prepackaging of air conditioning by extensive use of fan coil units. Another approach to fan rooms and similar areas is to prepackage machinery components in the shop for installation as a module.

Example: Foundation installation during “hot” prefit and “cold” prefit conditions imply trade sequences where hot work is done prior to blast and paint and “cold” installations may require paint repair and touch up subsequent to installation of small welded foundations or stud welding.

Design Information: (closely related to access)

ONE-TIME SKILL APPLICATION: It is inherently more efficient to do a single function one time rather than several times. Therefore the designer should provide ways to combine operations.

Example: Burning holes for pipe, duct, and cable all at once by means of hole drawings and lists is efficient; burning such holes by trade "as required" is not.

Example: Foundations installed by the use of standard method mounting or by use of studs can be accomplished all at once.

Design Information: Erection Sequence
Material Flow
Facilities Available

INSIDE WORK: Work done out of the weather is more efficient than work done subject to rain, ice, and wide temperature fluctuations. This fact is one of the fundamental reasons for preoutfitting as early in the stages of construction as possible. The typical stages of construction are fabrication, subassembly and panel work, unit assembly (in the largest assembly building), unit storage (where further work is done), erection on the ways, and post launching or outfitting work. Work done prior to erection, other than basic structure, is called preoutfitting. Shop-built items are called shop manufacture, e.g., pipe assemblies.

Example: Foundation fabrication in a shop under controlled conditions and installed according to plan during a preoutfitting sequence during sub-assembly, unit assembly is much preferred to those assembled or fitted aboard ship at a later stage of construction.

Example: Blasting and priming steel plates in a controlled environment blast facility is some 27 times cheaper than the same job done later on the ways.

Design Information: Example Affecting Design
Structural and Preoutfitting Procedures

DOWNHAND WORK: One of the corollary principles to access and location is the inherent efficiency of working downhand vice working overhead. The idea is by no means new; it has been measured with precision for downhand welding. The idea become more subtle when all operations are considered. The designer should facilitate planned downhand work by design.

Example: Pipe and cable hangers and some vent trunks will be installed on the decks inverted. Dimensions from the deck “below” cannot be used, unless there is *a* physically available reference point. Therefore, all dimensions must be from structure physically present at the time of construction.

Example: Foundations for equipment with upper supports can be installed in the down hand position with the upper support installed with the deck in the inverted position. With clever design fit-up to the equipment can be easily accomplished.

Design Information: Structural and Preoutfitting Procedures.

SHOP PACKAGES: Another corollary of the location principle is the need to get machinery assembled in parallel with overall ship construction. Access and sequence of work are improved by grouping equipment for installation together in a short period of time on board.

Normally installation of small auxiliary systems must be delayed at least to the unit assembly stage, and frequently to post-erection. By this time they are “critical path” items, demanding installation, hook-up and testing in a relatively short time. By assembling the components on a common subbase (packaging), assembly, hook-up and testing may proceed in parallel with steel work. The system when installed is ready to go. In addition to the savings resulting from doing the work early in the shop, security against schedule slippage is obtained. Such slippage would be made up using expensive premium time.

For warship design, systems are typically configured for packaging wherever technically feasible. Due to schedule constraints, actual pre-packaging may not be practicable on the lead ship. The configuration, however, will give a follow shipyard the option of packaging to the extent they desire.

Example: Pumps, valves, receivers, and piping can be grouped together on a common foundation. The clever use of the principle by the designer can greatly aid machinery installation.

In the structural area, shop packages imply the minimum number of parts, and a maximum number of identical parts.

Example: Brackets whose angle varies only slightly for several applications can be designed to allow fabrication of standard brackets and shop assemblies with later trimming.

Furthermore, a series of shop manufactured like items are often cheaper than purchasing. Standard designs for method mounting facilitate the design and installation of foundations.

Example: A series of many similar sheet metal jobs can be set up very efficiently.

Design Information: Structural and Preoutfitting Procedures
Work scopes for shops

STANDARDS: Standards reduce the design, engineering and production costs for foundations. Proper standards are developed to take into account production planning principles. Standards should address fabrication of the foundation and installation aboard ship to facilitate the most cost effective installation.

Example: Standard Foundation Method Mounting for power panels eliminates the need for engineering repetitive designs unless, of course, the standard can be revised to reduce costs of construction or installation. Standards facilitate planning, design development, preoutfitting and overall cost reduction.

6.2 **Production** Techniques

The selection of erection units as based on how to best accommodate various production requirements. Subassemblies and assemblies are utilized to provide flexibility in construction.

The boundaries for subassemblies, assemblies and units are determined based on compromise between conflicting considerations of weight, length, accessibility and erection sequence. Unit and sub-unit boundaries must reflect for each shipyard, the location and capabilities of certain shipyard operations, which affect the design. There must be access and provision for connecting systems that extend between subassemblies, assemblies and units.

Considerations that affect the selection of boundaries include the following

- Each unit is a block of the ship's structure and installed pre-outfit material. Its weight should beat or near the maximum lifting capacity of the yard. Heavy lifts result in fewer units per ship which in turn allows a shorter total elapsed time for ship erection and a greater opportunity for pre-outfitting cost savings. Each shipyard's lift capacity in assembly and erection varies. It is recognized that not all follow yards will have lift capacity as the lead yard in a agile enterprise. Such yards may transport the units without lifting or may make a further breakdown into sub-units. Virtual shipyards, using agile collaborative enterprise as a basis for cooperation can develop specific designs unique for each shipyard using Simulation Based Design (SBD) and a ship product model. In this fashion the ship product model can be tailored to suit the specific shipyard manufacturing requirements. Subassembly, assembly and unit size can be planned and executed for each agile collaborative member. Shipyard planning will be facilitated using such a model.

- The unit length (in the hull) is governed by yard planning considerations and shipyard equipment capability. The maximum usable length of the plate rolling equipment and at follow yards influences unit size.

- “Natural” breaks in the ship’s structure help to form a selection of unit boundaries. Breaks are arranged so that each succeeding unit is set in place by moving it toward existing structure and down, to minimize handling and fitting.

- A single deck unit usually includes the deck structure and the bulkheads and shell below. Multi-level units consist of single deck units stacked one above another. These units are generally constructed and pre-outfitted in an inverted position, then turned upright for final preoutfit and final painting. Decks are usually arranged to be continuous through bulkheads.

- Shell seams are usually arranged to be slightly above deck levels (6 to 12 in.), and shell butts such that they occur slightly (12 to 24 in.) forward or aft of transverse bulkheads, depending on the location of the bulkheads.

- Compartments which are to be heavily pre-outfitted are completely enclosed within the unit boundaries. The best examples are the auxiliary machinery rooms. Other examples include living and some electronic spaces.

The maintenance of unit boundaries is an important design function. Here are some generalities:

- To the extent controllable by the stage of design, transverse bulkheads should be kept in the same plane from level to level. The bulkhead line-up occurs almost naturally in the hull structure due to the compartmentalization. However, it requires careful consideration in the deckhouse. This requirement should also be applied to longitudinal bulkheads wherever possible. Such a design approach will produce very clean unit boundaries.

- Foundations for equipment should be located on a single surface, such as a deck, bulkhead or shell. An effort should be made to locate foundations to line-up with existing structure to eliminate headers. When possible headers on the same side as the foundation are preferred. Furthermore, extensive use of common foundations avoid the use of small headers. (This will not necessarily apply to main turbines, reduction gears, and major auxiliaries.) Where possible, machinery and other equipment to be installed on a deck should be located far enough inboard so that the next deck unit can be lowered into place without disrupting the installed equipment below it.

- Butts in longitudinal and transverse frames should occur at or as close to shell breaks as possible. In areas with shape the butt must occur on the "narrowing" side to facilitate erection.

- Systems must be designed with minimum crossing of erection breaks, and where crossing is necessary, with suitable make-up provisions in way of breaks.

Build strategies using modular construction methods typically organize modules into the following:

- Aft body and machinery spaces
- Mid-body sections
- Fore body
- Superstructure.

Modular construction is facilitated by organizing the design to produce modules that can be efficiently installed in the hull modules. They are

- Machinery equipment modules
- Main engine modules
- Propulsion system modules
- Cargo system modules
- Thruster modules
- Deck system modules
- Uptake modules
- Bridge system modules.

6.3 Design Considerations

Figure 6.1 illustrates how Production Planning Principles effect producibility and Production Techniques which will naturally lead to design considerations that must be undertaken if cost saving production results are to be achieved. The build strategy employed results in a set of design and engineering requirements necessary to achieve productivity goals and assurance of achieving performance requirements.

Modern Organizational Approach to Design: The consortium approach to the shipbuilding design and shipbuilding process is to use Simulation Based Design (SBD) to facilitate shipyard build processes. Agile manufacturing techniques require designs to be developed that can be built in different facilities with varying build strategies. Or conversely, hull units can be built in different facilities and joined together. There is a danger in the use of SBD for ships where construction details emulated are based on construction techniques that are traditional and labor intensive. There has been a tendency in warship design to enshrine obsolete design and construction methods. Simulation Based Design affords the opportunity to employ labor saving standards for foundations, equipment, outfit and systems installations. SBD employed in this manner will amplify ship design and construction cost and time savings.

Design Strategy and Scope to Facilitate Build Strategy: Design and engineering requirements that will facilitate a competitive build strategy include

- Production information requirements
- Procurement information requirements
- Modeling and Composites (traditional and/or SBD)
- Key Drawings
- Design and engineering schedules
- Datums and Molded definition
- Functional space allocations

The competitive build strategy will be enhanced by the development of appropriate standards and guidelines:

- Design Standards
- Material Standards
- Production Standards
- Detail Design Guidelines
    -- Steel Work -- Machinery

-- Pipe Work -- Electrical
-- Joiner Work -- Paintwork

- Change Order Management

Considerations of Producibility During Design During detail design development, pre-outfitting and other cost saving techniques can be implemented by careful attention to erection breaks, installation sequence, producibility design in general. For convenience the following list represents a summary of considerations for producibility:

1. Work simplification by spreading the operations out during several stages of construction.
2. Materials in process and flowing to the constructions stages requiring Material Control techniques.
3. Production planning using units and work scopes.
4. Access during assembly, erection, and installation.
5. Sequencing of trade work.
6. Combine production operations for savings inherent in applying skilled work once.
7. Inside work for efficiency.
8. Downhand work - a planned sequence.
9. Shop packages for manufacturing groups of items, some on common foundations.
10. Unit boundaries for structure and systems; as elaborated further below.
11. Standardization of all types affecting production.
12. Drawing content and format for best use by loft, trades and production planners.
13. Design control to avoid interferences.
14. Standard details for clarity, etc.
15. Ease of checking and validation during design and construction.
16. Allowance for changes on drawings resulting from corrections, refinements, and innovations.
17. Allowance for differences in follow ships built by follow yards and partners in virtual shipyards consisting of agile collaborative enterprises.
18. Awareness of the reasoning behind the selection and maintenance of unit and subunit structural breaks.
19. The critical nature of the machinery zone during construction.
20. Cost factors associated with the stages of construction.
21. Welding.
22. Straightening.

23. Testing of tanks and compartments.
24. Testing of systems.
25. Surface preparation together with preservation.
26. Sheathing and insulating.
27. Installation of distribution systems.
28. Installation of purchased equipment.
29. Protection of equipment during construction
30. Erection joints: testing, preparation, and preservation.

6.4 Benefits to Production

As indicated in Figure 6.1 production planning principles which lead to complimentary production techniques require producibility design considerations that will result in benefits to production in terms of good access, optimum trade sequence, optimum work station time and position, maximum machinery and systems packaging, minimum structure, parts and pieces, simplified foundations and systems installations and fewer equipments. The total producibility enterprise embodied in the preceding sections will result in a ship design baseline that thoroughly reflects production thinking.

Historically, the management of the design and engineering effort evolved around the practice of extrapolating designs from past practice to provide assurance that designs were satisfactory from performance standpoints. The sequence of design development required that draftsmen and designers expend significant effort to develop an integrated design package adequate for engineering review and approval. This process resulted in little chance to integrate producibility or production considerations into the development of foundation designs.

A turnabout in concern for competitiveness and cost required that producibility and production considerations be given equal billing with performance issues. By reordering the priorities and the sequence of the design and engineering effort, producibility and production considerations have been incorporated into the development of foundation designs early in the design sequence so that significant production cost savings can be achieved while engineering into the design adequate foundation system performance capability. The development of standards also will reduce design and engineering costs.

7.0 PRODUCIBILITY AND INNOVATION FOR FOUNDATIONS

This sections elaborates in detail the producibility features and cost-saving production techniques for foundations and installations. Some very innovative producibility concepts in compliance with principles and techniques of ship production are also highlighted. Weight and cost reduction through standardization of foundation design, fabrication and installation are also discussed.

7.1 Producibility Principles for Foundations

The following guide-lines reflect the concept that "producibility assurance is a way to lower follow ship production costs by communicating shipyard production considerations to the designer. "Through achievement of an understanding of how shipyard construction of lead and follow ships will be affected, the designer is guided to select approaches reflecting shipyard optimum construction methods. Implementation of designs which reflect the most cost effective construction methodology will collectively achieve substantial cost savings during follow ship construction. This approach when consistently applied should result in the development, when appropriate, of the standardization of scantlings for various foundation configurations consistent with equipment weight and geometry.

The elements of effective principles of producibility design for foundations are identified in the following guide-lines. They are:

1. The Producibility of Foundations should be based on achieving the most producible structural designs while meeting the requirements of the specifications. For any one foundation there should be a best solution in terms of structural fabrication producibility. However, the science or art of shipbuilding is a multi-disciplinary effort, where each discipline tries to achieve producibility engineered designs. As a result designs developed to suit producibility considerations in one discipline may preclude development of equally producible designs within other disciplines.

   Since foundation design normally takes place after the functional arrangement of the equipment has been integrated into the ship design with supporting ships systems, there may be only limited geometrical flexibility remaining to achieve producible foundation designs. However, some accommodation by systems or equipment arrangements may be possible and should be pursued in order to achieve optimum producible foundations.

2. Foundations should be initially designed by the hull draftperson to provide minimum support for equipment. The brackets, bracing & scantlings should be checked by the hull designer and reconfigured if necessary by both designer and draftsmen.

3. Develop designs which require a minimum number of operations per piece.

4. Make foundations rectilinear in configuration.

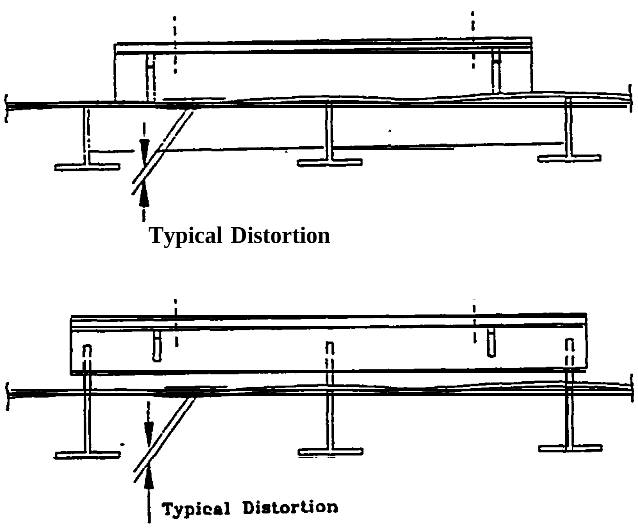
5. Foundation headers on opposite sides of bulkhead or deck should be avoided where possible. Production scheduling usually causes headers to be added after the basic structure is finished.

6. Provide sufficient access to facilitate installation and welding.

Producibility principles leading to lightweight cost effective foundation designs include:

- Lifting foundation off structure

    - Reduces weld length/volume
    - Simplifies fitting in way of distorted deck and bulkhead plating
    - Reduces the possibility of “locked-in” stresses, and in some cases reduces hard spots
    - Flexible foundations decouple the equipment from the ship reducing the shock load on the equipment



A V O I D

Foundation fitted to BHD requires **Scribbing to** BHD or pulling the plating to the Foundation **-- (This procedure usually distorts the foundation)**

PREFER

Foundation spans distortion, minimal fitting required

Figure 7.1: Lifting Foundation Off-Deck

- Simplify foundation designs/improve fitting

  Reduce manufacturing aids/lofting effort
  Reduce number of pieces required
  Substitute studs for welded plate foundations
  Establish quality standards that are consistent with product functions
  Eliminate unnecessary bolt chocks

- The minimum use of underdeck and far side headers; the benefit

  Results in significant weld and weight reduction
  Eliminates/reduces lofting of headers and fitting problems associated with full depth headers
  Eliminates pre-outfitting and planning to install headers with sub-assemblies

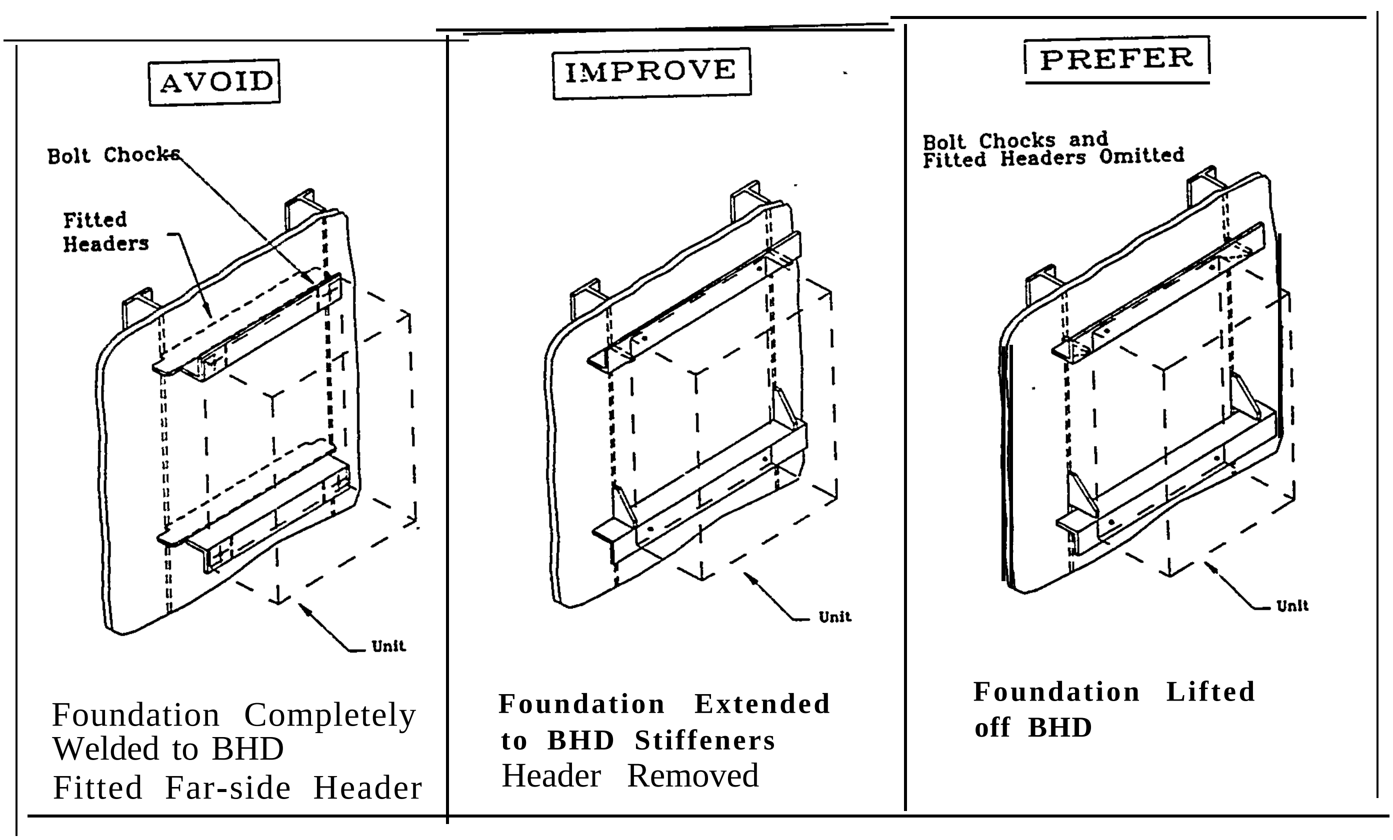


Figure: 7.2: Eliminate Far-side Headers & Lift Foundation Off BHD

- By emphasizing producible frame and truss type foundations and foundation configurations of minimum scantling thickness; the benefit:

  Reduce weld size/passes
  Elimination/reduction of prepared edges

- Simplify hull equipment items

  Redesign top and bottom connections on bins, racks, storage cabinets and furniture support items

- By the minimum use of bolt chocks and brackets, having the benefit of:

  - Minimizing cutting, handling, fitting, and welding small pieces

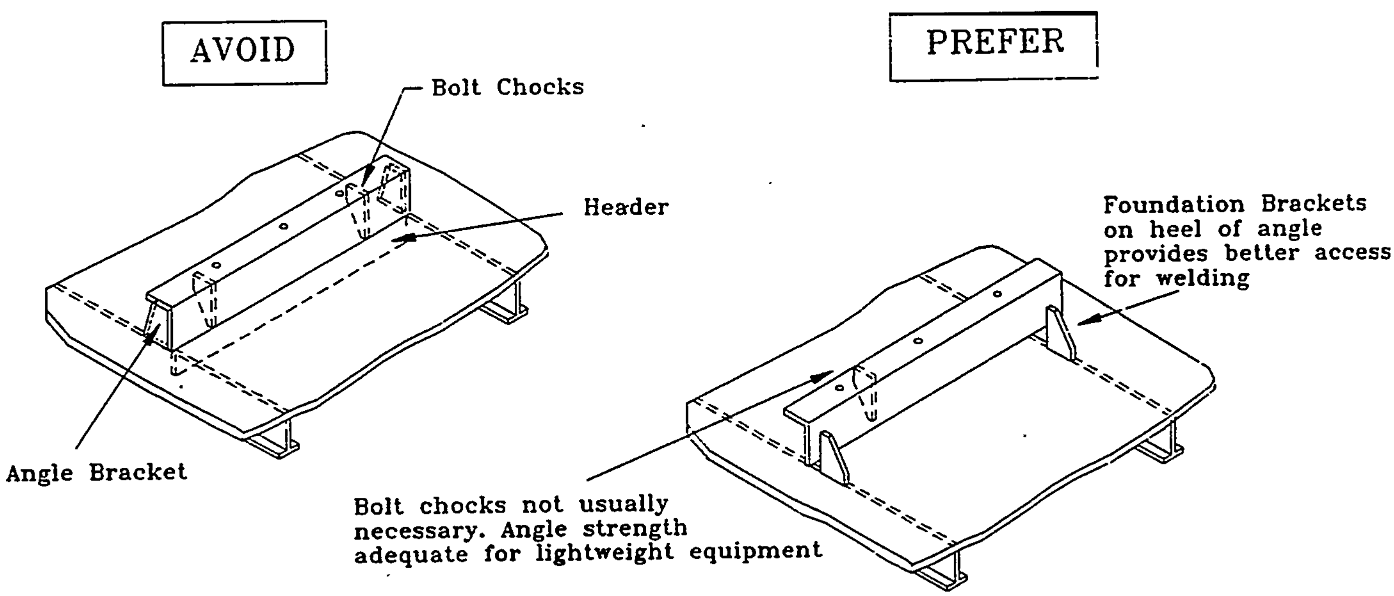


Figure 7.3 : Minimize Bolt Chocks and Brackets

- By the use of stud welding to the maximum extent possible including a unique approach using mounting plates installed with studs

- By utilizing "method mounting" standard foundation designs for lightweight equipment; the benefit:

  - Significantly reduces engineering analysis and construction time

7.2 Innovative Producibility Concepts

Producibility design concepts are inherently a part of structural optimization and are especially necessary to stay within the cost constraints of the final price of the specific ship or series of ships. While the majority of technical specifications strive to achieve the best technical solution for a given issue, the producibility design objective is to quantify the design performance requirements and to satisfy the requirement with an economical design solution.

The design of foundations specially for naval ships has become very complex. Vibration, stiffness, and shock criteria are but a few of the factors involved. In the past little analysis of fabrication methods had been conducted. Recently conducted studies provide quantitative guidance to the designer. Results of these studies indicate that combined shape and flanged plate construction result in least cost construction.

Steel foundations were categorized as to the type and then divided into two groups depending on the weight of components they support, for study. The conclusions are as follows:

1. In general shapes, especially angle bar, produce the least expensive construction
2. In somecases combining flanged plates and shapes may be less expensive.
3. In high weight equipment foundations weldments are approx. 60% more expensive than shapes.
4. In case of light weight foundations weldments are approx. 43% more expensive than shapes
5. Weldments and flanged plate construction tend to be 7% to 10% heavier than shape construction.
6. Do not use a flanged plate to replace a standard shape.
7. Consider flanged plates to replace weldments.
8. Weldments may be used where shapes and/or flanged plates are impracticable.

7.3 Foundation Integration with Hull Construction

There is great savings potential through foundation integration with hull construction. The methods used to achieve these savings should be intelligently implemented so that the performance and maintenance of the supported equipment is not compromised with.

- Eliminate back-up structure

  Lift foundations off structure
  Develop simple attachments
  Land on soft plating

- Employ standards for equipment foundations and systems

  Statistics and technology used to develop standard designs reduces/eliminates repetitive engineering
  Hi-tech manufacturing, flexible automation and robotics reduces labor and time for manufacturing standards
  Standards reduce/eliminate labor-overhead for handling small piece-parts
  Standards designed for installation simplicity reduce labor and time for installation
  Standards reduce sub-assembly erection, pre-outfit labor and overtime for ship construction

- Accelerate equipment and systems installations. This reduces time and achieves savings in overall time of construction

- Equipment shall not be supported directly on the shell or other structure exposed to gun blast, missile blast, wave impact, or propeller excited vibrations if the resulting distortion or vibration would damage the equipment or limit its performance.

- Foundation members that overhang supporting structure and extend onto deck or bulkhead plating shall be modified to prevent puncturing of the plating by end rotation. Means of accomplishing this include landing the foundation member on a pad to effect a smooth transition and to reduce the stress in the plating in way of the pad below the fatigue limit. Relative motion of the adjacent boundary structure and maximum permissible vibration amplitudes should be used to calculate the induced stresses in the plating at the edge of the pad. Pad geometry and thickness should be designed to minimize plating stress.

- Accessibility shall be provided for inspection and maintenance of equipment foundation structure and adjacent hull structure.

- Foundations shall be constructed to avoid pockets which can contain liquid. Openings shall be provided at the base of deck mounted equipment.

- Foundations shall be rigid enough to ensure that the requirements for limiting twist, bend, level and parallelism with the master datum as specified by equipment manufacturers are met.

- The rigidity of foundations and supporting structure shall be sufficient to prevent misalignment which would interfere with operation of the machinery and equipment, and to preclude excessive vibratory motion or rocking on the foundation.

- Foundations shall be designed to prevent misalignment or excessive strains due to thermal expansion under all operating conditions. Large units of machinery such as turbines, gears, generators, and condensers which must be aligned with connected equipment shall be installed in proper chocks.

7.4 Foundation Standards and Cost Reduction

Ship costing is an extensive task and involves innumerous iterations. Specific costing on foundations is hard to obtain because the foundation design, fabrication and installation include many processes. Handling, preparation, dead time are difficult to determine. Costing by measuring weight saved, weld length is too simplistic and will give erroneous estimation. An aggressive policy on foundation weight reduction combined with producibility initiatives to reduce the labor involved in fabrication and installation must be pursued and should be integral with the overall Weight Control Program.

A substantial extent of ship construction cost saving can be achieved by

1. Foundations, equipment, and ship system installations on critical path

2. Savings in time and cost of foundation and system hanger fabrication and installation

3. Savings in time and cost of equipment and system installations

4. Savings in time and cost of construction of sub-assemblies

5. Savings in overall time and cost of ship construction

The following steps highlight the means to achieve weight reduction and ship construction cost savings:

- Standardization of foundations to achieve cost savings

  Make foundations and ship system hangers more cost effective
  Foundations and ship system hangers are a small percentage of overall steel weight and outfit - however, relative cost is very high
  Historically - a great effort has been made to optimize primary hull structures. Little attention has been given to reducing the very high cost of foundations.
  Standardization of equipment foundations and system hangers using statistics and technology development will lead to significant reductions in fabrication cost and installation time
  Standard design and installation will lead to smaller shipyard schedule

- Time and cost savings design features

  Develop standard foundations for a variety of equipment
  Reduce welding
  Reduce material
  Reduced fabrication / fit-up
  Reduce installation time
  Unique cost savings installation techniques
    Weight savings potential: 45% to 50%
    Cost savings potential: 50% of welding
    Reduce number of pieces: 50%
  Develop simplified attachment techniques:
    Reduces time for installation of foundations
    Paves the way to install equipment and systems with their foundations
    Reduces sub-assembly construction time on critical path
  Reduces overall time for ship construction

- Additional cost savings can be achieved by incorporating the following change types as mentioned in the attached illustrations for weight and labor savings

  Lighter weight deck backup pads are used which are easier to fabricate and install. Coping of angle in way of pad is eliminated.
  Lighter weld is used, decreasing weld time
  Snipe size is reduced, allowing a single continuous weld on each side of the chock to be used. Weld wrap around the chock at each side of the snipe opening is eliminated.
  Delete backup pads, save fabrication, fit up and weld time
  Delete angle stiffening chocks, save fabrication, fit up, and weld time
  Lifting angle off of deck or bhd
    Deleted cope and pad at ends of angle, saving pad fabrication and installation, saving coping of angle.
    Eliminate welding of angle to deck or bhd. Raised angle allows for complete painting without requiring complete seal Welding. Fit up to irregular surface is simplified since only the chocks need be trimmed at installation.
  Relocate chock from bosom of angle to heel
    Eliminates trimming to fit between flange and deck or bhd plate
    Decreases welding by 1/3
  Delete chock, reduces material and fabrication, installation and weld time
  Deleted angle header, eliminates fabrication of header, fit and weld
  Extend chock past flange of angle, eliminate snipe on backside of chock
  Reduce thickness of pad or chock, reduces fabrication time, reduces weld required
  Delete flat bar
  Replaced welded support fabricated from pipe with a double ended shot stud, fabrication and weld of length of pipe is eliminated. Electrician isenabled to install foundation, since a shot stud is used rather than a welded foundation, pipe fitting trade is eliminated from process, fitting and welding trades are eliminated from installation process. Stud welding saves fitting and welding time.
  Replaced angle and F.B. foundation with 4 threaded shoulder studs. Fabrication, fitting and welding of foundation are eliminated. Electricians can install foundation, eliminating the requirement for several trades to complete each foundation. Templating time when studs are shot is offset by templating and drilling time at time of equipment installation. Blast, paint, and insulation in way of studs is facilitated.

FOUNDATION PRODUCIBILITY PREFERRED DESIGN DETAILS

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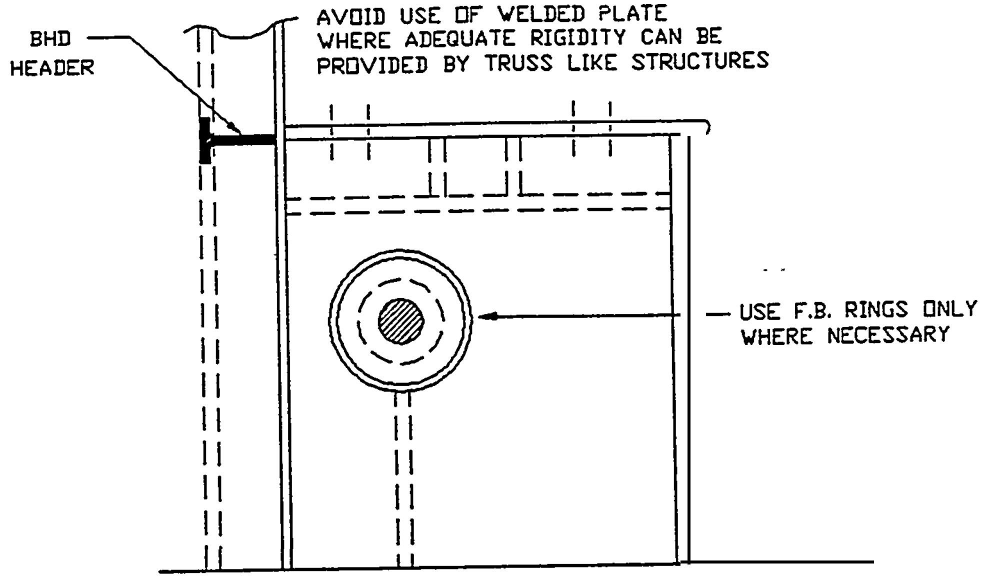

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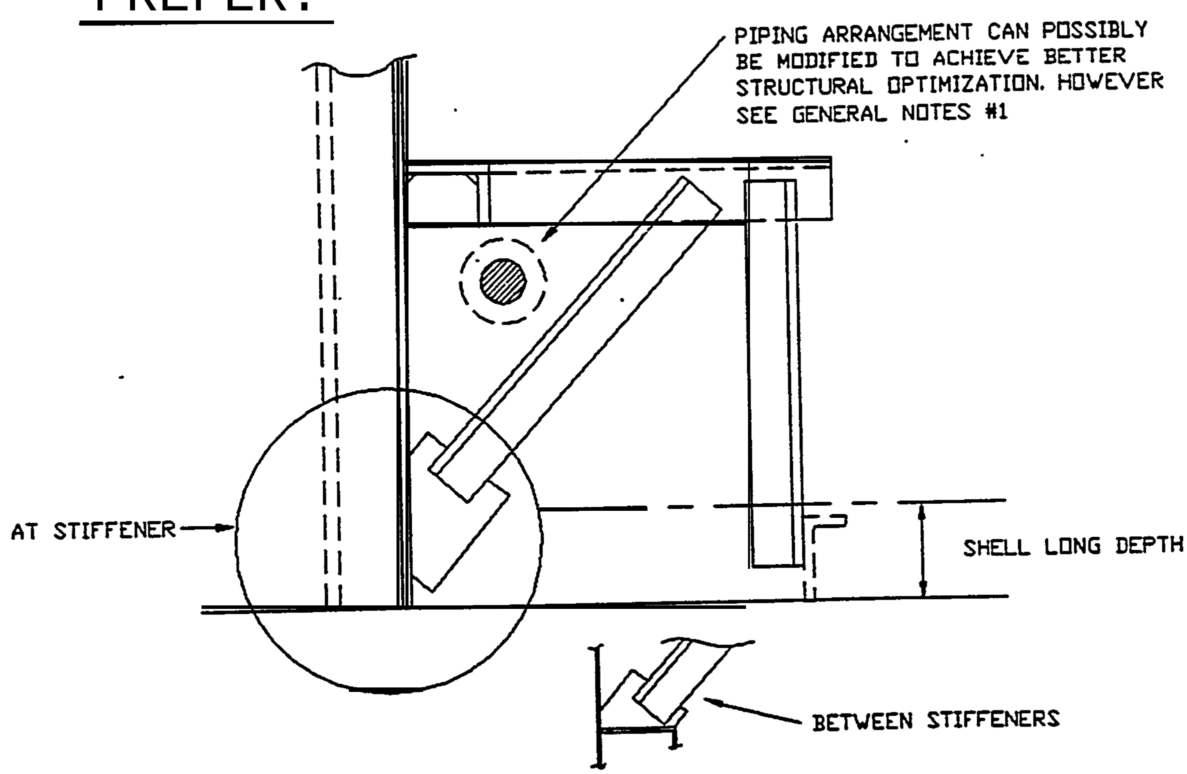

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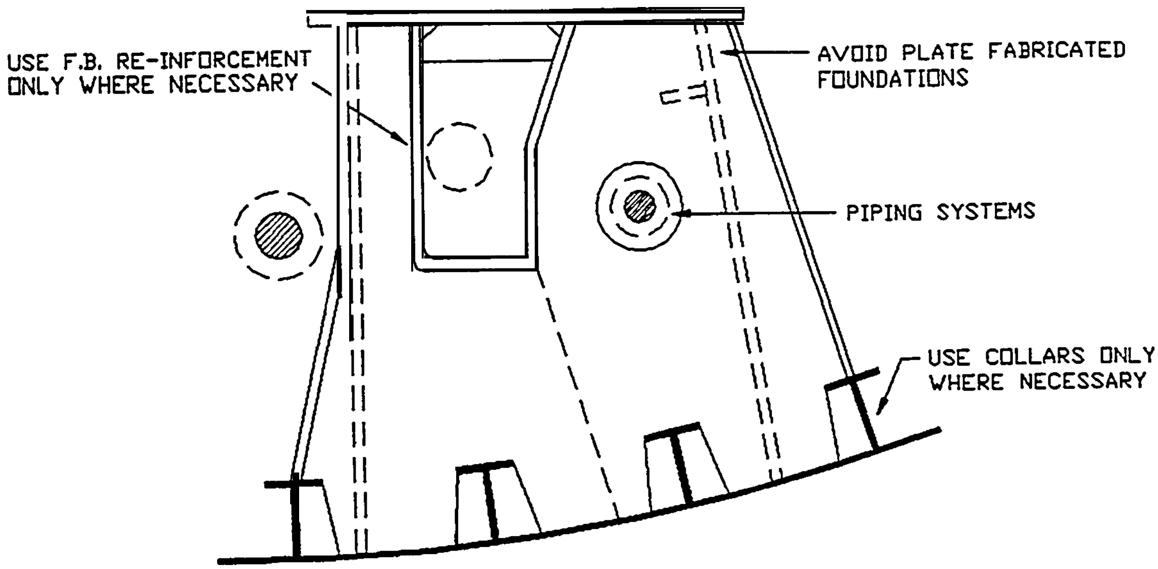

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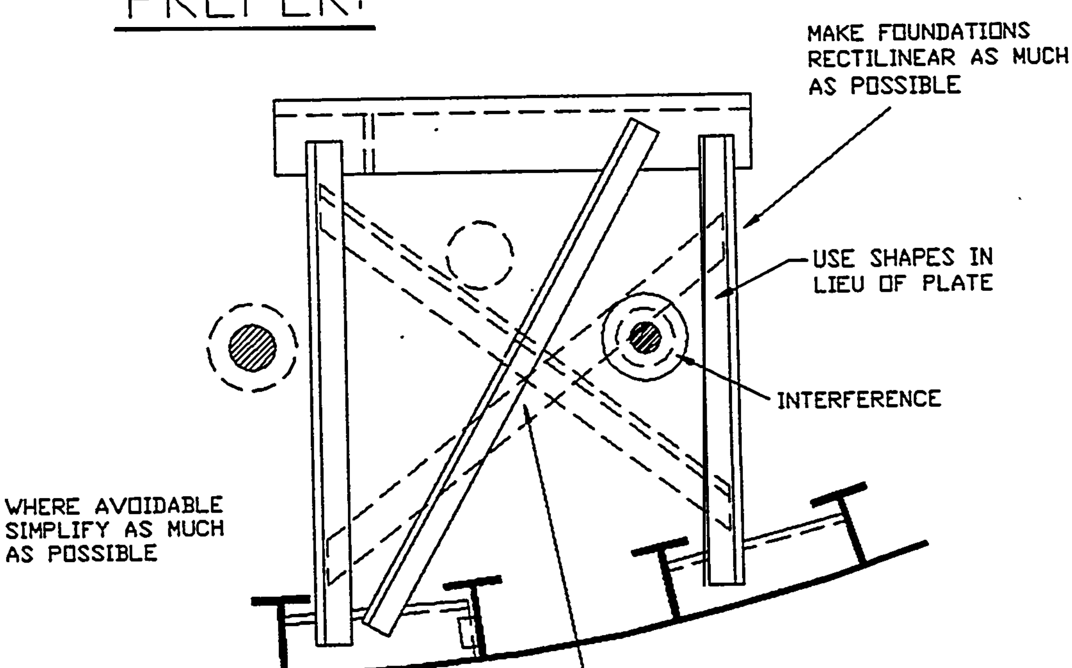

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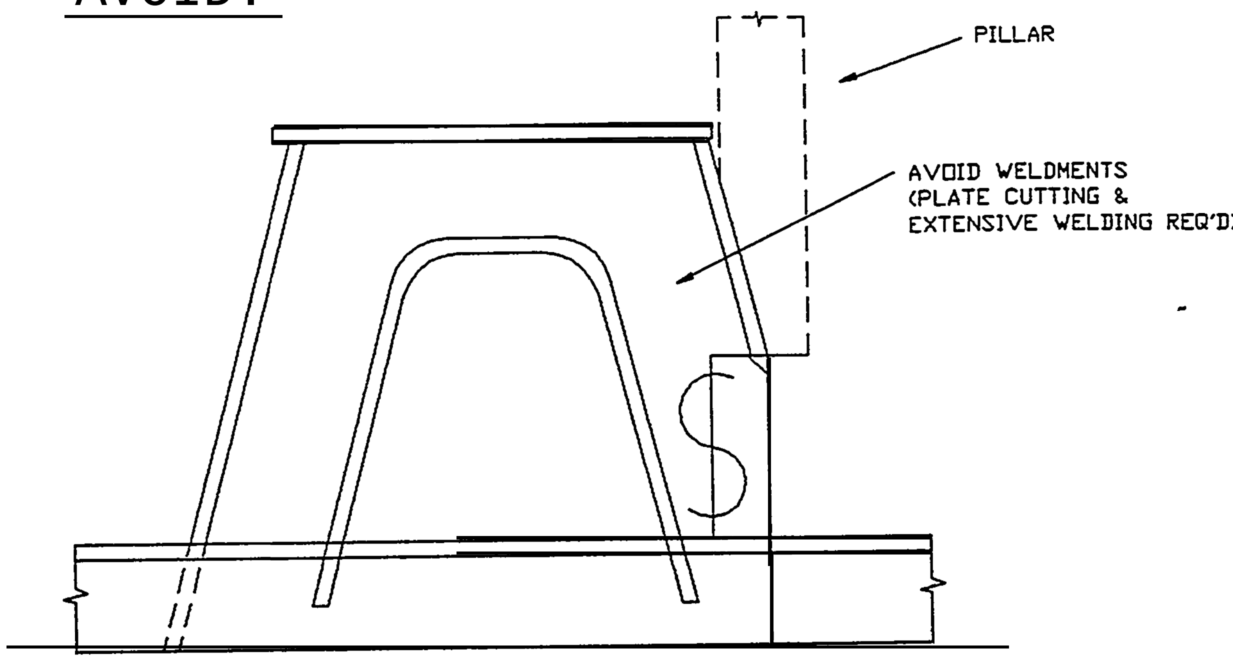

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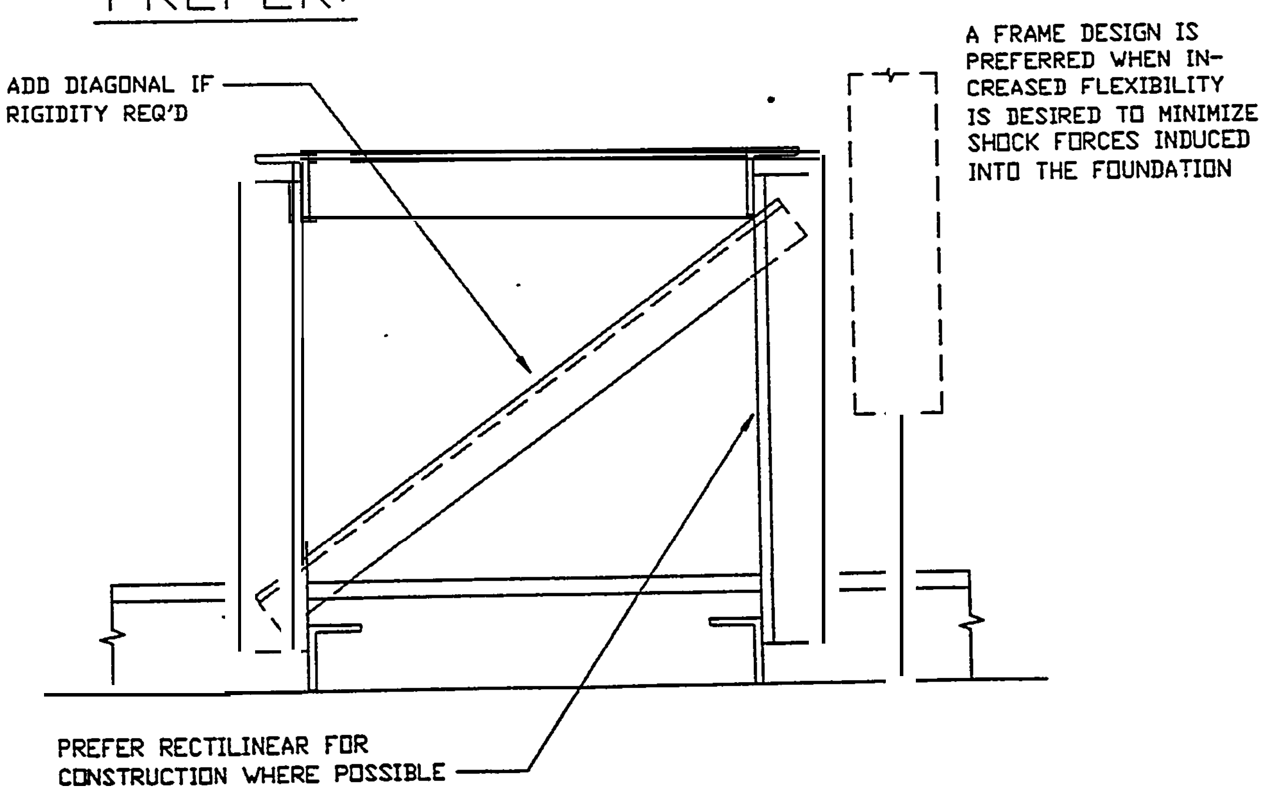

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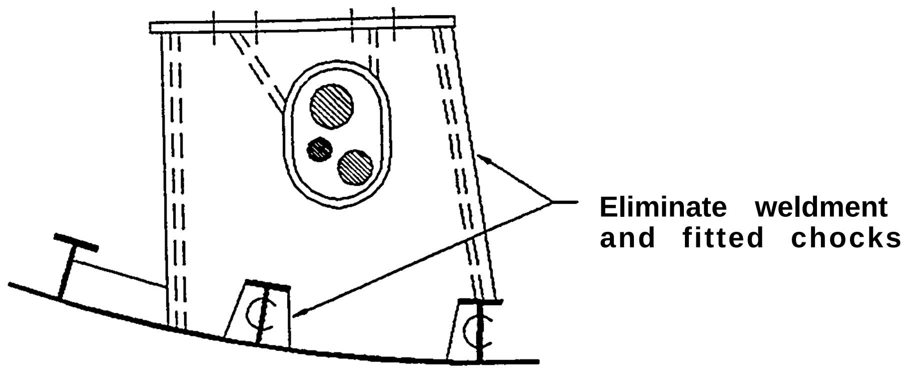

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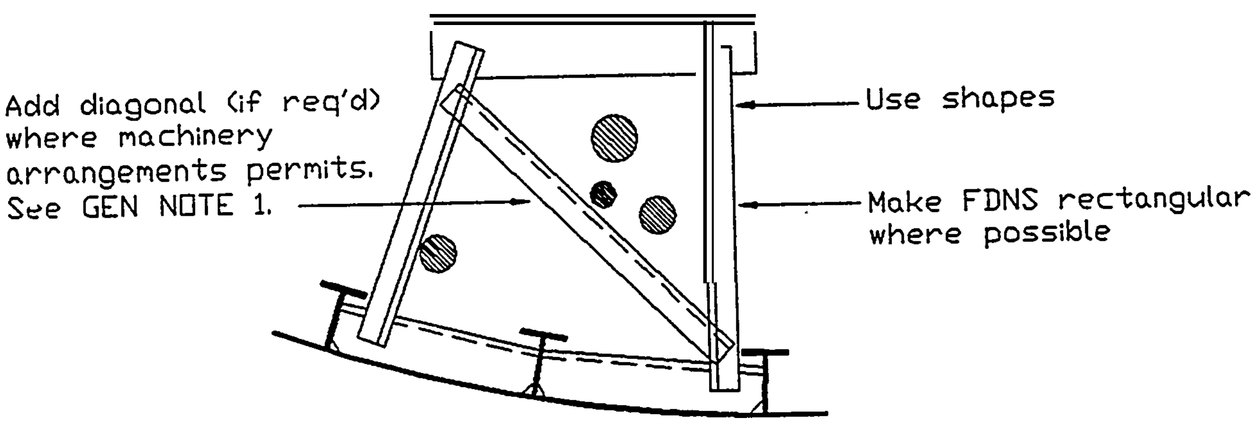

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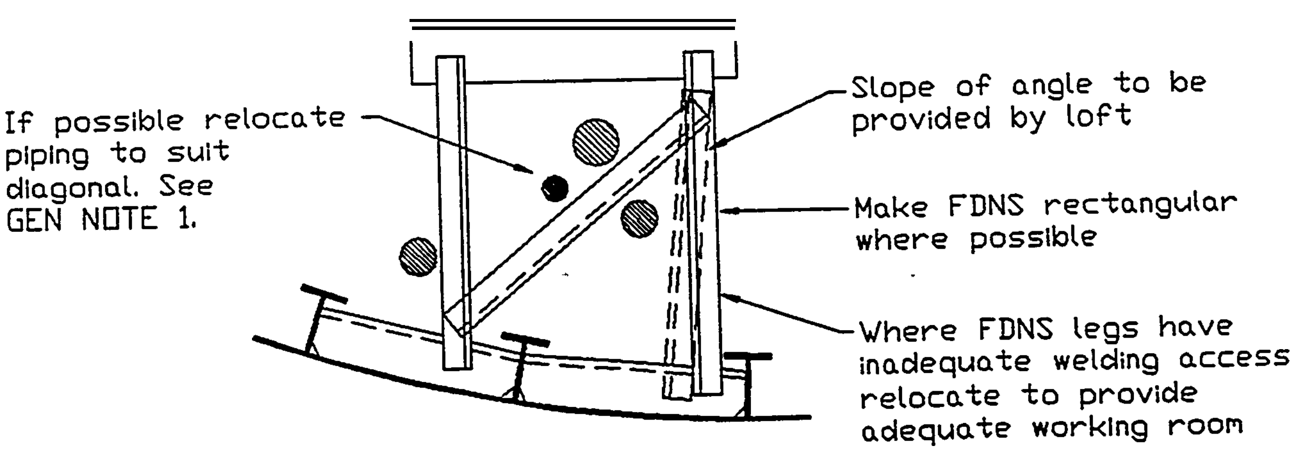
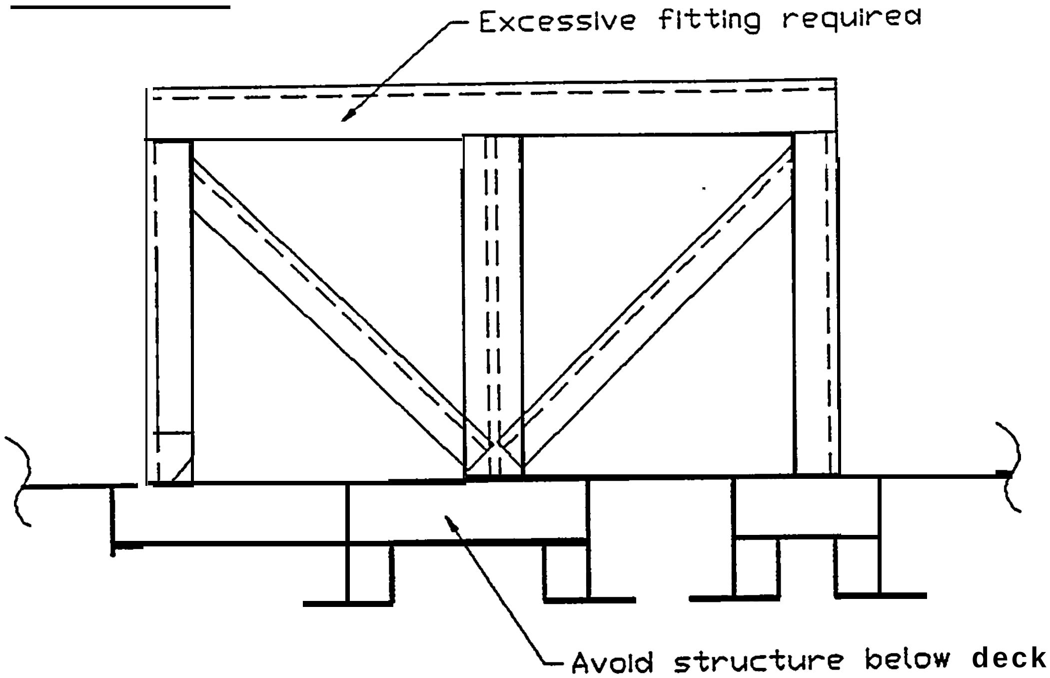


FOUNDATION PRODUCIBILITY PREFERRED DESIGN DETAILS

AVOID:



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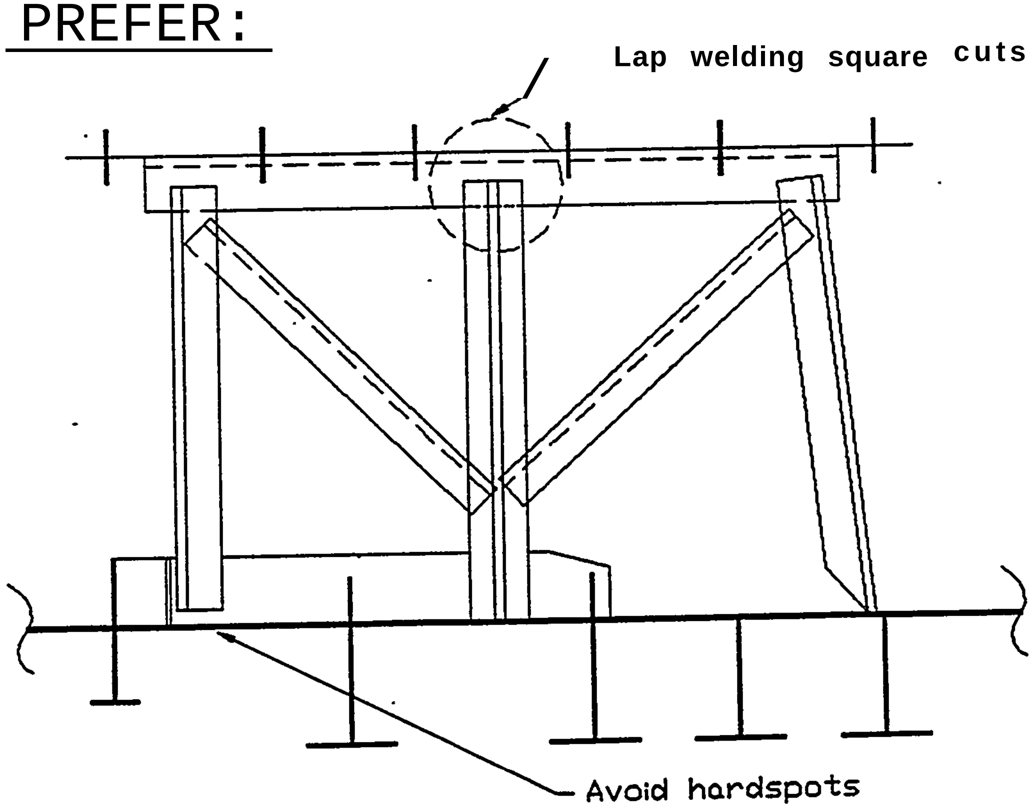
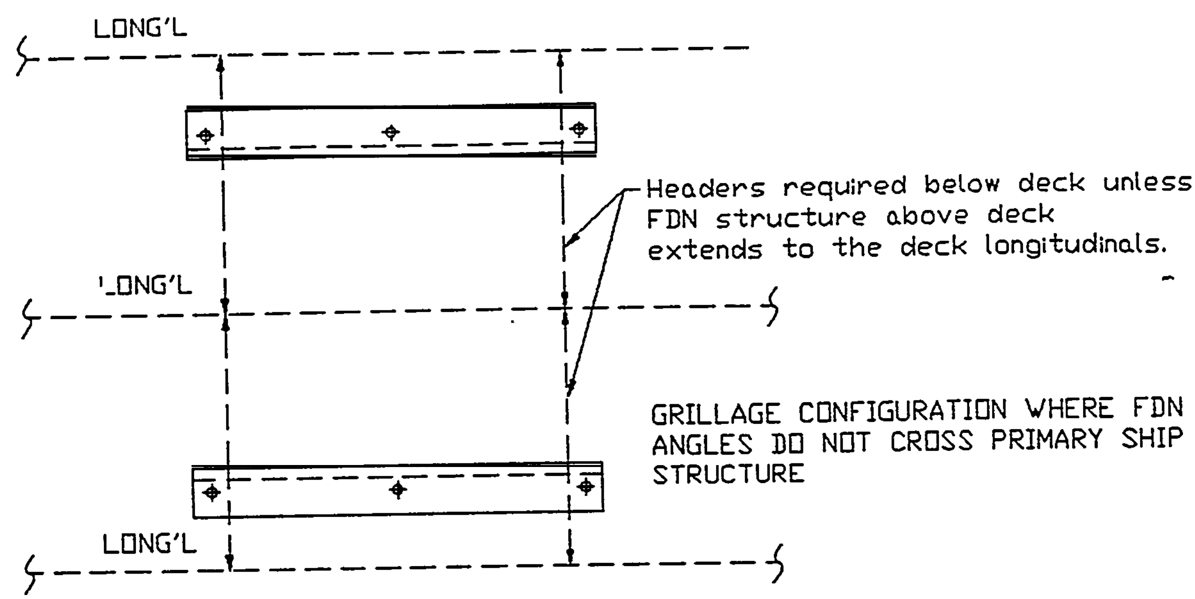


FOUNDATION PRODUCIBILITY PREFERRED DESIGN DETAILS

AVOID:



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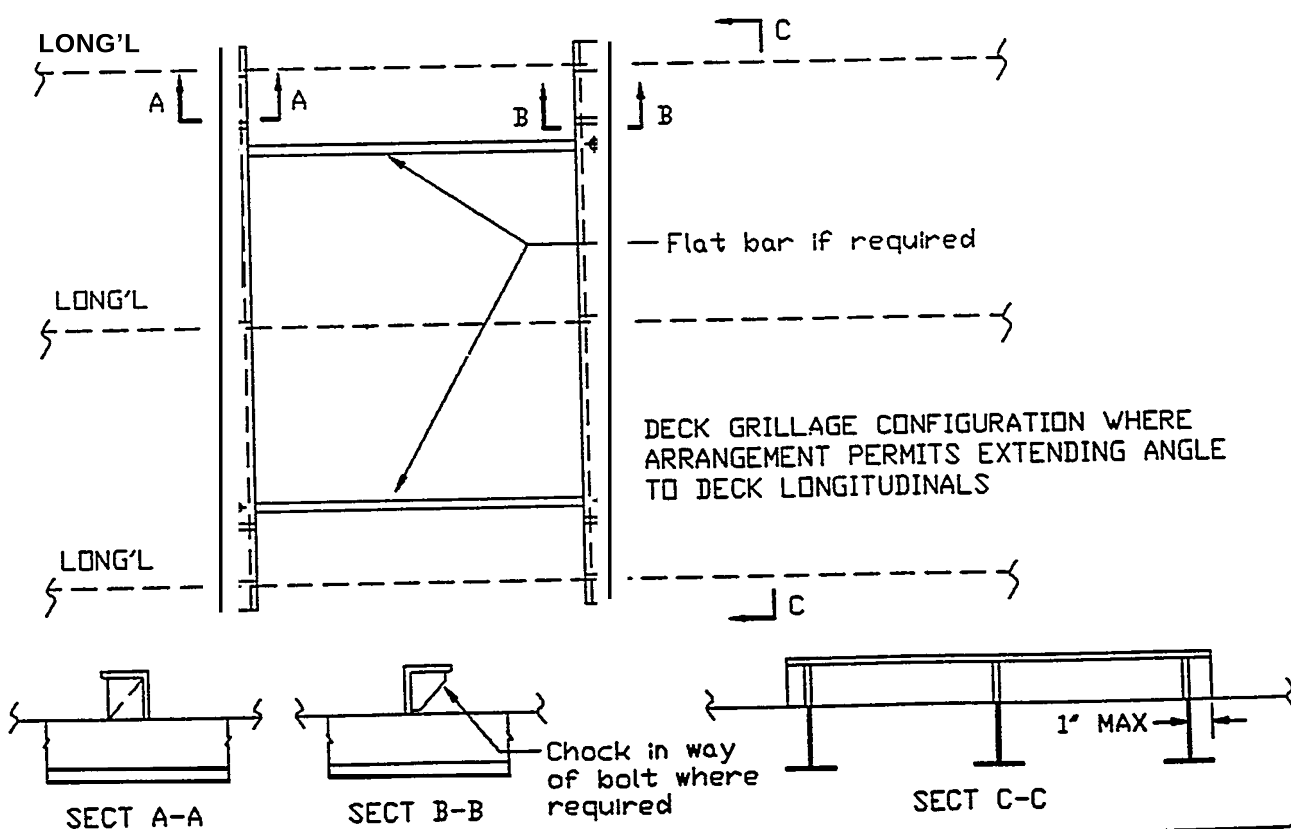
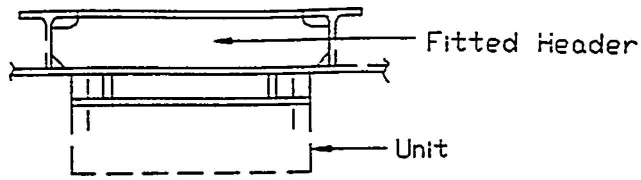


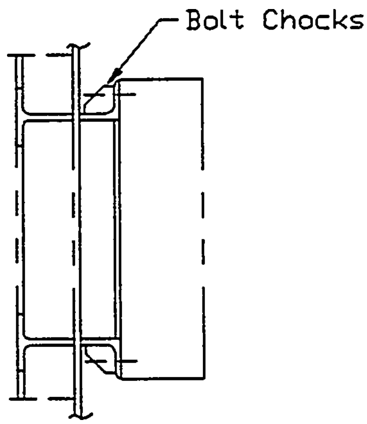
FOUNDATION PRODUCIBILITY
PREFERRED DESIGN DETAILS

AVOID:

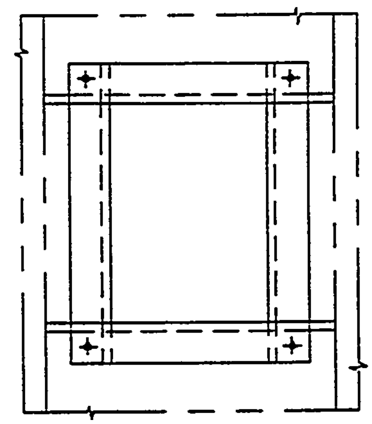
FOUNDATION COMPLETELY
WELDED TO BULKHEAD



PLAN VIEW



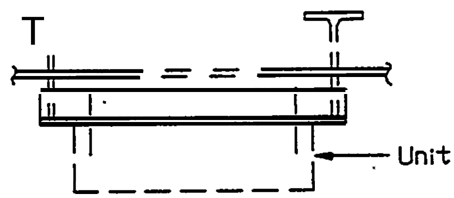
SECTION



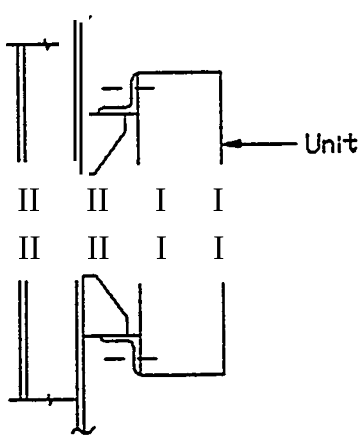
ELEVATION

PREFER:

FOUNDATION LIFTED
OFF BULKHEAD

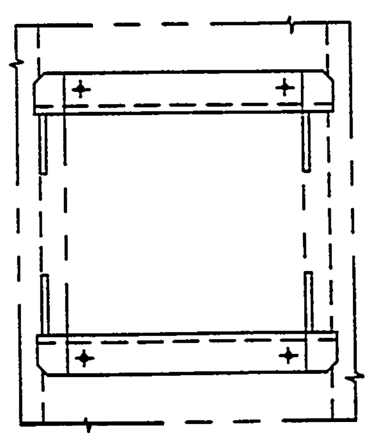


PLAN VIEW



SECTION

Bolt Chocks &
Fitted Headers
Omitted

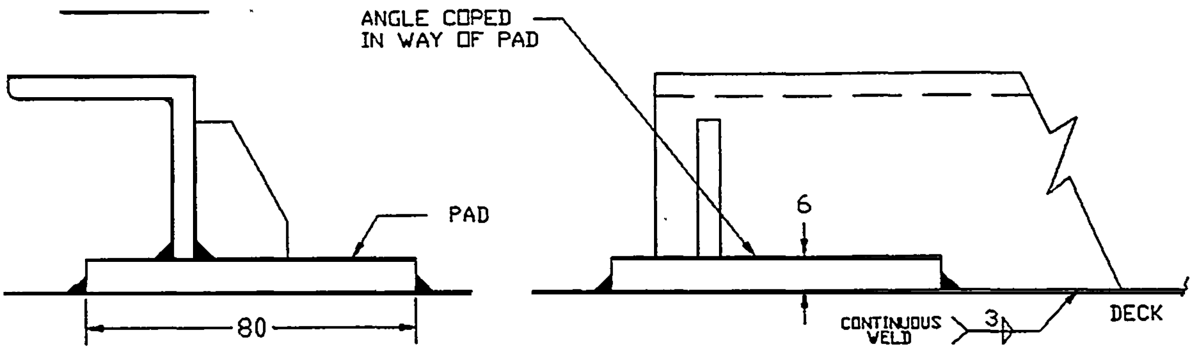


ELEVATION

LABOR SAVINGS ILLUSTRATION

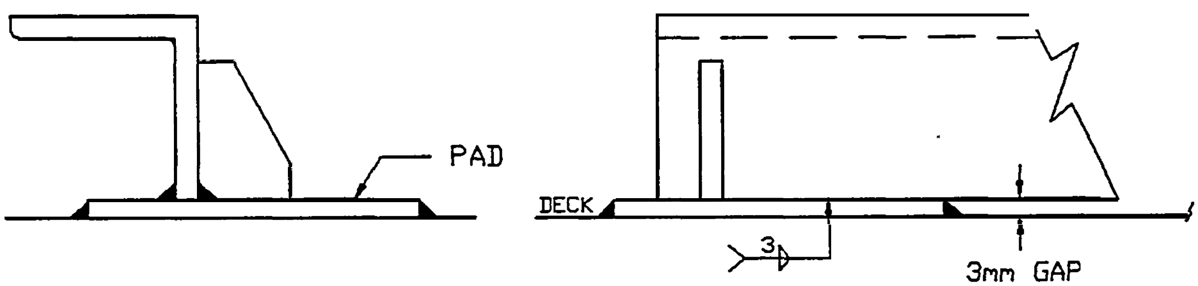
CHANGE TYPE : 1 (LIFTING ANGLE OFF DECK OR BHD)
(SEE "LABOR SAVINGS TYPICAL DESCRIPTIONS")

WAS:



PROFILE   ELEVATION

IS:



DESCRIPTION OF LABOR SAVED

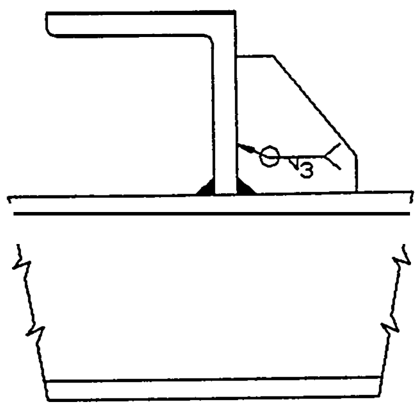
Lifting the angle off the deck involves welding the angle to the top of a small pad or to the side of a chock. This way the angle does not need to be coped in way of the pad. Also, this method saves significant welding time because the angle does not need to be continuously welded to the deck. This method saves even more fitting time in the case of an irregular surface in way of the angle. The raised angle allows for complete painting of the angle without requiring complete seal welding to the deck.

Lifting an angle off a bulkhead implies equivalent savings.

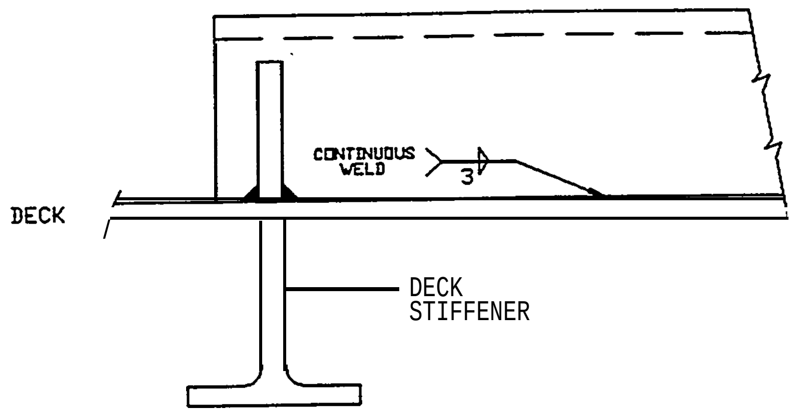
LABOR SAVINGS ILLUSTRATION

CHANGE TYPE : 1 (LIFTING ANGLE OFF DECK OR BHD)
(SEE “LABOR SAVINGS TYPICAL DESCRIPTIONS”)

WAS:

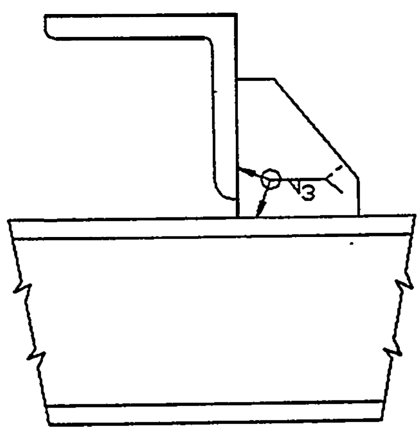


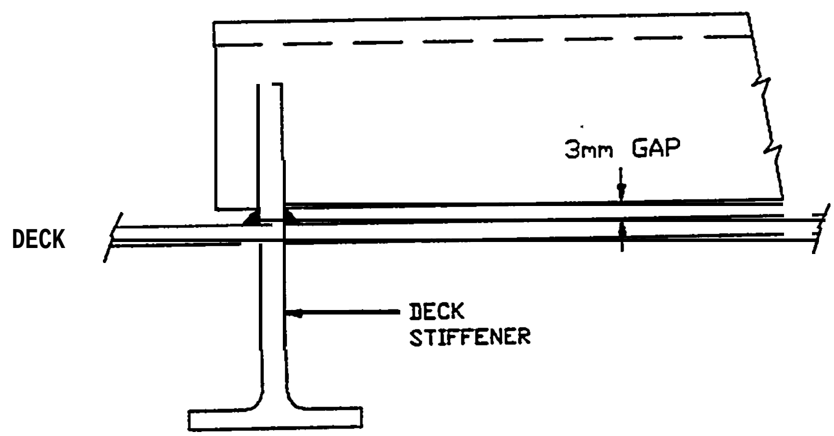
PROFILE



ELEVATION

IS t



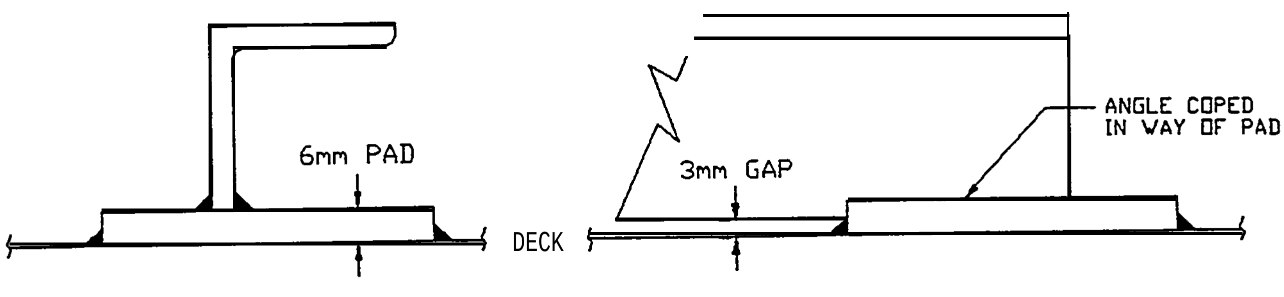


ALTERNATE APPLICATION
(NO DECK PADS)

LABOR SAVINGS ILLUSTRATION

CHANGE TYPE : 2 (REDUCE PAD THICKNESS, ELIMINATE COPE))
(SEE "LABOR SAVINGS TYPICAL DESCRIPTIONS")

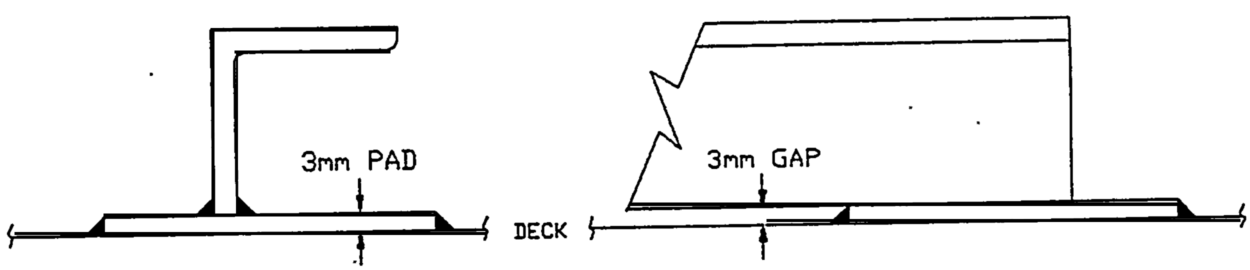
WAS:



PROFILE

ELEVATION

IS

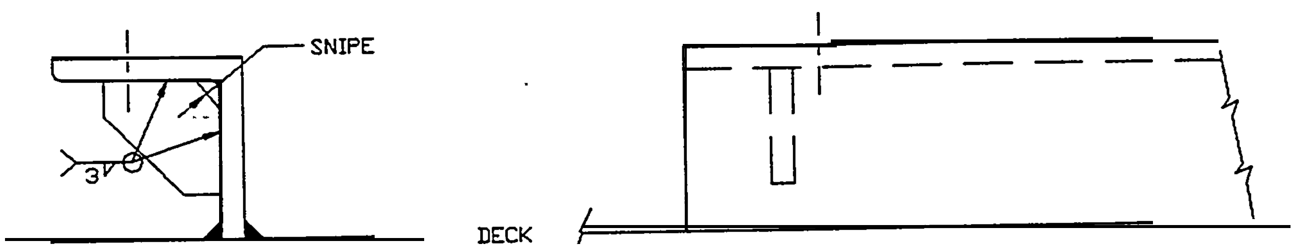


Reducing the thickness of the pad saves material costs because a smaller, thinner pad requires less material. Fabrication time is saved because a thinner pad is easier to cut. The angle does not need to be coped out in way of the pad, so the fit-up time of the foundation is reduced. Welding time is saved because the circumference of the pad is reduced.

LABOR SAVINGS ILLUSTRATION

CHANGE TYPE : 3 (DELETE **ANGLE STIFFENING BRACKETS)**
(SEE "LABOR SAVINGS TYPICAL DESCRIPTIONS")

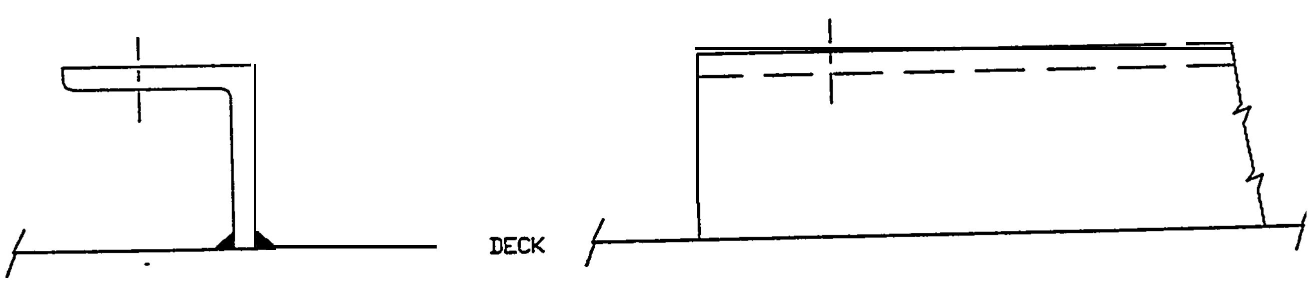
WAS:



PROFILE

ELEVATION

IS

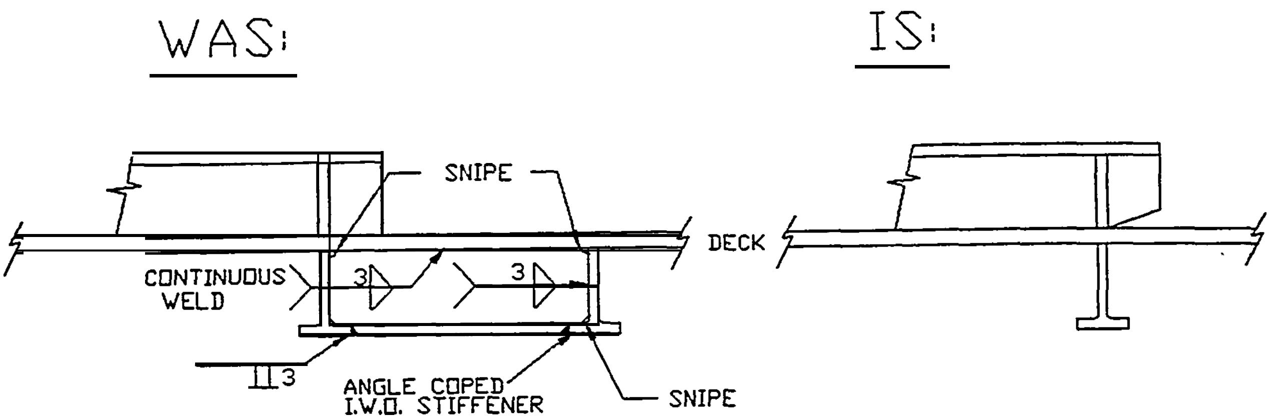


DESCRIPTION OF LABOR SAVED

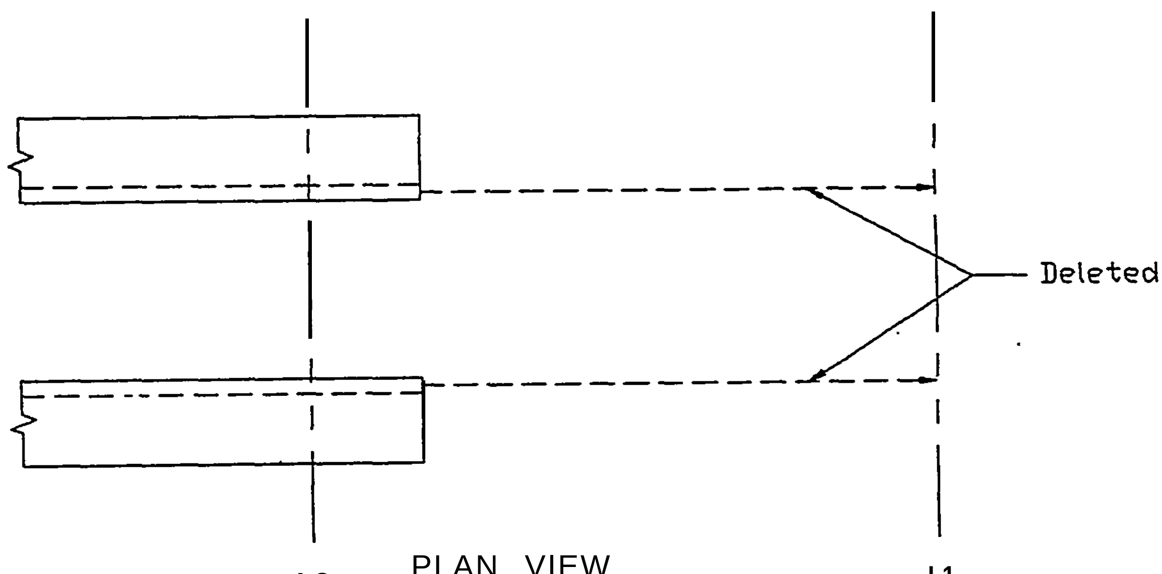
The deletion of a chock means that the material for the chock does not need to be acquired. The chock does not need to be fabricated, saving cutting time. The locations for the chocks do not need to be found aboard ship, and the chocks do not have to be welded into the bosom of the angle.

LABOR SAVINGS ILLUSTRATION

CHANGE TYPE : 4 (DELETED ANGLE HEADER)
(SEE "LABOR SAVINGS TYPICAL DESCRIPTIONS")



ELEVATION



PLAN VIEW

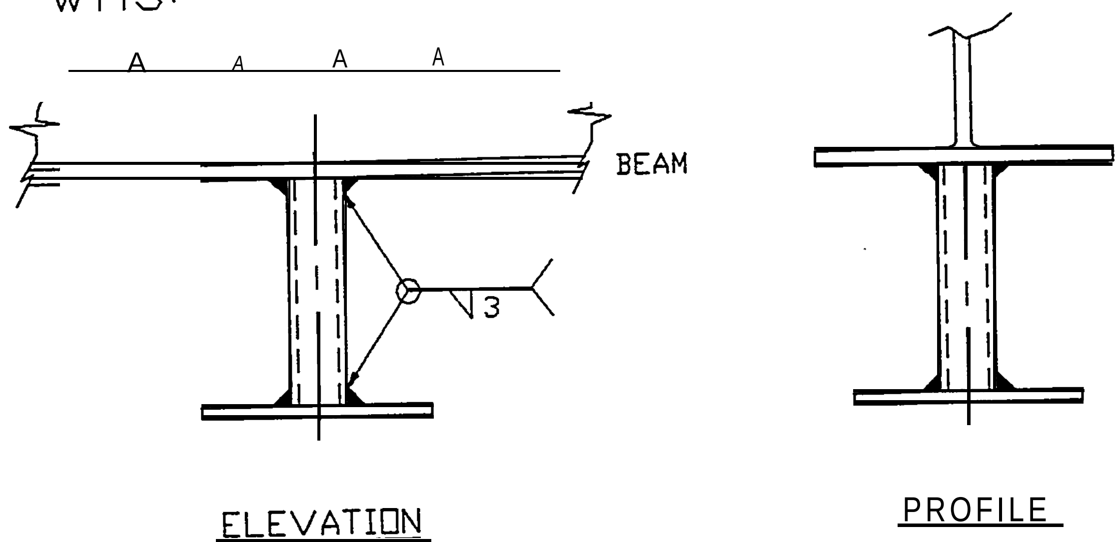
DESCRIPTION OF LABOR SAVED

Deletion of an angle header saves material costs and fabrication time, because the matelal does not need to be acquired or cut. Significant fit-up time is saved because the angle does not need to be coped out, cut-to-fit, and sniped to fit between two stiffeners. Significant weld time is also saved because the angle in question does not need to be welded on five edges, in hard-to-reach places.

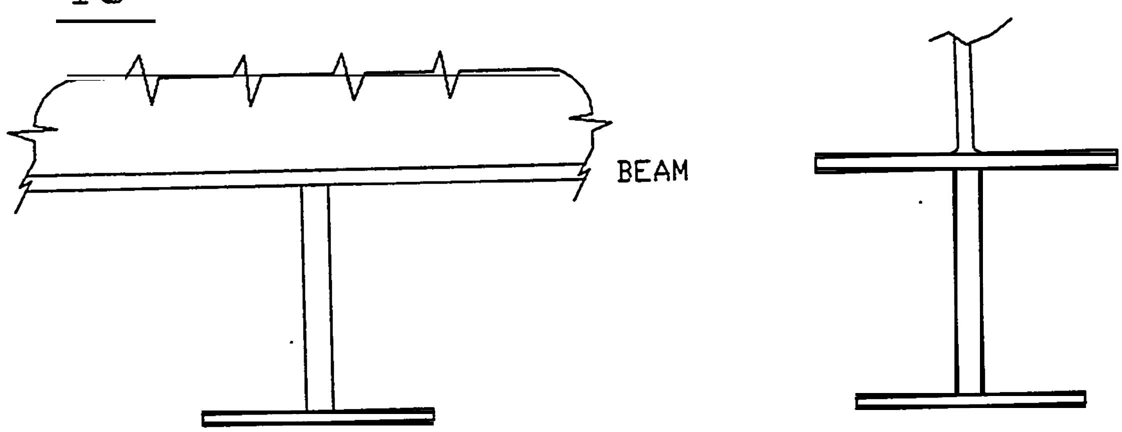
LABOR SAVINGS ILLUSTRATION

CHANGE TYPE : 5 (REPLACE PIPE FABBED FDN WITH A STUD)
(SEE “LABOR SAVINGS TYPICAL DESCRIPTIONS”)

WAS:



IS:



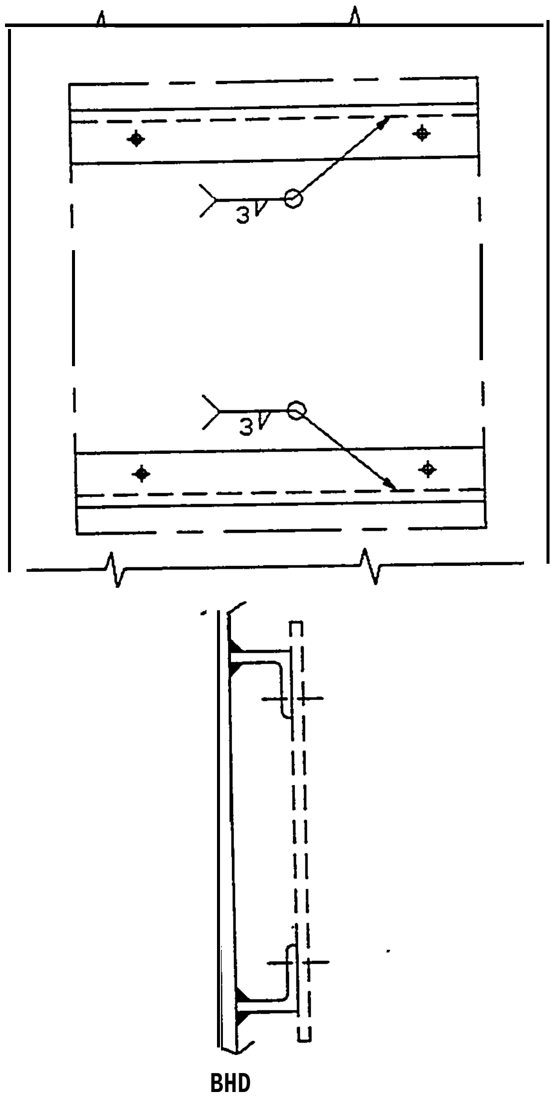
DESCRIPTION OF LABOR SAVED

Replacing the pipe with a stud significantly reduces fabrication time, because the stud is pre-fabbed. There is no need to cut the pipe to the right length. Installation time is also significantly reduced because there is no need to weld the pipe to the stiffener and the flatbar. There is only a double-flux stud to be shot, which can be done by an electrician. An electrician can install the whole foundation by himself, while the pipefitting and welding trades are completely eliminated from the process.

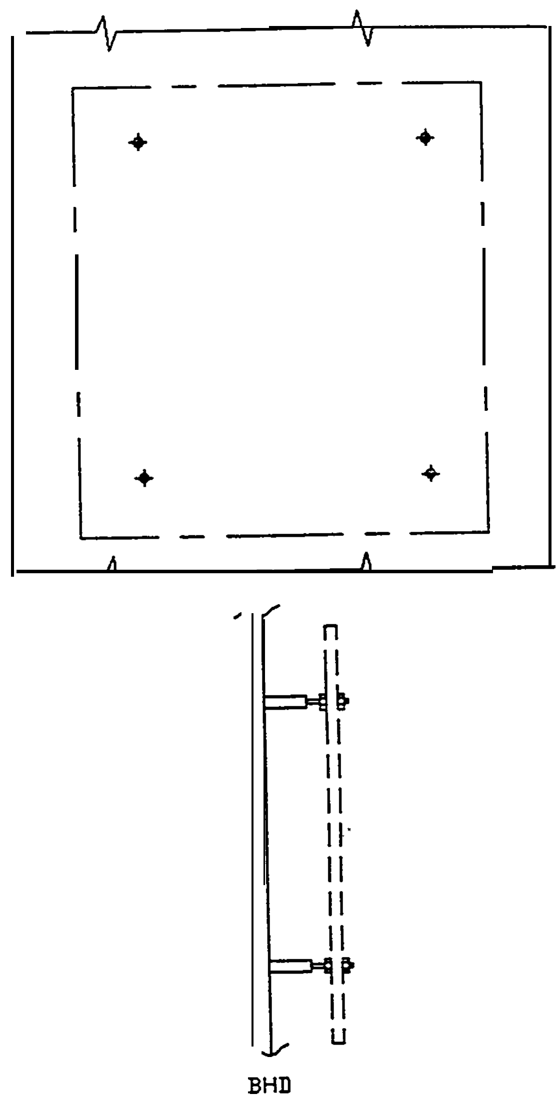
LABOR SAVINGS ILLUSTRATION

CHANGE TYPE : 6 (REPLACE ANGLE FOUNDATION WITH STUDS)
(SEE "LABOR SAVINGS TYPICAL DESCRIPTIONS")

WAS:



IS:



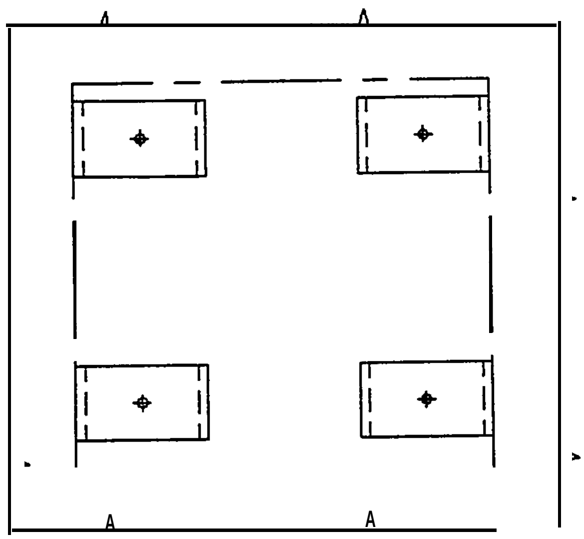
DESCRIPTION OF LABOR SAVED

Replacement of angle bars with studs significantly reduces material cost because angle bar need not be acquired. Fabrication cost is significantly reduced because the studs are pre-fabbed. Fit-up time is reduced because there is no need to locate the positions of the foundations aboard the ship. Weld time is eliminated because there is no need to weld anything. An electrician can install the entire foundation by himself, and the fitting and welding trades are eliminated from the process.

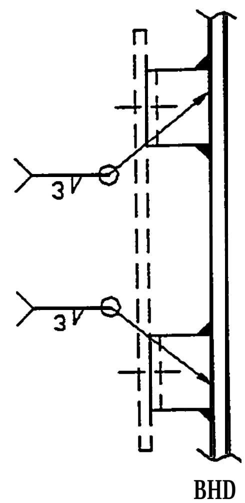
LABOR SAVINGS ILLUSTRATION

CHANGE TYPE : 6 (REPLACE FLAT BAR **FDN WITH STUDS)**
(SEE "LABOR SAVINGS TYPICAL DESCRIPTIONS")

WAS:

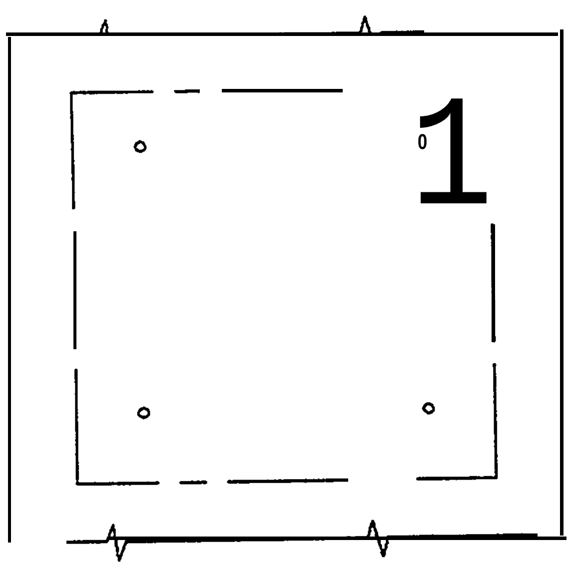


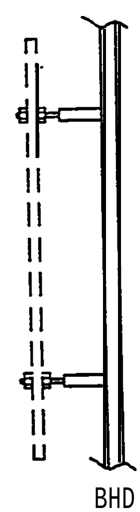
ELEVATION



PROFILE

IS:



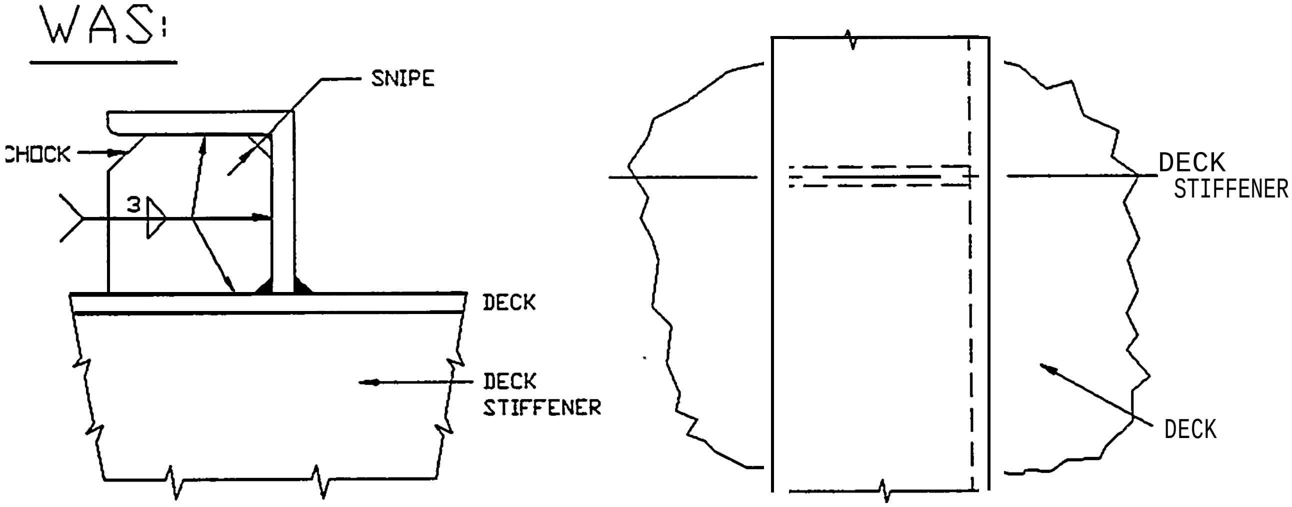


ALTERNATE APPLICATION

LABOR SAVINGS ILLUSTRATION

CHANGE TYPE : 7 (RELOCATE CHOCK TO HEEL OF ANGLE)
(SEE "LABOR SAVINGS TYPICAL DESCRIPTIONS")

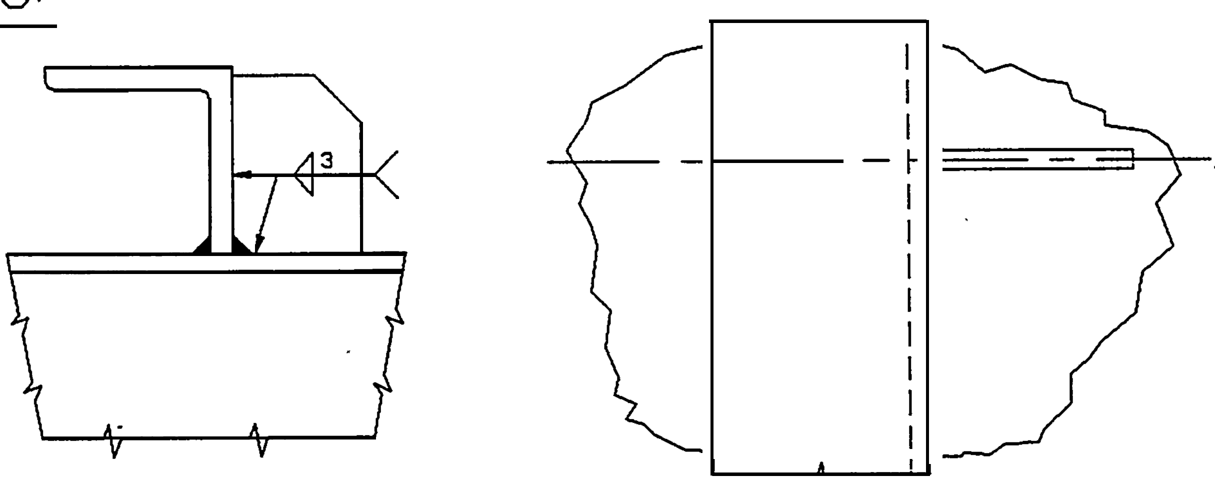
WAS:



PROFILE

PLAN VIEW

IS:



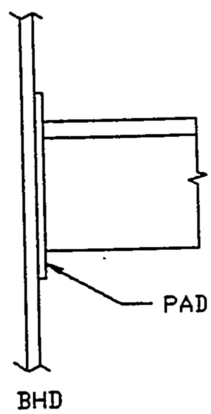
DESCRIPTION OF LABOR SAVED

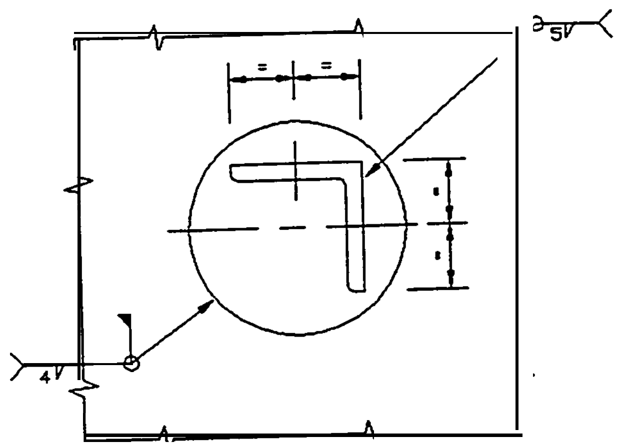
Relocating a chock from the inside of an angle to the outside saves Fabrication time because the chock does not need to be sniped, and the chock does not need to be trimmed to fit between the angle and the deck. Relocation to the outside also saves welding time because it requires 1/3 less welding to adequately attach the chock to the angle and the deck or bulkhead.

LABOR SAVINGS ILLUSTRATION

CHANGE TYPE : 8 (DELETE BACKUP PADS)
(SEE “LABOR SAVINGS TYPICAL DESCRIPTIONS”)

WAS:

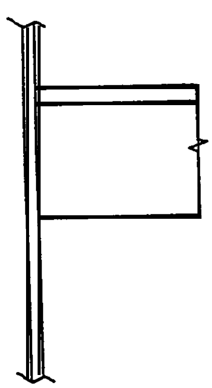




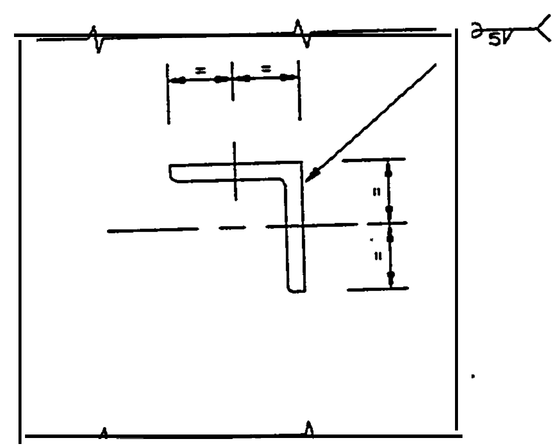
ELEVATION

PROFILE

IS:



BHD

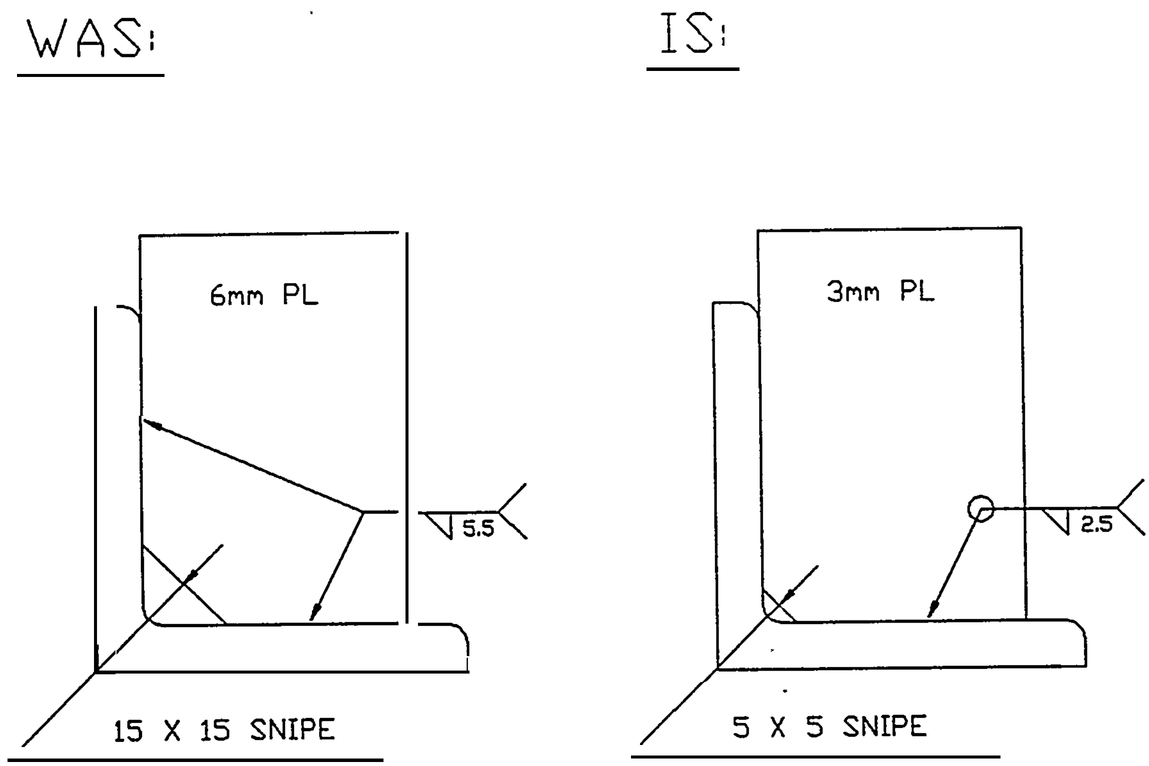


DESCRIPTION OF LABOR SAVED

Deletion of backup pads eliminates need for fabrication, so material costs are reduced, The process of cutting the pad material, finding pad locations aboard the ship, and welding the pads to the deck is eliminated, saving significant labor on each pad.

LABOR SAVINGS ILLUSTRATION

CHANGE TYPE : 9 (SNIPE SIZE DECREASED)
(SEE "LABOR SAVINGS TYPICAL DESCRIPTIONS")



DESCRIPTION OF LABOR SAVED

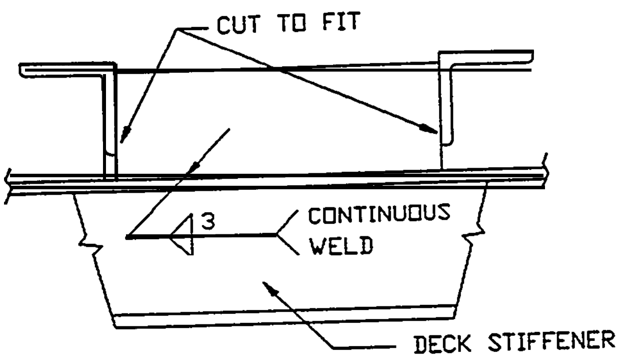
A smaller snipe allows for a single, continuous weld on each side of the chock as an adequate attachment to two sides of an angle. A single weld eliminates weld wrap-around at each side of the snipe opening. This saves significant weld time per piece.

Problems with Q.A. approval of weld wrap at the snipe are eliminated along with elimination of associated rework after inspection.

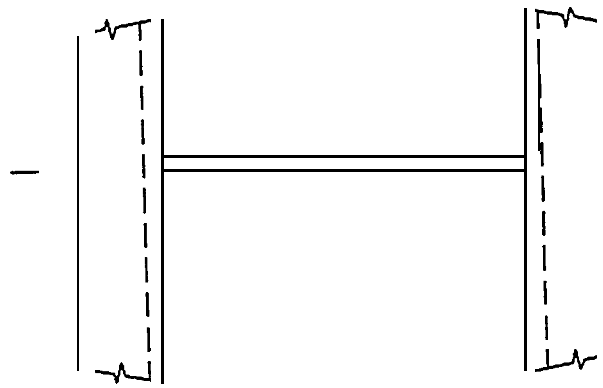
LABOR SAVINGS ILLUSTRATION

CHANGE TYPE : 10 (DELETE FLAT BAR)
(SEE "LABOR SAVINGS TYPICAL DESCRIPTIONS")

WAS:

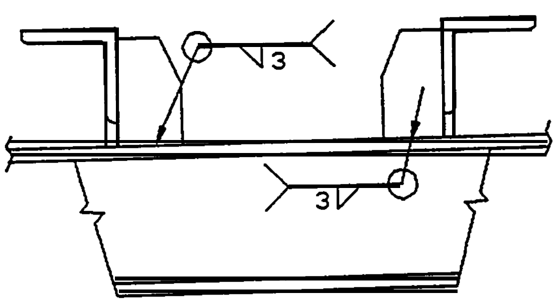


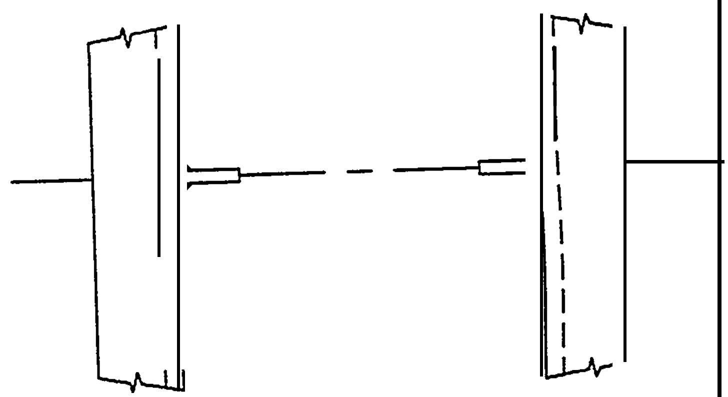
ELEVATION



PLAN VIEW

IS:





DESCRIPTION OF LABOR SAVED

Deletion of the flatbar (to be replaced with chocks) will save material costs because the chocks will require less material than the flat bar. Fit-up time is reduced because the chocks need not be cut to fit between the two angles, Welding time is also reduced because the length of the weld to the deck is shorter with the chocks.

8.0 TECHNICAL APPROACH

This section provides a description of the design requirements, criteria and specifications used in this design manual. The design data sheets and view-graphs in Section 9.0 are based on these design specifications. Some innovative design and analysis approaches are given towards producible and standard foundation engineering. The design methodology elaborated in a latter section describes an integrated approach using the design data sheets and how to modify the design to meet the specific design requirements.

8.1 Criteria, Requirements and Specifications

SHIP MOTION LOADING -- The strength of commercial ship foundations is typically governed by accelerations resulting from ship motions in a seaway. Ship specifications typically specify formulas for determining accelerations at different locations on the ship based on heave, surge, roll, pitch, and yaw motions. These "g" values or multiples of the weight to be supported are based solely on ship motions and equipments' location and do not vary with equipment weight or foundation stiffness.

It should be noted that a factor of safety should be used in the design of foundations limited by ship motions. This factor of safety helps ruggedize the foundation against other environmental loads such as pounding, wave slamming, and forces due to weather elements (wind, ice and snow) and helps avoid fatigue-related problems resulting from a design based purely on strength requirements. For combatants the shock induced forces generally produce the greatest load the foundations may experience, thus driving the design requirements, even then cyclic loading, fatigue and other factors may also affect the design of the foundations.

A conservative approach would be to allow the foundation to be loaded up to 50% of the material yield strength due to the worst ship motions. Since ship motions typically produce 2-3 times the static load, a foundation designed to this criteria would be able to support at least 4-6 times the static load. In design data sheets the seaway loading or the equivalent acceleration values of 3 g's vertical, 1.5 g's transverse and 0.75 g's longitudinal are used,simultaneously.

ADDITIONAL LOADS -- Foundations must be able to support attached equipment and a variety of additional loads and redistribute them into the hull structure. Weights of machinery and equipment, including liquids at operating levels and one half of the unsupported lengths of connected piping and cables, plus the dynamic effects of ship motion and vibration shall be included in the foundation assessment.

VIBRATION -- Vibration issues affecting foundation systems are those resulting from hull girder excitation caused by propeller forces on the hull and from deck vibration excitations initiated by unbalanced forces in rotating machinery, structure/machinery resonance conditions or both. Reduction and/or control of structural response to the source of the excitations is essential since excessive vibration can appreciably affect the proper functioning of the supported components, can lead to damage of ship structure, machinery, equipment or systems. Vibration is also a problem when it interferes with personnel safety, comfort or proficiency. There are foundation detail design requirements for vibration that evolve from the specifications and the shipbuilder's plan for implementing the requirements.

Any unsatisfactory condition resulting from the excitation of a resonant frequency in any equipment by the propeller or other exciting force shall be corrected by local stiffening of structure, by installation of suitable mountings, by modification of components, or other effective means. Means of preventing excessive vibration during normal ship operating conditions should be anticipated and incorporated in the design and construction of the ship. The correction of a resonance problem in a finished ship can be a very costly and time consuming effort.

The objective of a vibration analysis is to avoid vibratory resonances. The vibratory driving frequencies normally considered include: (1) ship's blade rate, (2) ship's primary hull modes, and (3) machinery rotating speed. A foundation should be designed such that its natural frequencies are not in resonance with any of the driving frequencies. The action of a ship's propeller rotating in a seaway will produce periodic vertical and transverse forces directed at the ship's stern structure. These harmonic forces will excite vibration in the hull at a driving frequency of the rotating rate of the propeller times the number of blades on the propeller. Since the propeller can be rotating at any rate through a range of speeds, the practice has been to design foundations such that their natural frequencies are above the maximum blade rate (maximum shaft revolutions per minute times the number of propeller blades). This criterion need only be applied for foundations located within 1/3 of the length of the ship from the stern since hull structure will tend to dampen the harmonic driving forces and reduce the response amplitudes away from the stern. Typical ship specifications for foundations in the aft 1/3 of the ship require that the foundations and local supporting structure natural frequency should be at least 25% above blade rate. In the forward 2/3 of the ship, caution should be exercised to ensure that foundation frequencies are out of the range of the specified propeller blade operating ranges. In practice there is a low frequency that should be avoided by at least 10% and there is an upper band of frequencies close to blade rate that should be avoided. This results in a fairly wide band between the upper and lower level propeller blade rates within which foundation natural frequencies may reaccommodated. However, since the propeller blade rate will pass through these frequencies as power is increased or decreased, there exists the possibility that a transitory resonant condition may exist.

The action of a ship travelling through a seaway will tend to produce harmonic motion of a ship's hull. These motions can be approximated by considering the ship's hull girder as a free-free beam with added mass included to represent the damping effect of the seawater. The resulting natural frequencies and mode shapes are referred to as ship's primary hull modes. It is these hull driving frequencies which should be avoided in the design of foundations located within the forward part of the ship. Blade rate is usually much higher than any of the primary hull modes and as a result is critical in the aft end of the ship. However, as mentioned above, due to structural damping the blade rate criterion is not critical in the forward length of a ship and as a result the hull mode criterion takes precedence. In designing foundation structures, to avoid resonances with ship's primary hull modes, it is imperative that the mode shape of the driving frequency be considered. The direction of the driving forces for each hull mode will determine which of the foundations natural frequencies should be considered in the criterion. For example, the ship's torsional or rolling mode will have tendency to excite the transverse bending mode of a cantilevered foundation structure mounted to the deck.

The case of a foundation supporting a piece of machinery with rotating parts, which occurs often on board ship, requires an additional vibration criterion. For this situation it is also imperative that a resonance condition does not exist between the machinery's driving frequency and the natural frequencies of the foundation structure. Different criteria exist for units which are hard mounted and units which are resiliently mounted. For hard mounted units it is necessary solely to avoid the machinery's rotating frequency or frequencies, however, for resiliently mounted units it is necessary that all foundation natural frequencies be a factor of 1.25 above the machinery's rotating frequency. The foundation natural frequencies for units which are resiliently mounted are determined by considering the stiffness of the foundation with associated ship's structure and considering solely the mass of the foundation and not of the unit-foundation combination. This is done due to the uncoupling effects of the resilient mounts and to ensure that there is adequate foundation stiffness and mass in way of the mounts.

In case of combatants, the mechanical vibration requirements for all machinery and equipment are typically in accordance with MIL-STD- 167. The equipment, as installed, shall not have vibration interference with the operation of the ship's combat system nor degrade the accuracy or sensitivity of the ship's sensors and radar. All limitations, calculations, and analyses for vibration and balancing of electrical, hull, and machinery equipment and components are also complied with MIL-STD- 167.

Commercial ship foundations are often more flexible due to the lack of shock requirements. This reduced stiffness and corresponding lower frequency can increase the potential for a vibration problem. However, the situation is helped by the fact that commercial ships typically have a much lower propeller blade rate than combatants. For the design data view-graphs which are developed keeping in mind more of commercial applications, are based on a limiting frequency of 15 Hz.

NOISE -- All the foundation design requirements for the reduction and control of structure-borne noise are based on the requirements contained in the specifications and identified in the shipbuilders overall silencing plan. The silencing plan considers the established ship noise goals; the contribution of machinery and overall equipment vibration, propeller cavitation and flow noise to the noise levels; the transmission characteristics of the resilient mounts, foundation structures and hull structure. A guide to the implementation of the specification requirements for structure-borne noise reduction and control, which affect foundation design, are generally provided in the Noise Control Program of the specific ship. For combatant ships, structure borne noise requirements are based on operational requirements to reduce and control the radiated noise signature and to decrease the ship’s detection susceptibility.

Practical design implications for foundations are as follows:

- The average stiffness of the support points in *way* of equipment mounts should be designed to provide a stiffness at least ten times greater than the total dynamic stiffness of the array of mounts resting on it. The dynamic stiffness values of rubber mounts are greater than the static stiffness values used in load-deflection calculations (1.2 to 1.6 x the static stiffness). From a practical standpoint 1/4” to 1/2” plate or angle thicknesses stiffened with small brackets in way of mount attachments are adequate to meet the dynamic stiffness requirements.

- The distribution of mass in a foundation fitted with noise mounts should be such that the mass of the foundation within a periphery of 3“ of the mount should be at least 1/50 to 1/100 of the mass supported by the mount.

Knowing the weight of the equipment and the number of mounts, one can easily calculate the structural mass required *at* the mount. Given the fact that the stiffness can be achieved with 1/4” to 1/2” plate, mass and stiffness can be increased with the use of plate brackets or welded liners in way of the mounts. In this manner, the overall weight growth in the foundation can be held to a minimum. To reduce engineering time, graphs can be plotted for each mount type depicting the mass requirements of the foundation as a function of the equipment weight supported. Since the mounts are designed to suit a specific and usually narrow band weight range, it can be shown that a single plate/liner combination with brackets will meet all mass requirements for a given mount.

SHOCK-- An underwater explosion generates a shock wave of intensive pressure which impinges against the ship hull and induces severe transient motions in the primary hull structure. These motions constitute the shock excitation environment that is transmitted through the hull to the base of the foundation system. The ideal characterization of any underwater explosion and shock excitations is the known time history of the hull shock motion at the structural interface with the foundation. Since such data are not readily available, an alternative approach of either quasi-static analysis method or Dynamic Design Analysis Method (DDAM) is used.

For combatants the shock requirements almost always govern the foundation design. GeneralIy the foundations requiring shock qualifications which are not qualified by shock testing are designed for shock in accordance with “Shock Design Criteria for Surface Ships” Publication NAVSEA O9O8-LP-OOO-3O1O, 1976. Shock design values used for foundation analysis are Specified in the Design Data Sheet DDS-072- 1 (confidential). These foundations shall be designed using appropriate shock values for location and direction using the allowable stress criteria associated with either the elastic or elasto-plastic design as indicated in NAVSEA O9O8-LP-OOO-3O1O.

The shock motion inputs for analysis purposes are described as shock design values. These values, are based on a characterization of the maximum response of: (l)Single-mass single-degree-of-freedom systems or (2) Uni-directional multi-mass systems to the shock motion time history and also takes into account the mass of the item. The values are based on standard formulas developed from experimental data.

The shock design values can be characterized as a “cut-off” acceleration, Ao, or as a “frequency relief” velocity, Vo. Both values are functions of the modal weight of the foundation/equipment system. The formula for “cut-off” acceleration provides a value for Ao directly. The formula for frequency-relief velocity provides an interim value which is then converted to acceleration employing the natural frequency of the foundation i.e., w. The forces thus computed are then compared to the forces associated with the bolt strength method. The lowest value for Ao, Vo, or the force associated with the bolt strength method is used in the subsequent shock computations.

The magnitude of the shock design values to be applied in the shock analysis are modified by other factors, such as the shipboard location of the foundation, the direction of the shock input and the degree of deformation permitted in the foundation. The shock design values are expressed in units of acceleration (g's) to be applied in a quasi-static manner to each modal mass. The math models for the foundation component system are represented as lumped mass spring configurations for single degree of freedom systems. The model of a multi-mass system is three dimensional and represents the equipment and foundation. The math model provides the foundation geometry and dimensions, the weights of the lumped masses and the spring or stiffness properties of the foundation.

This is information is used to calculate the fixed base structural dynamic (modal) characteristics of the system. The analysis technique utilizes the modal frequencies, mode shapes, modal masses and modal participation factors. The modal frequency and modal mass values are used in DDAM to determine the shock design value inputs, while the mode shapes and modal participation factors are used in the subsequent response analysis.

ALLOWABLE STRESSES Under the normal design loads, stresses in steel should not exceed the following allowable limits. These limits are based on allowable criteria generally used for commercial ships, the limits can vary depending on the specifications of specific ships. The design data view-graphs in section 9.0 are based on these allowables.

- Tensile and bending stresses-where there is no danger of failing from instability, allowable limits for the algebraic sums of axial and bending stresses are 50% of material yield strength as listed in Table 1.

- Shear Stresses - where there is no danger from instability, allowable limits for shear stresses are 75 percent of the allowable tensile &bending stress.

- For both Elastic and Elastic/Plastic design, the tensile stress in an axially loaded member shall not exceed the material static yield strength.

TABLE 8.1

ALLOWABLE LIMITS FOR FOUNDATION STRUCTURAL MEMBERS

MATERIAL	Nom. Yield Strength KS1[1]	Elas Allow. Stress KSI	Elas Shear Stress KS1	Elas/Plas Bending Stress KS1[2]	Elas/Plas Shear Stress KSI
steel					
Ordinary Strength (OS)	34	17	13	34	26
Higher Strength (HS)	51	26	19	51	38
High Yield (HY-80)	80	40	30	80	60

NOTES: . 1) Yield strengths for steel shall be obtained from applicable material specifications.

2) 100% of nominal yield strength.

Threaded fasteners and hold down bolts requirements for components shall be as defined in the applicable component specification. In case of stud fabricated foundations and stud mounted equipments the stud allowable stress in bending can be 60% and in shear 45% of its material yield strength, respectively. A

The limiting frequency as discussed before should be 1.25 times the maximum propeller blade rate. The limiting frequency used for the design data view-graphs is 15 Hz.

8.2 Innovative Design Analysis and Testing Validation

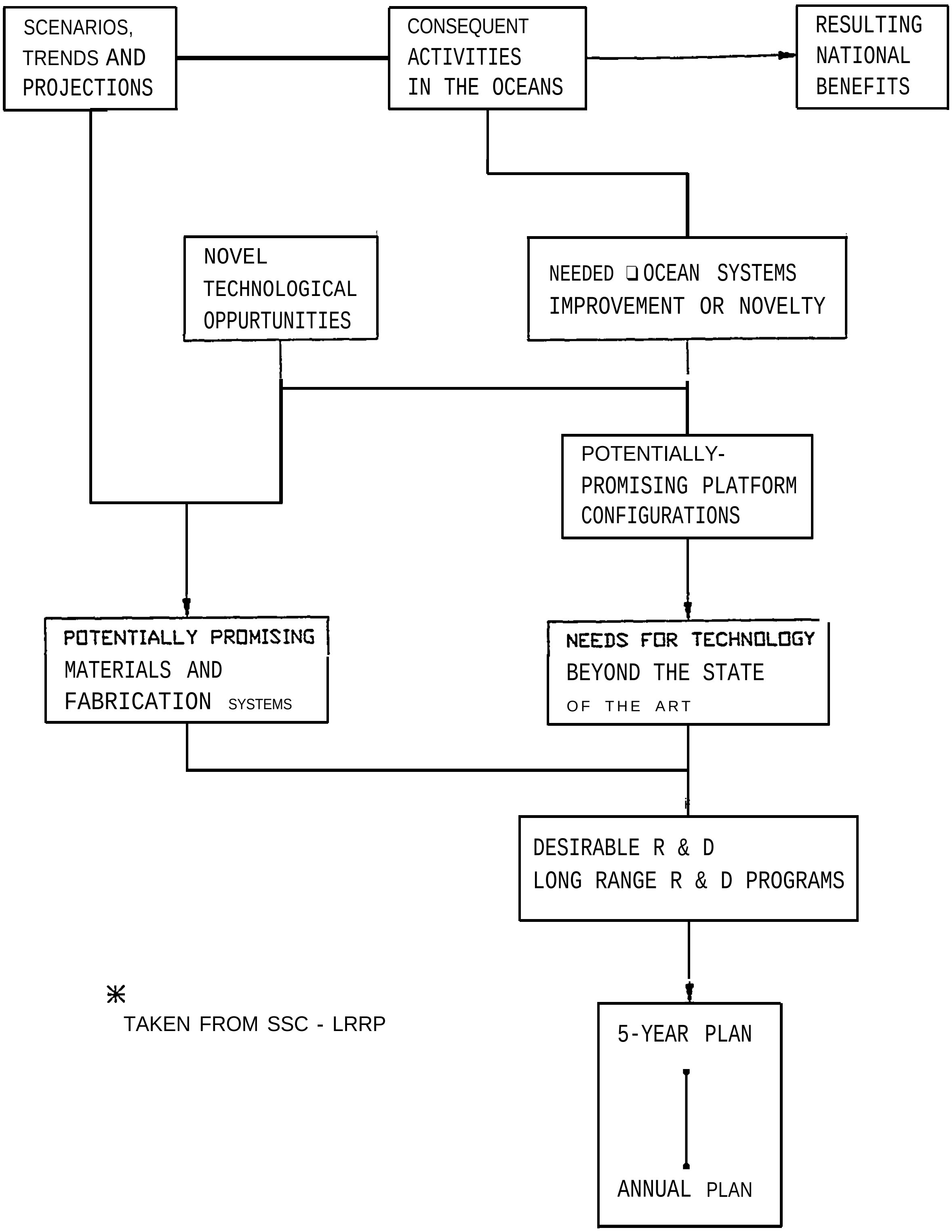
World class shipbuilding competitiveness is based on acquiring state of the art shipyard process technology; achieving the high productivity of a motivated workforce within the framework of a high performance organizational structure and innovative and creative ship design technology that will provide a technological edge of superiority over our world class competitors. The combination of these attributes, shipyard process technology, high performance workforce and innovative world class design are the cornerstones of a powerful world class commercial shipbuilding organization based on flexibility, cooperation and agile collaborative enterprise among it’s members. This organizational structure will seek to pool resources and core competencies to achieve the flexibility, creativity, and innovative spirit that can capture the essence of the economic development needs of the intemational market. This type of organization can quickly and efficiently translate those needs into products that spur economic development within the world transportation markets. Critical ingredients to world class shipbuilding as it applies to design, manufacturing and cost competitiveness are:

- Producibility
- Innovation
- Creativity
- Technology
- Design
- Manufacturing
- Shipbuilding Process
- Workforce Development

A strategy that will support long term innovation, that will underpin world class competitiveness is the ability to provide the proper technical validation for innovative concepts through analysis and testing verification for system cost and performance goals and attributes.

A well thought out strategy for innovative development is articulated in the Ship Structure Committee's (SSC) Long Range Research Plan. The plan formulation described in figure 8.1 reviews trends and projections, investigates novel technological opportunities, identifies promising materials and fabrication systems, characterizes promising platform applications and the need for technology beyond the state of the art and develops the appropriate and desirable research and development that can be verified by analysis and testing.

FIGURE 8.1 - PLAN FORMULATION *



* TAKEN FROM SSC - LRRP

Cutting edge technology must be based on well founded and documented research and development in order to provide assurance and acceptance of the technology by the industry. Furthermore, application of the results of research earned throughout development is a drawn out process that takes time and significant resources to implement in practical shipbuilding applications. There has been a significant research and development effort over the last 40 years that has been sponsored by the Ship Structure Committee (SSC) that will help to provide a first principles approach to the development of innovative structure and, consequently, foundation design. In the interest of providing a rational basis to ship structure design the SSC - Long Range Research Plan identifies goal areas for the research they sponsor i.e. Loads, Responses, Materials, Fabrication, Reliability and Design Methods. See table 8.2 for the more defined set of research areas regularly investigated upon which innovative and creative design changes for ship structures and foundations may be based. With appropriate research conducted to establish loads and the response of structure, the choice of materials and fabrication techniques for unique designs, can be evaluated for reliability and safety. Appropriate design methods have been developed that can assist the designer in achieving acceptance by the Navy and/or commercial classflcation agencies for unique and innovative designs.

TABLE 8.2

Long Range Research plan for the Ship Structure Committee

Goal Area 1: Loads
- Non-Linear Effects
- Experimental Models
- Seaway Representation
- Ice Loads
- Load Combinations

Goal Area 2 Response
- Ultimate Strength of Ship Structures
- Responses to Transient Loads
- Analytical Techniques for Predicting Structural Responses
- Structural Responses to Collision and Grounding Loads

Goal Area 3: Materials
- Marine Concrete Development
- Development of Composites for Marine Utilization

Goal Area 4: Fabrication

- Weld Inspection Methods and Criteria
- Design for Production
- Improved Welding Methods, Equipment and Consumables
- Rational Regulatory Requirements
- Technology Transfer/Diffusion

Goal Area 5: Reliability

- Formulation of a Reliability Model
- Data Feedback into Reliability Model

Goal Area 6: Design Methods

- "Rational" Ship Design Process
- Ship Vibration - Improved Parameter Definition, Criteria and Calculation Methods
- Fatigue of Ship Structural Elements, Criteria Design Methods and Structural Detailing

Innovative Design solutions that provide the basis for resolving world class shipbuilding transportation problems is dependent on our understanding of the worlds economic conditions and the resulting transportation needs that must be satisfied through innovative design. In order to have a fundamental strategy for design innovation, the designer should target likely candidates that offer solutions to identified problems. Such a strategy should embody the following elements characterized in table 8.3.

Forecasting should be conducted within the context of an understanding of the state of international cooperation (scenarios for forecasts). Global trends provide insight to innovative alternatives. Pervasive trends offer problems for long term solutions. Promising technology offers the opportunity to exploit new discoveries to resolve old and new problems. Technical developments in manufacturing provide an innovative means to improve competitiveness. Finally an internationally competitive workforce will employ innovative design solutions to traditional problems within the context of a new invigorating labor-management paradigm.

TABLE 8.3

Strategy for Innovative Competitiveness

Forecasting :

- Forecasting for 10 to 20 years are very risky
  - political whim
  - Economic, social or technological surprise

- Long lead time in the use of new knowledge
  - Scientific research takes 16 years to implement
  - Gestation Period -6 to 8 years - Merchant Ships
  - Preliminary Design to commissioning -3 to 5 Years
  - Navy Ships -5 to 8 Years

Scenarios for Forecasts:

A -- High Interdependence - Global Cooperation
B -- Moderate Interdependence -, Most Probable Cooperation
C - Break Between Developed and Developing Countries
D - Break Between Developed Nations - Protectionism

Trends:

- Technological Innovations
- Resource Availability
- Trends - Ship Platforms and Populations
- political Trends
- Legal Trends
- Economic Trends
- Military Trends
- Environmental Trends

Pervasive Trends:

- Rising Cost of Energy
- Increasing Scarcity of Key Minerals
- Increasing World Shipbuiltig Competition
- Degeneration of US Commercial Shipping
- Maintenance or Increasing Naval Force
- Increasing Operations in Cold Waters

- Larger Vessels

Promising Technology :
- Computer Technology
- Computer Aided Manufacturing
- Statistical - Parametric Methods
  - Failure Analysis
  - Reliability and Risk
  - Seaway Description
- Structural Condition Monitoring
- Lifetime Cost Optimization in Design
- Maintenance Cost Optimization in Operation
- Advanced Information Exchange
- Advanced Education and Training
- New Sources of Scarce Minerals
- Advanced Environmental Prediction

Promising Manufacturing Systems:
- Electronically Controlled Robotics
- Agile Manufacturing
- Enhanced Accuracy Control - 99% Outfitting

Internationally Competitive Workforce:
- Motivated Workforce
- Cross-Trade Training - Shipyard Mechanic
- New Labor - Management Paradigm

Innovative design if properly conducted and verified by acceptable analysis and testing validation should be accepted for use by the worlds classification societies. Ideas must be translated to real products in order to provide the competitive edge our U.S. shipbuilding industry requires. Our shipbuilding industry should capitalize on the significant investments made in technology research and development over the last 40 years to revitalize our shipbuilding industry.

8.3 Design Methodology

Develop **Preliminary Design Sketch & Integrate With Ship:** The designer selects an appropriate foundation configuration to suit the particular installation based on vendor furnished equipment information (VFI), equipment shipboard location and preliminary scantlings selection. One of the 27 representative foundation designs and 18 standard method mounts described in section 9.0 may be used as a guide to develop the initial configuration. Preliminary scantling selection for commercial ships can be done using the design data tables in section 9.0.

Once a foundation configuration is selected, an initial sketch showing the ship structure and ship systems that impact on the foundation is developed. The designer should conduct the interference check with ship systems composites at this initial stage. At this point consideration should also be given to the preferred methods as described in producibility recommendations and cost saving guidelines. Once the initial sketch is developed, design validation through standard design or engineering analysis may proceed. The design validation of the proposed foundation through quantitative review should be conducted by a engineer trained in ship structure and foundation design.

Design validation Through Standard Designs: During the course of development of this design manual a parametric approach to foundation design was developed and used which drew upon a design philosophy of Standard Foundation Installations.

Foundation installation statistics reveal that the variety of combinations of geometries and equipment weights is limited and can be clearly defined. Utilization of a parametric analysis approach provides solutions for broad ranges of possibilities at one time, rather than each time the possibility is encountered, which can b-e drawn upon later to significantly reduce engineering and design time. Standard foundation designs could be developed which satisfy a wide variety of applications. In this design manual, design data tables and view-graphs for foundations are included in section 9.0 which would allow the engineer to quickly determine if a foundation sketch proposed by the designer is adequate enough by comparison, rather than by performing the detailed analysis for the same scenario repeatedly.

The design data tables are generated for commercial applications. In case of naval ships where shock, nuclear blast, noise. and other criteria predominantly govern the foundation design, foundation design validation through standard designs can still be accomplished by performing a parametric approach to foundation analysis and obtaining standard design tables for foundations based on the navy ship requirements and specifications. This task is beyond the scope of this design manual, but recommendations in Appendix B can be a good starting point.

- To validate the initial foundation design the engineer can verify the foundation geometries and scantling sizes with design data tables for adequacy, provided the requirements, specifications and allowables are similar to that used in this design manual. If the requirements and allowables vary then the engineer can scale the foundation geometries and scantling sizes accordingly. For example, if a designer designed a foundation for an equipment whose actual weight is W_d and then the engineer checked that according to the requirements the foundation should be designed for a sea-load acceleration value of G in a particular direction, and not G_d which is used in this design manual. Thus the engineer computes a virtual weight, W_v to be used in the design data tables using the following equation, so that the scantling size can be scaled accordingly.

$$W_v = \frac{G}{G_d} W_d \tag{1}$$

The scantling size gets changed to the size which could adequately support this new virtual weight as opposed to the real weight. Similar scaling can be done to incorporate any variations in the specifications from that used in this design manual, in vibration limits, stress allowables, material properties, etc.

Design Validation by Engineering Analysis : In order to validate by engineering analysis, the engineer creates a finite element beam model of the initial foundation sketch with appropriate boundary conditions where the foundation meets ship structure. Slight adjustments may have to be made so that element nodes coincide with bolt hole locations, neutral section axes, etc. The model should have a 1 kip load applied at the equipment CG in each of the three orthogonal directions. Rigid beams should connect the equipment CG to the hold down bolt locations. Nodes between rigid beams and foundation scantling beams should have end releases about the bolt axis.

The engineer records the stresses and deflections at the equipment CG resulting from the 1 kip load. For each orthogonal direction a spring rate is determined by dividing 1 kip by the deflections recorded.

The three orthogonal foundation frequencies are found by using the equation:

$$\omega = \sqrt{k \times \frac{g}{W}} \tag{2}$$

where,

k = spring rate (lbs./in.)

g = gravitational acceleration (386 in/sec.^2)

W = weight of equipment + 1/2 foundation weight in lbs.

The "g-loading" that the foundation must support must be determined at this time and depends on whether shock or sea loading requirements apply.

A. For shock design of U.S. Navy combatants, the lower of the acceleration or velocity-governed shock inputs must be used. G_{A_o} can be directly determined using the equipment weight, mounting location and shock direction as inputs for formulas given in DDS-072-1 (confidential).

Vo is determined using formulas given in DDS-072-1 and varies depending on equipment weight, mounting location, shock direction, and whether the equipment can tolerate slight yielding of foundation members. Velocity-governed "g" shock loadings (referred to as G_{vo}) are given by the equation:

$$G_{V_o} = V_o \times \frac{\omega}{g} \tag{3}$$

where,

V_o = the maximum shock velocity as given in DDS-072- 1 (in./seC.).

w= the frequency of the foundation and equipment in the direction being analyzed (rad./sec.)

B. For foundation design of commercial ships, the maximum acceleration produced by sea loading is very rarely greater than three "g's", including the normal one "g" of gravity.

For foundations where shock criteria apply, the lower of the G_{V_o} and G_{A_o} values should be used in the following equation to determine shock stresses, replacing seaload "g" values by shock values. For all foundations the equation below with the $G_{seaload}$ value should be used to calculate seaload-induced stresses and also scale the values based on the ratio of the equipment weight plus 1/2 the foundation weight to the 1 kip load.

$$\sigma_{seaload} = G_{seaload} \times \frac{W_{eqpt.+1/2fdnwt.}}{W_{unitload}} \times \sigma_{unitload} \tag{4}$$

where,

$\sigma_{seaload}$ = Max stress in foundation due to sea loads

$\sigma_{unitload}$ = Max stress in foundation under unit load (1000 lbs.)

$G_{Seaload}$ = Worst ship's motions accelerations due to sea loads

$W_{cqpt+\ 1/2fdn}$ = Equipment weight + half the foundation weight in lbs

$w_{unit\ load}$ = The unit load (1000 lbs.) applied to the FEA model

The shock or seaload stresses should then be compared with allowable stresses to determine if the foundation meets strength requirements.

A. Foralignment-critical equipment on shock-governed foundations the allowable material stress is 100% of the material yield strength. Allowable shear stresses are 60% of the material yield strength.

For non-alignment-critical equipment on shock-governed foundations the allowable stress is 200% of the material yield strength. Allowable shear stresses are 120% of the material yield strength.

B. For commercial ship foundations being checked for strength to resist ship's motions forces, the allowable stress is often 50-80% of the material yield stress. The allowable shear stress is often 30-48% of the material yield stress.

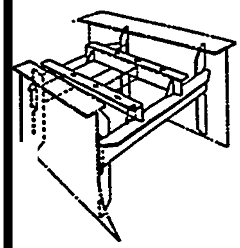
9.0 FOUNDATION DESIGN GUIDE FOR STANDARD FOUNDATION TYPES

This section is the core of the foundation design manual, and offers the designer a set of very comprehensive options to choose from in the initial foundation design phase. It also provides complete guidance with required building blocks to both designer and engineer to design producible and cost-effective foundations with minimum analyses. The beginning of this section provides standard foundation configurations to choose from which could well offer standard foundations to most of the equipment/machinery on board ship. Along with the configurations this section also provides typical scantlings for standard foundations, making the design cycle shorter.

A brief description of foundation Method Mounting along with typical scantlings for method mounting are also provided in this section. Method mountings are standard equipment mountings stemming from the concept of a parametric approach to foundation design & analysis and standardization of foundation design to reduce repetitive engineering. Finally Stud Mounting methods for equipment installations and typical stud configurations and sizes are also given.

9.1 Standard Family of Foundation Types

Enclosed are the configurations of 27 standard foundation types. These view-graphs can offer the designer to choose a representative foundation for almost any equipment to be installed. This eliminates the possibility of varied types of foundation designs popping out of the designers' imagination and therefore limits the engineering analyses and validations to a finite number of foundation configurations, and thereby leads to standardization of foundation designs. Along with the foundation shape and geometry, these design view-graphs also provide computer model representations of these foundation types. The computer models provide the engineer with a ready representation of foundation type to perform the analyses either using structural engineering by first principle or using finite element techniques. The computer models show the deflection characterization of foundations under each orthogonal direction load application, giving the engineer the required parameters to compute the structural stiffness, load distribution and stress developed.



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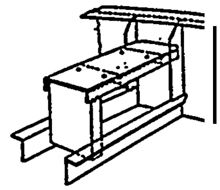

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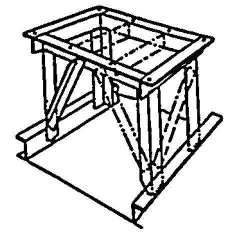

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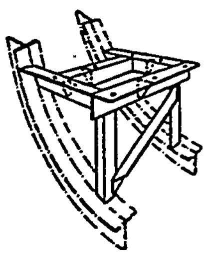

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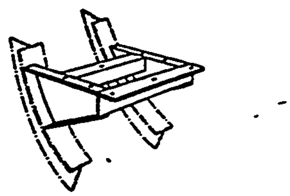

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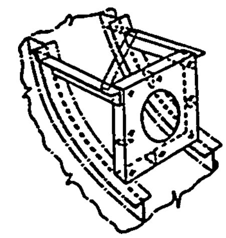

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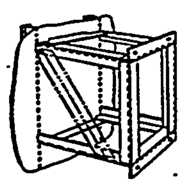

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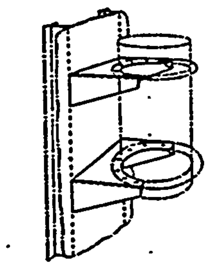

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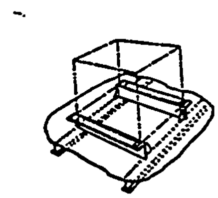

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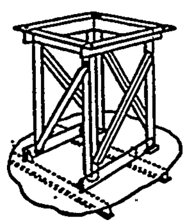

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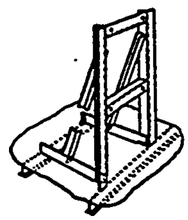

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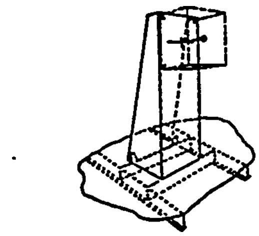

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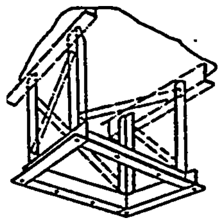

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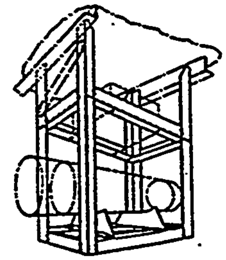

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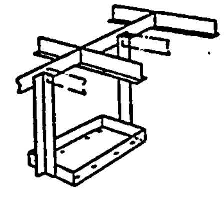

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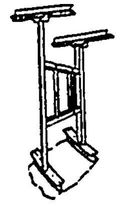

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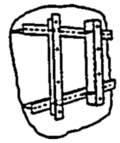

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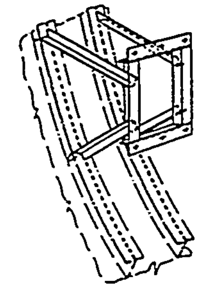

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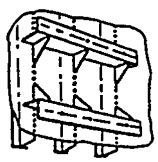

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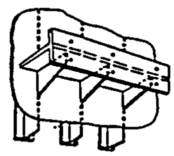

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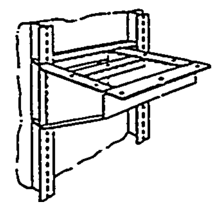

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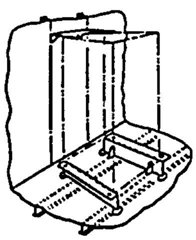

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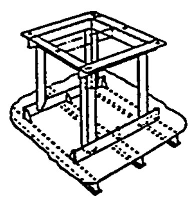

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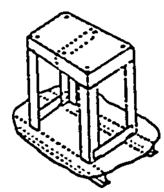
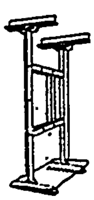


TYPE 18



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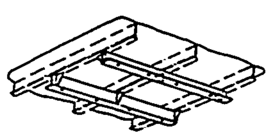

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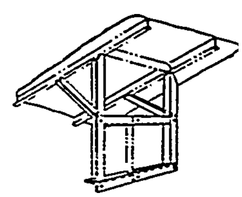
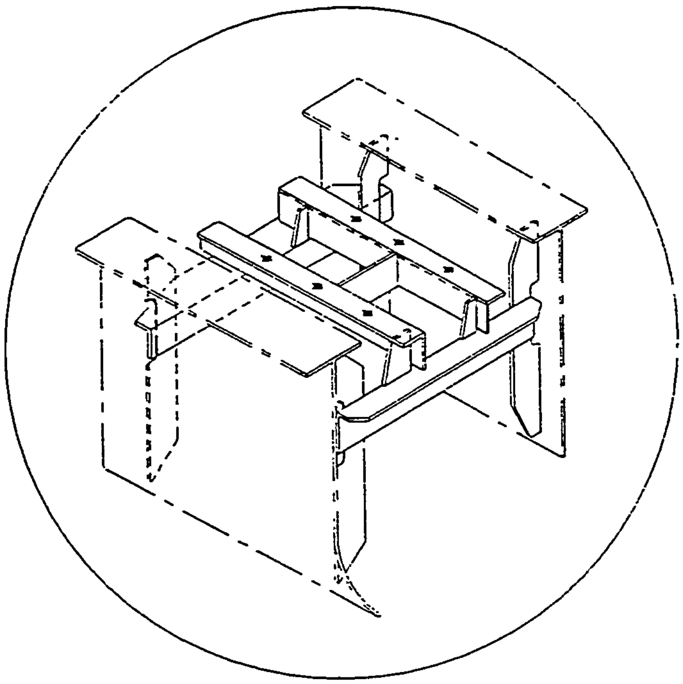
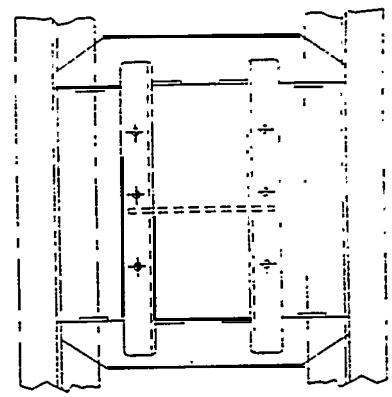
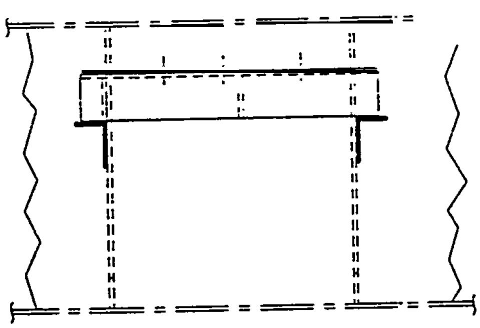


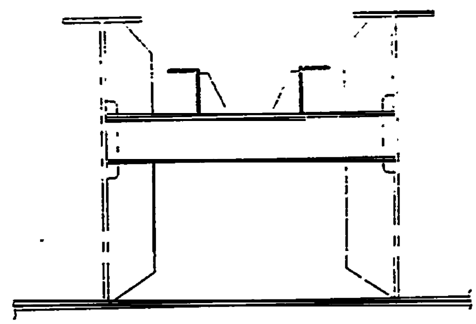
TYPE 24

FAMILY OF
STANDARD FOUNDATION TYPES

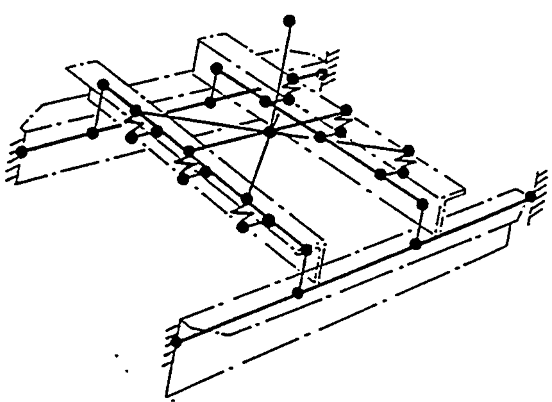








Computer Model



Hull Mounted Bottom Shell Grillage

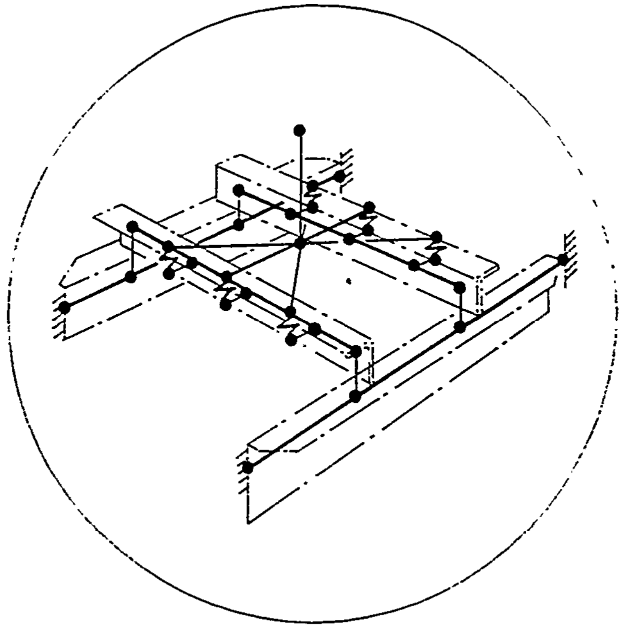
STANDARD FOUNDATION TYPE 1

VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

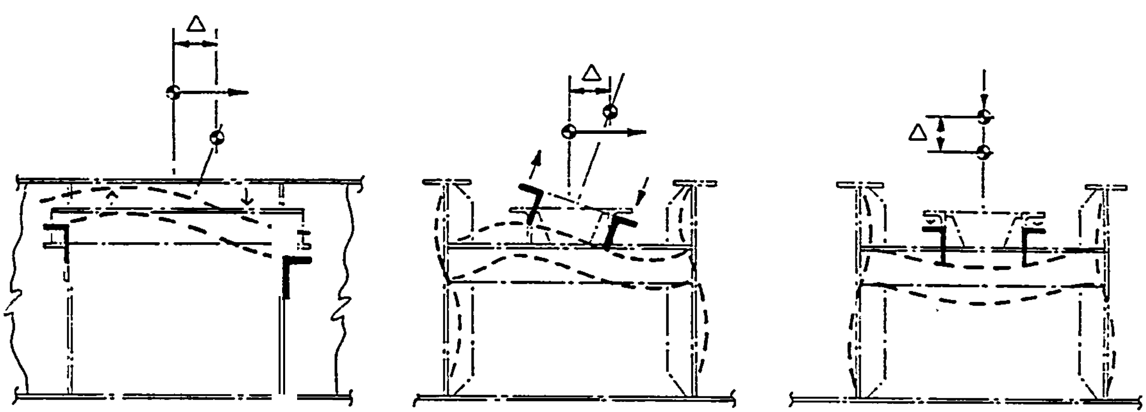
DRWN BY: S. Ducharme
CHCK BY: M. Gupta
APPR BY: JJH
SCALE: NONE
DATE: 25 Aug. 93

REV A

Computer Model



Load Application and Deflection Characterization



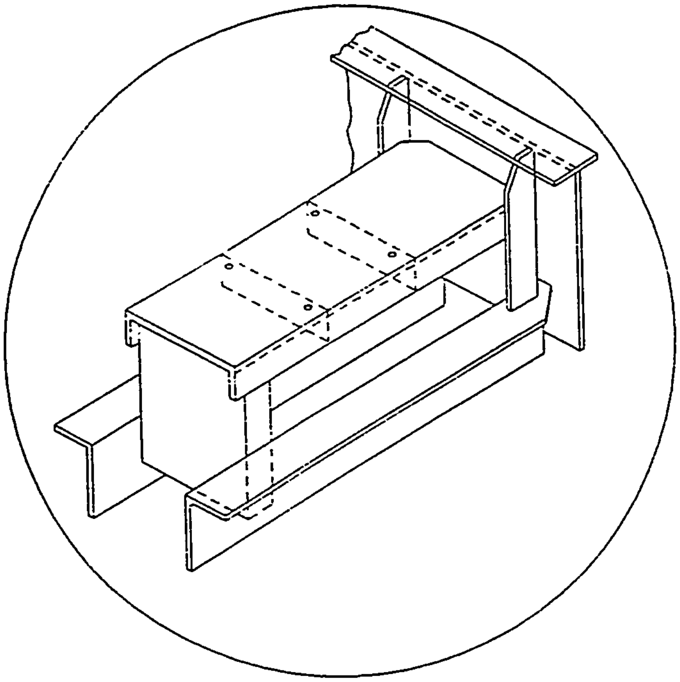
1. BEAM BENDING/TORSION	1. BEAM BENDING/TORSION	1. BEAM BENDING/TCRSION
2. FRAME BENDING	2. FRAME BENDING	2. FRAME BENDING
3. FLANGE BENDING	3. FLANGE BENDING	3. FLANGE BENDING
LONGITUDINAL	TRANSVERSE	VERTICAL

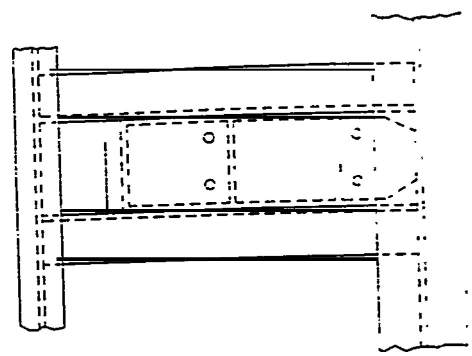
Hull Mounted Bottom Shell Grillage

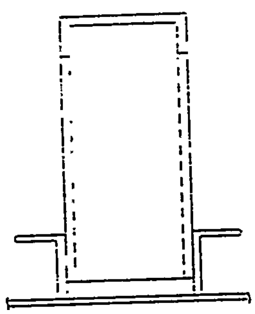
STANDARD FOUNDATION TYPE 1

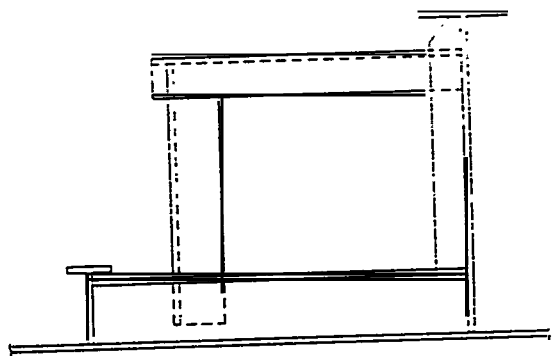
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY: S. Ducharme
CHCK BY: M. Gupta
APPR BY: JJH
SCALE: NONE DATE: 16 Aug. 95
REV A

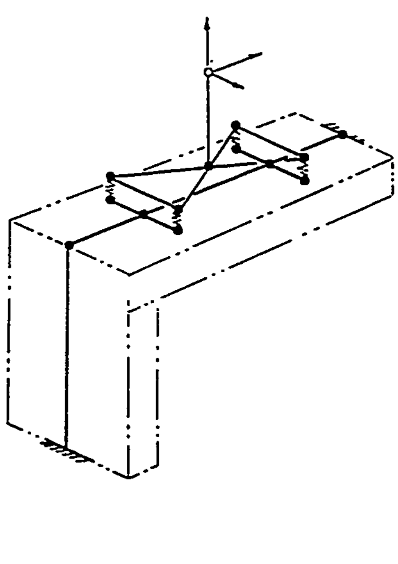








Computer Model

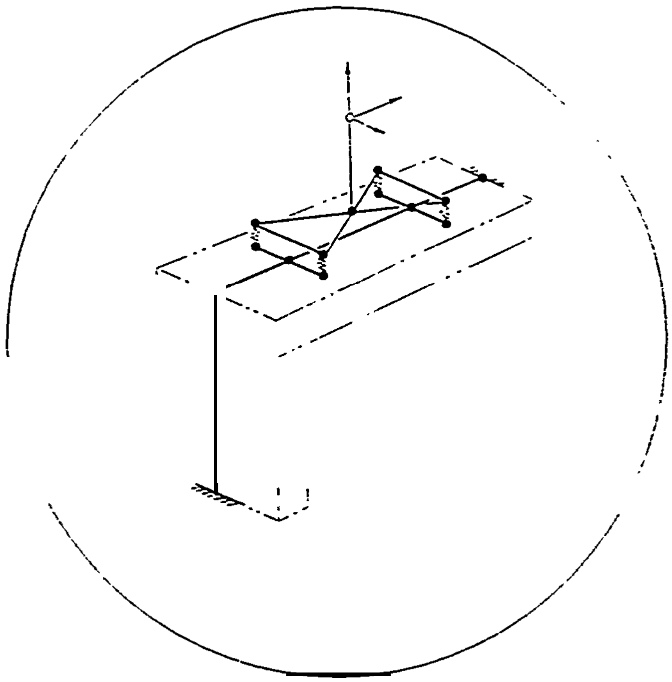


Hull Mounted Bottom Shell Frame

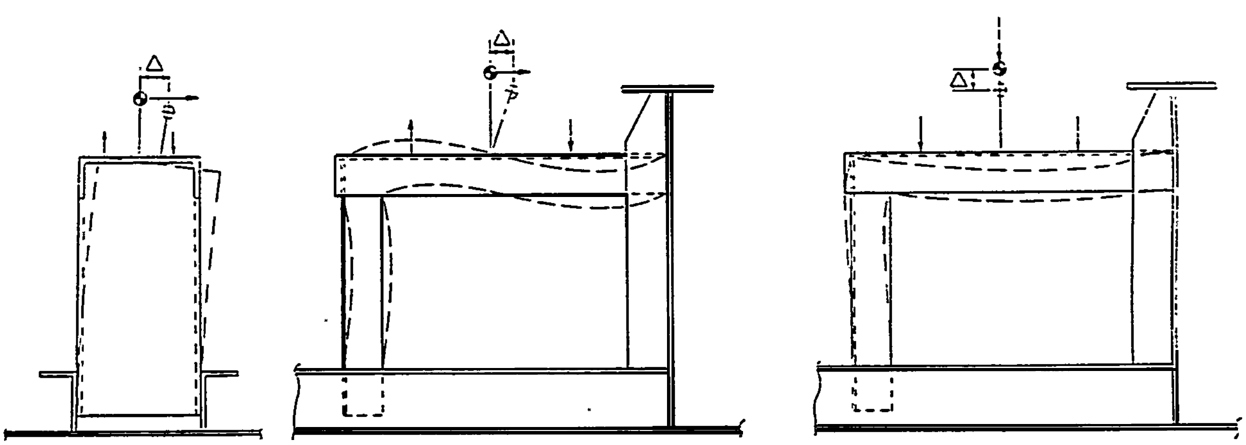
STANDARD FOUNDATION TYPE 2

VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1580 FAX: 401/295-2592	DRWN BY: S. DUCHARME CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 Aug. 93	REV A

Computer Model



Load Application and Deflection Characterization



3. FLANGE BENDING

LONGITUDINAL

1. FRAME BENDING
2. FLANGE BENDING

TRANSVERSE

1. FRAME BENDING
2. FLANGE BENDING

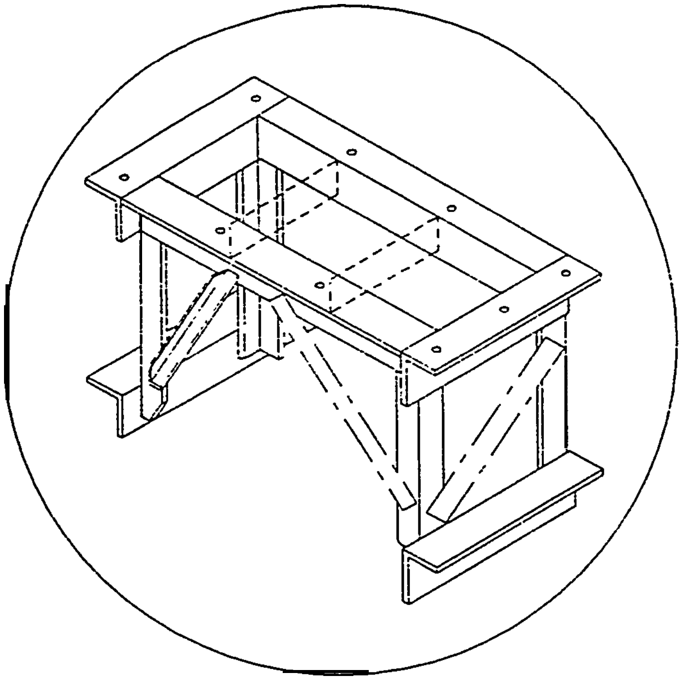
VERTICAL

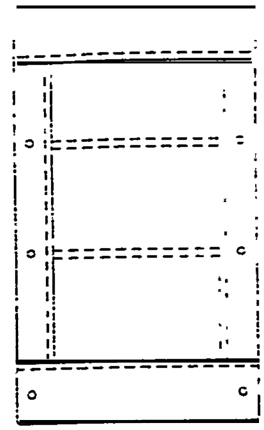
Hull Mounted Bottom, Shell Frame

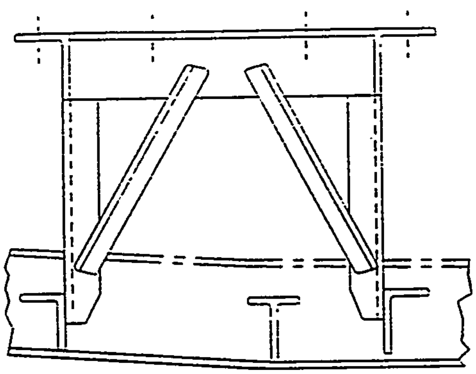
STANDARD FOUNDATION TYPE 2

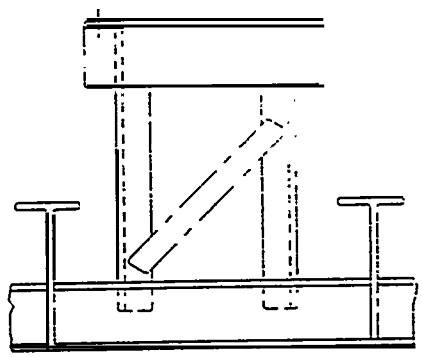
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY:	S. DUCHARME	REV
CHCK BY:	M. Gupta	A
APPR BY:	JJH	
SCALE: NONE	DATE: 16 Aug. 95	

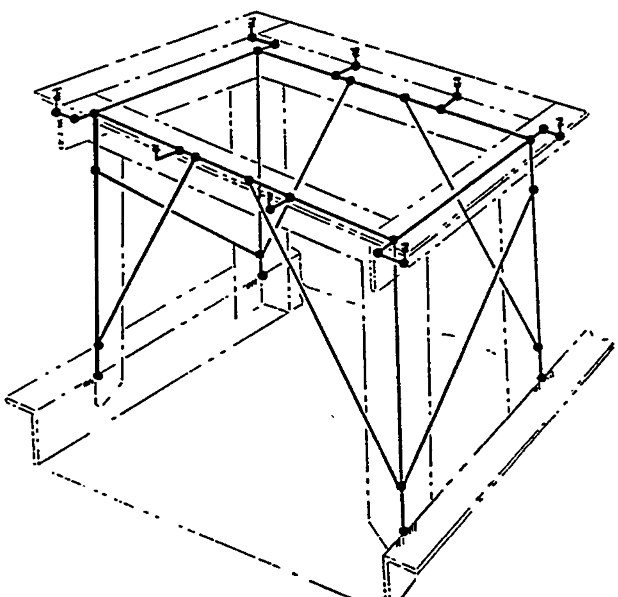








Computer Model



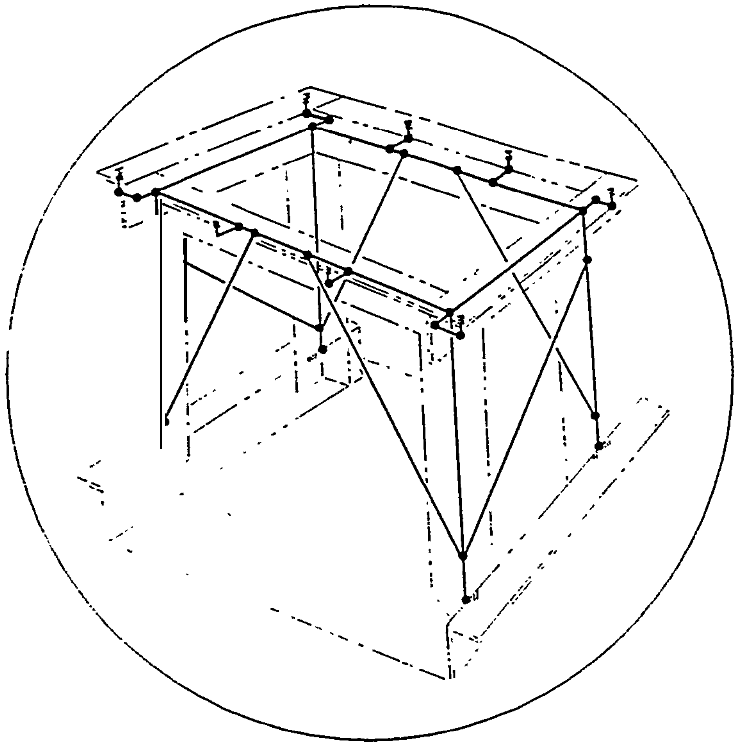
Hull Mounted Bottom Shell Truss/Frame

STANDARD FOUNDATION TYPE 3

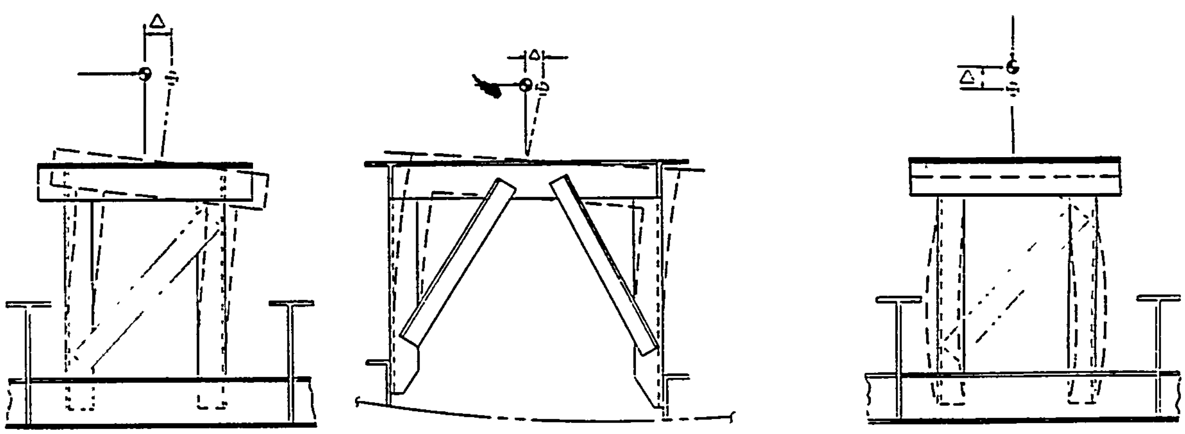
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY:	S. DUCHARME	REV
CHCK BY:	M. Gupta	A
APPR BY:	JJH	
SCALE: NONE	DATE: 10 Aug. 95	

Computer Model



Load Application and Deflection Characterization



1. TRUSS RACKING
2. FLANGE FLEXURE
3. LEG FLEXURE

LONGITUDINAL

1. TRUSS RACKING
2. FLANGE FLEXURE
3. LEG FLEXURE

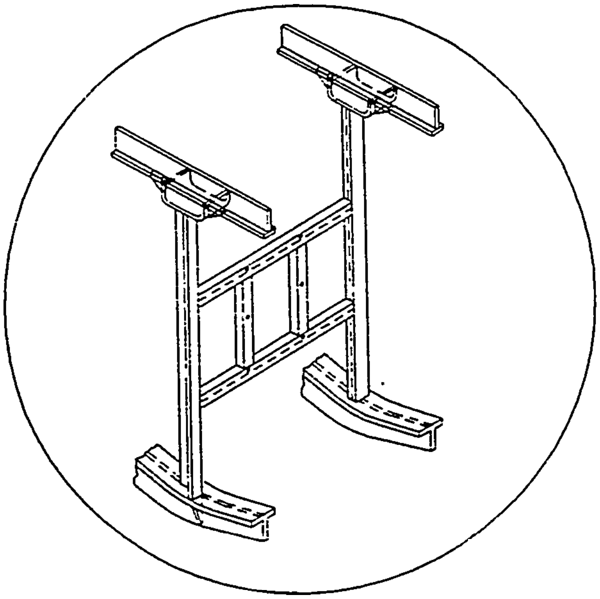
TRANSVERSE

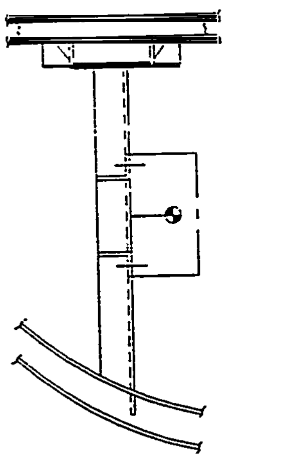
1. FLANGE FLEXURE/BEAM TORSION
2. LEG COMPRESSION

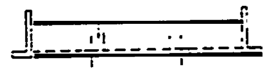
VERTICAL

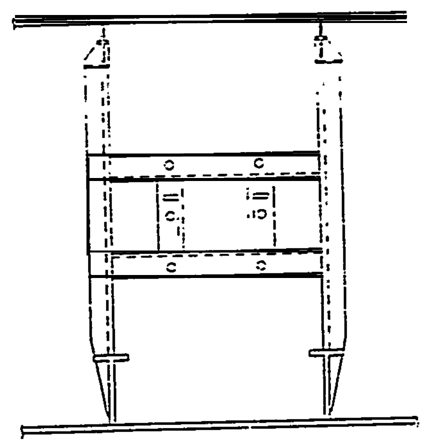
Hull Mounted Bottom Shell Truss/Frame

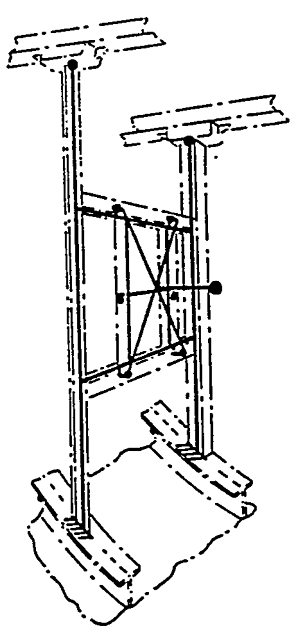
STANDARD FOUNDATION TYPE 3		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. DUCHARME CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 10 Aug. 95	REV A











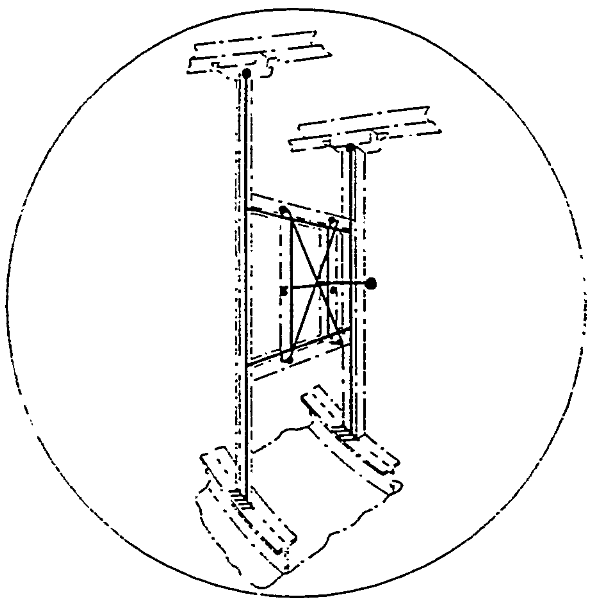
Computer Model

Hull Mounted Hull to Deck

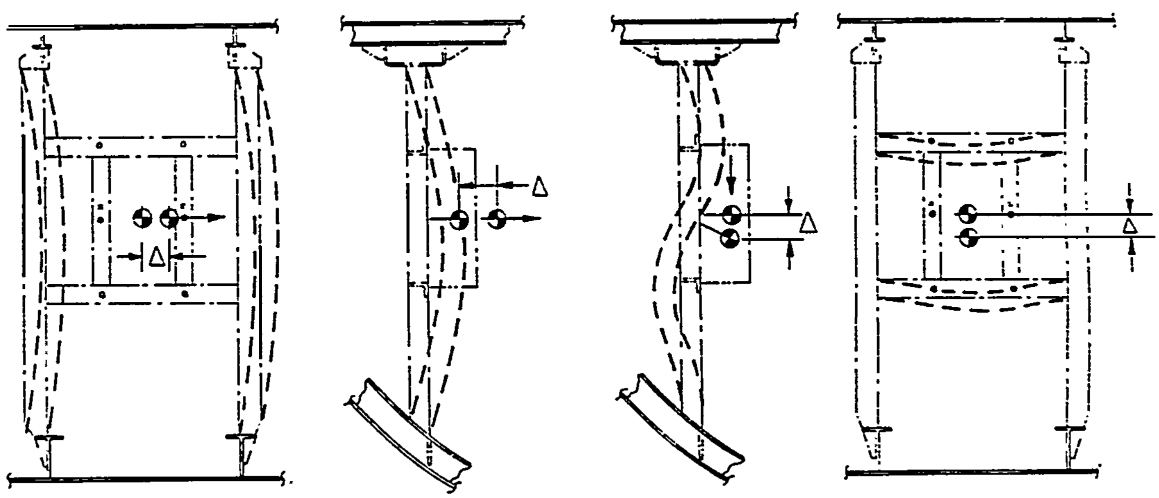
Rack/Panel

STANDARD FOUNDATION TYPE 4		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 10 Aug. 95	REV A

Computer Model



Load APP lication and Deflection Characteri zation



1. FLANG BENDING
2. FLAME BENDING

LONGITUDINAL

1. FLANGE BENDING
2. BEAM BENDING

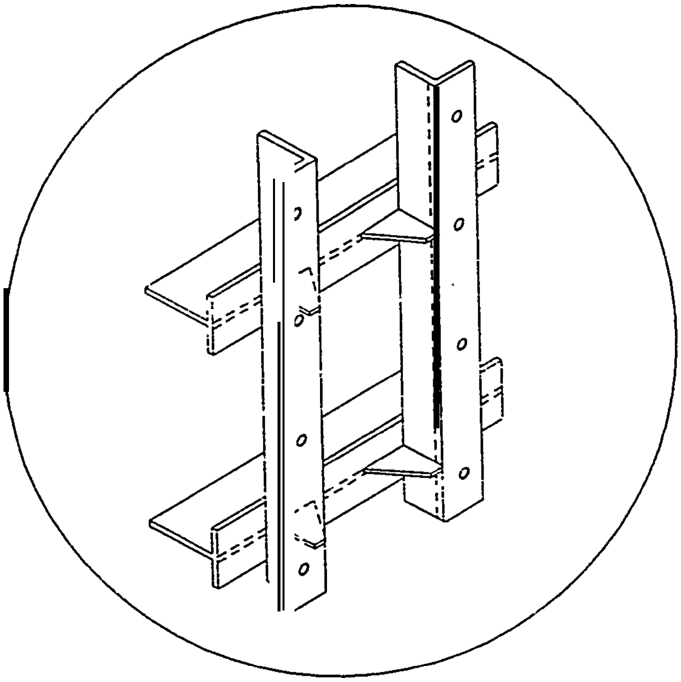
TRANSVERSE

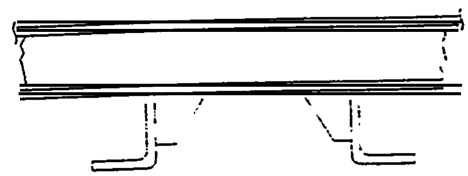
1. FLANGE SENDING
2. BEAM BENDING
3. LEG FLEXURE

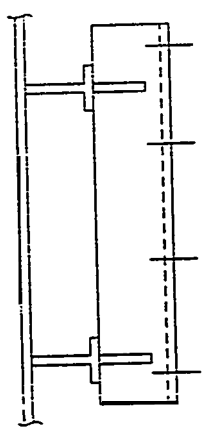
VERTICAL

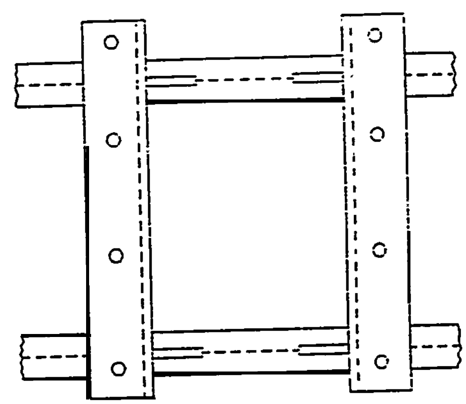
Hull Mounted Hull to Deck
Rack/Panel

STANDARD FOUNDATION TYPE 4		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	CRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 10 Aug. 95	REV A

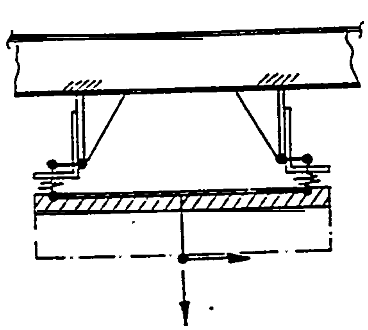


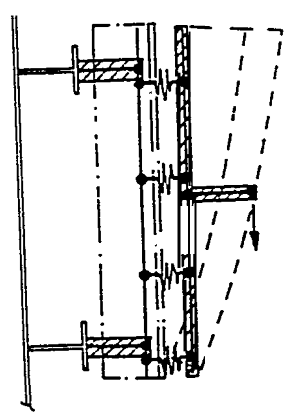






Computer Model

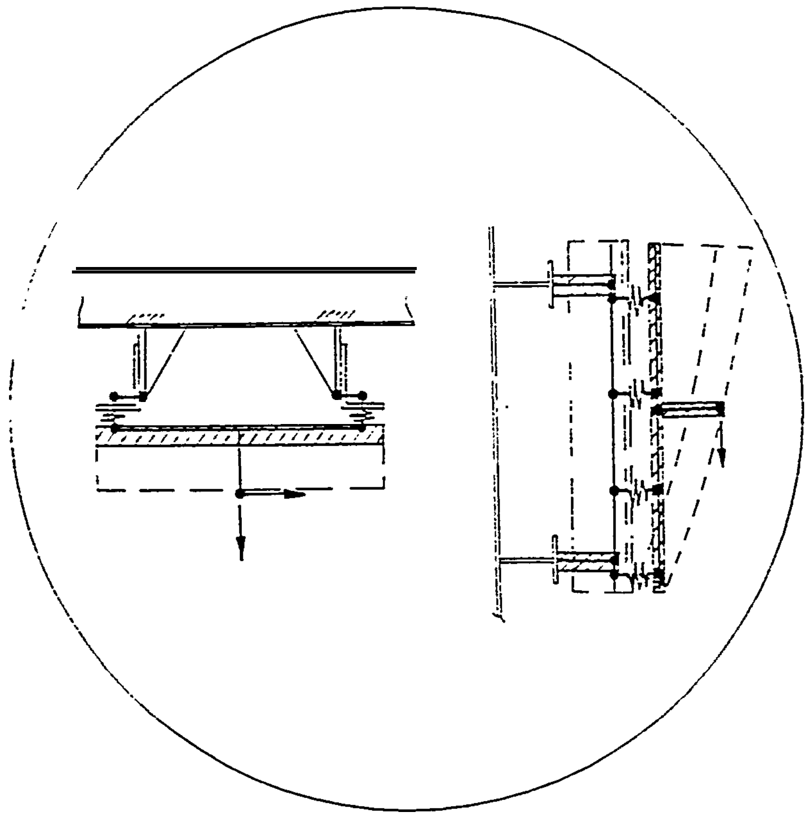




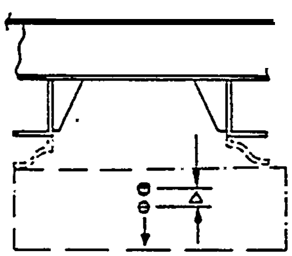
Hull Mounted
Side Shell Grillage

STANDARD FOUNDATION TYPE 5		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2582	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPD BY: JJH SCALE: NONE DATE: 06 Aug. 95	REV A

Computer Model

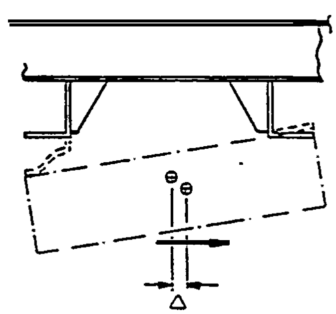


Load Application and Deflection Characterization



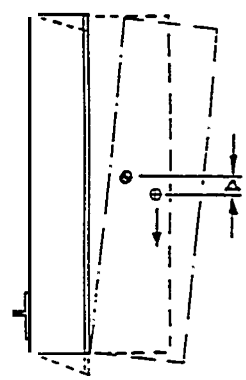
1.) FLANGE FLEXURE
2.) WEB ELONGATION

TRANSVERSE CR LONG'L



1] OVERTURNING FLANGE BENDING
2] WE3 TENSION / COMPRESSION

TRANSVERSE OR LONG'L

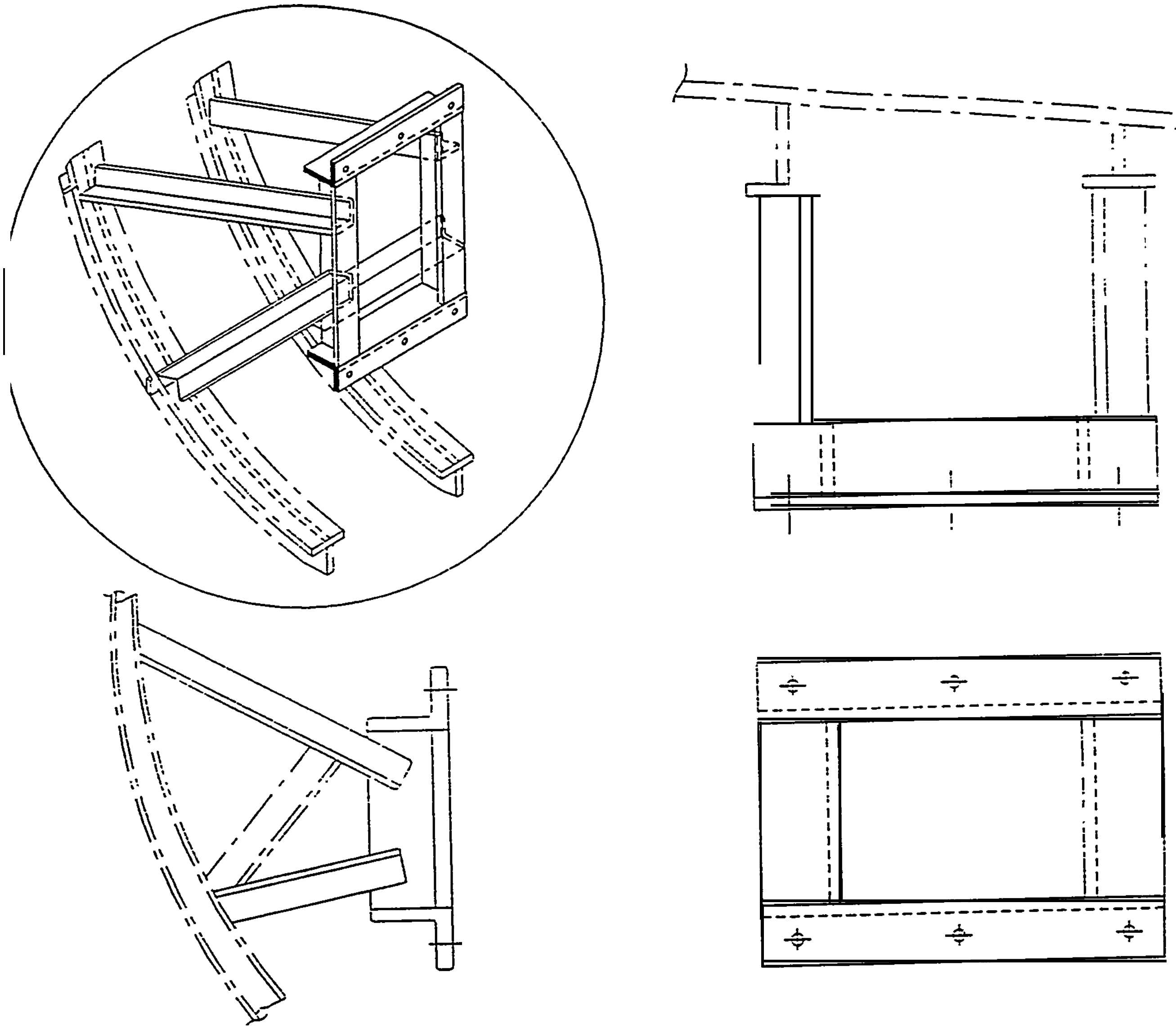


1) OVERTURNING FLANGE BENDING
2.) SHEAR DEFLECTION IN WEB.

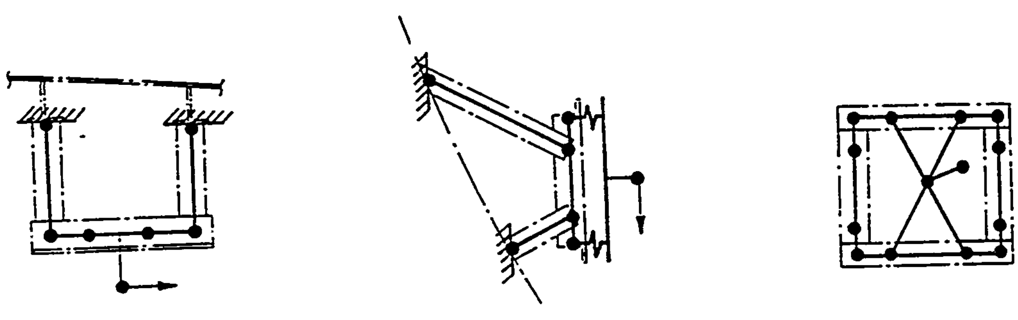
VERTICAL

Hull Mounted
Side Shell Grill age

STANDARD FOUNDATION TYPE 5		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 06 Aug. 95	REV A



Computer Model



Hull Mounted Side Shell Frame

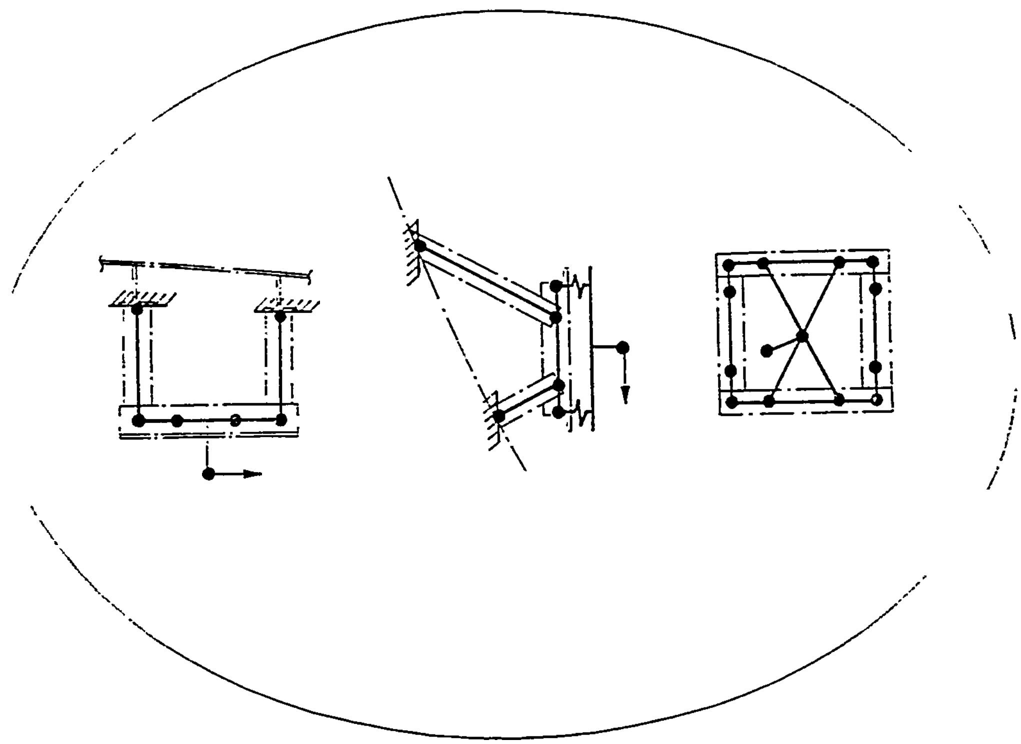
STANDARD FOUNDATION TYPE 6

VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

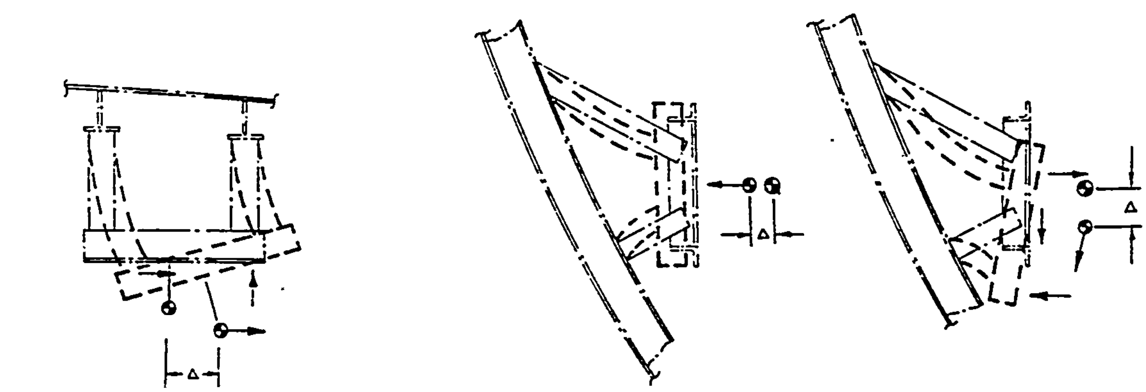
DRWN BY: S. Ducharme
CHCK BY: M. Gupta
APPR BY: JJH
SCALE: NONE
DATE: 08 Aug. 95

REV A

Computer Model



Load Application and Deflection Characterization



1 OVERTURNING LEG COMPRESSION
2 FLANGE FLEXURE

LONGITUDINAL

1. LEG COMPRESSION K1
2. FLANGE FLEXURE K2

$K_{c} = \frac{K1 \times K2}{K1 . K2}$

TRANSVERSE

1. GUIDED CANTILEVER
2. OVERTURNING FLANGE BENDING

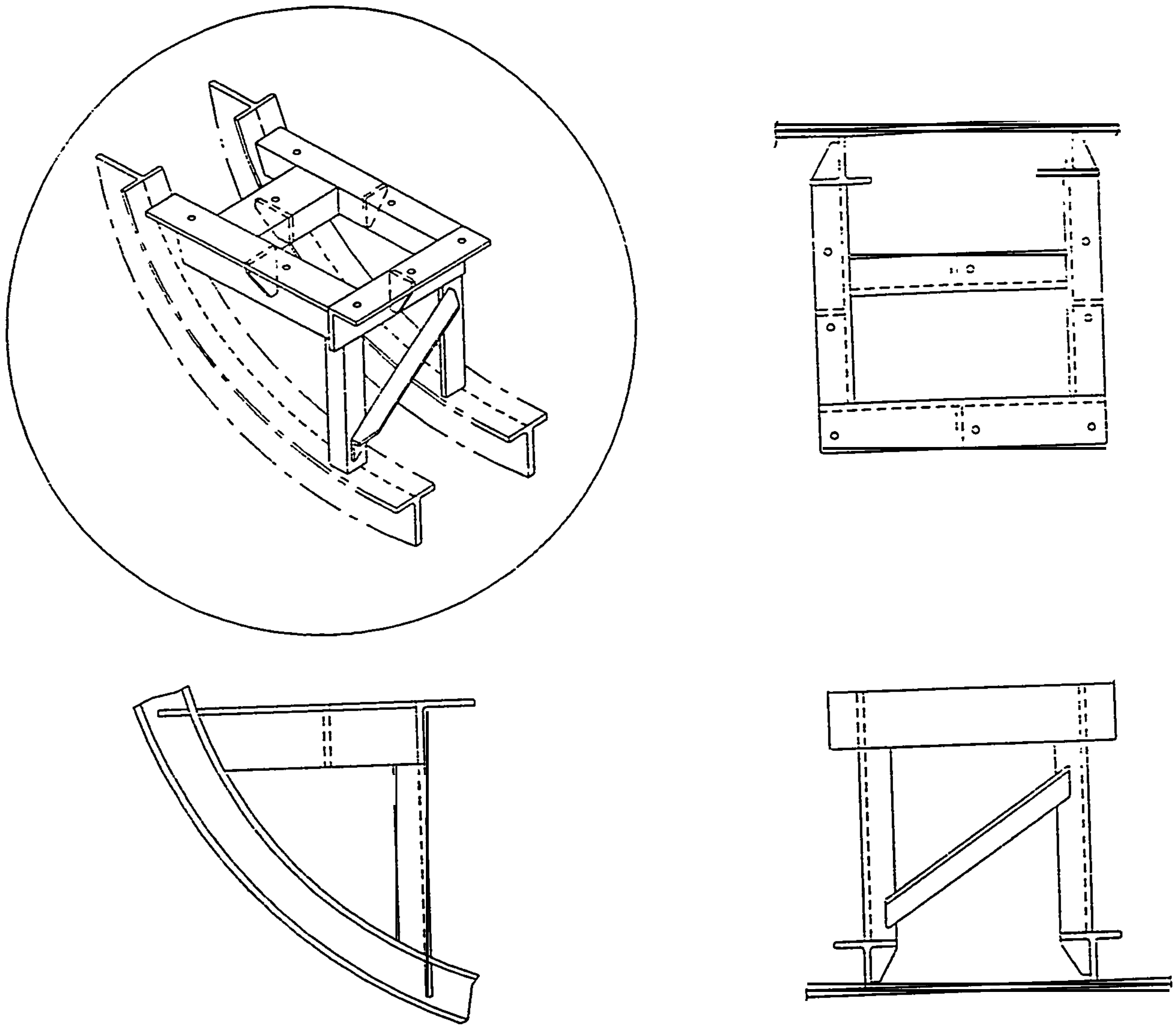
VERTICAL

Hull Mounted Side shell Frame

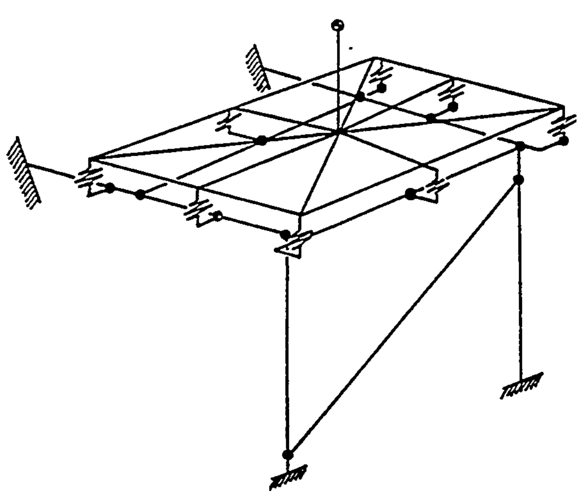
STANDARD FOUNDATION TYPE 6

VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY:	S. Ducharme		REV
CHCK BY:	M. Gupta		A
APPD BY:	JJH		
SCALE: NONE	DATE: 08 Aug. 95		



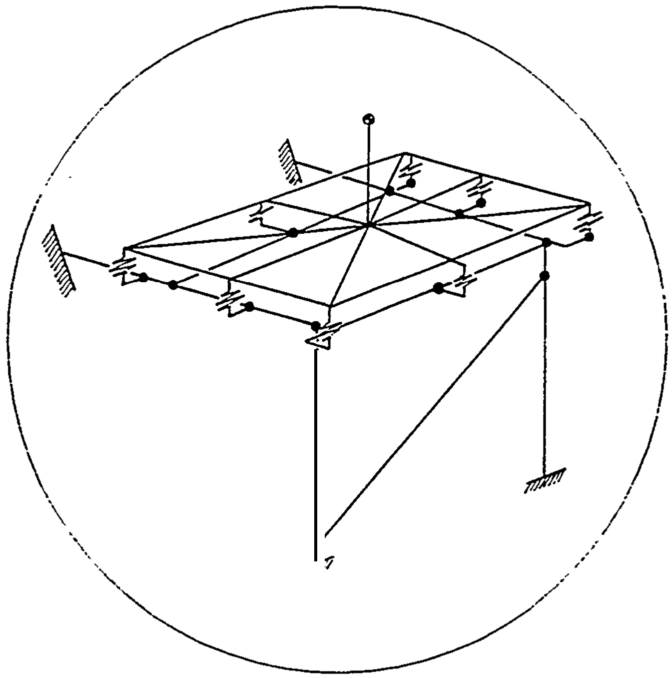
Computer Model



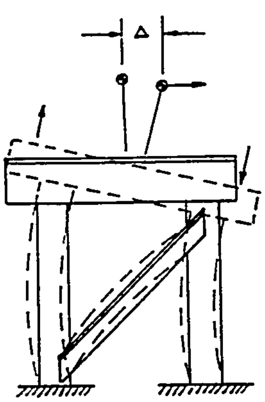
Hull Mounted Side Shell Frame/Truss

STANDARD FOUNDATION TYPE 7		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A

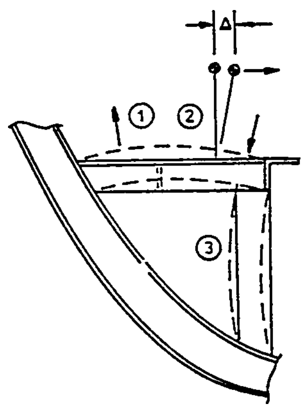
Computer Model



Load Application and Deflection Characterization

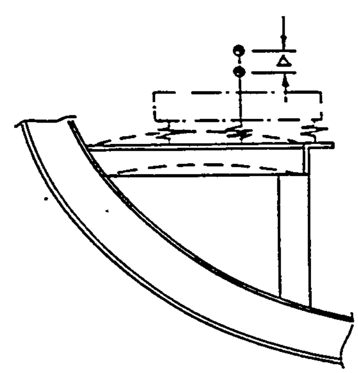


LONGITUDINAL



1) BEAM SE BENDING/ TORSION
2.) FLANGE BENDING
3) LEG COMPRESSION

TRANSVERSE



1.) BEAM BENDING
2.) BEAM TORSION
3.) FLANGE BENDING
4.) LEG TENSION

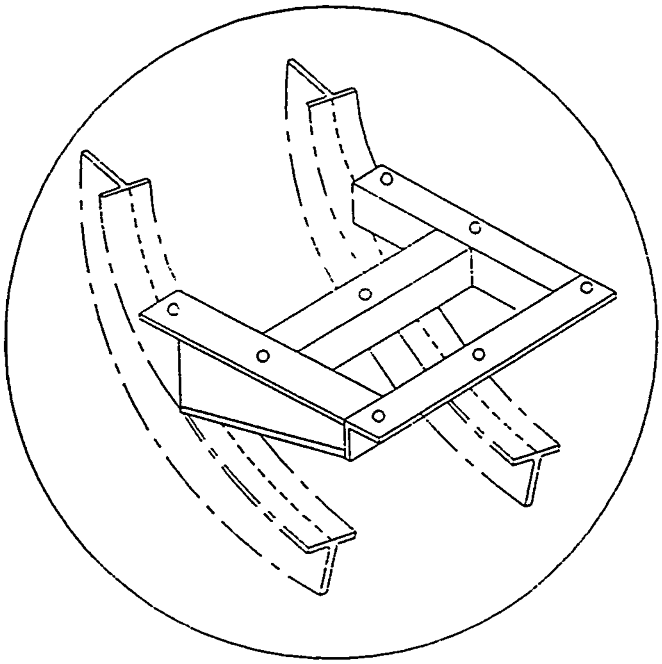
VERTICAL

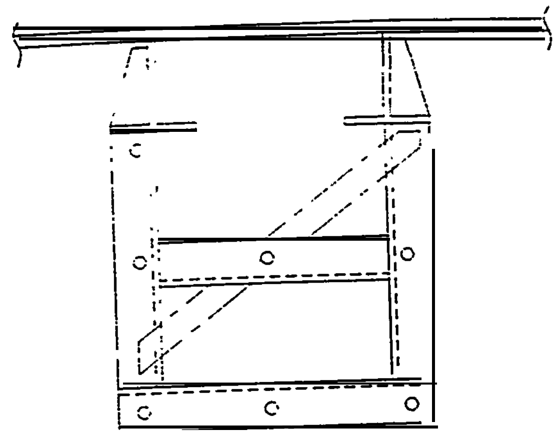
Hull Mounted Side Shell Frame/Truss

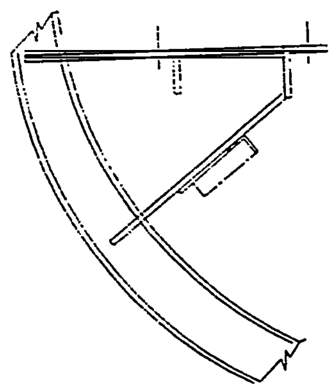
STANDARD FOUNDATION TYPE 7

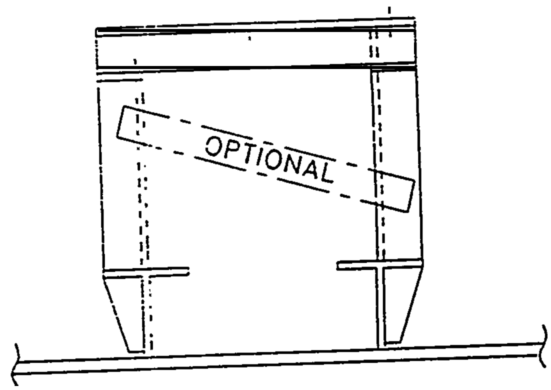
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY:	S. Ducharme
CHCK BY:	M. Gupta
APPR BY:	JJH
SCALE: NONE	DATE: 16 AUG 95
REV	A

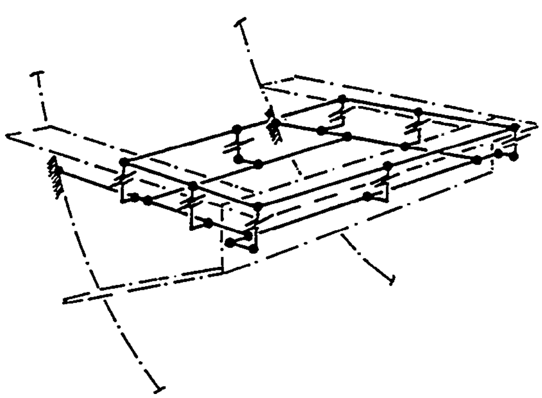








Computer Model

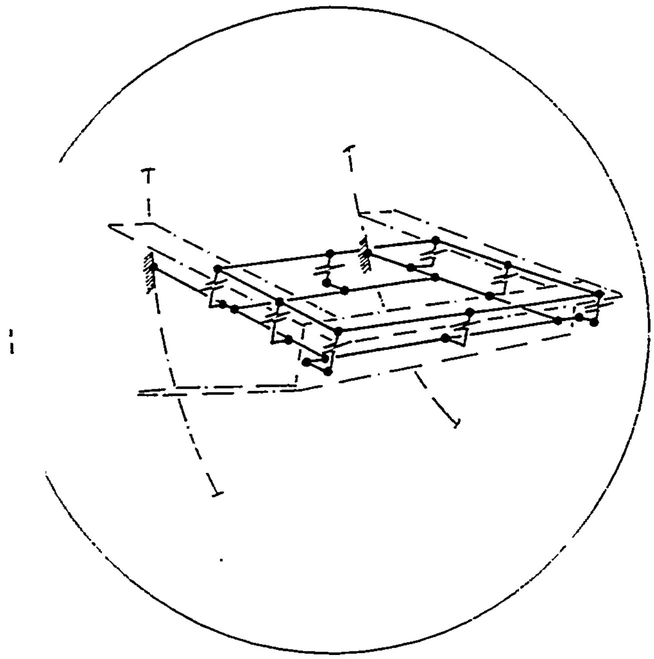


Hull Mounted Side Shell
Shelf Cantilever

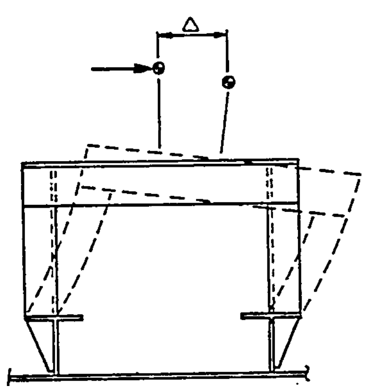
STANDARD FOUNDATION TYPE 8

VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: P. Vogt CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A

Computer Model

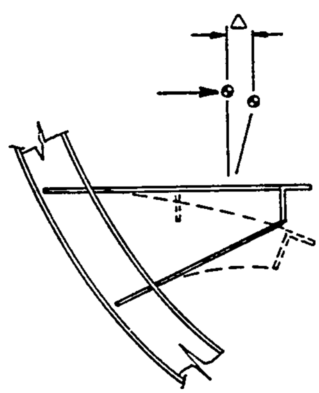


Load Application and Deflection Characterization



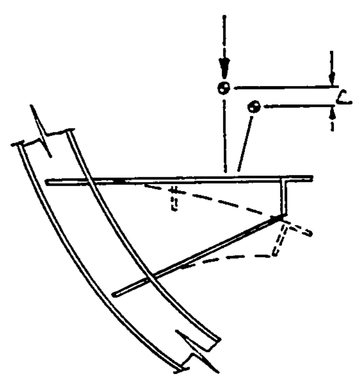
1. FRAME BENDING (GUIDED CANTILEVER)
2. FLANGE BENDING

LONGITUDINAL



1. CANTILEVER BENDING
2. FLANGE BENDING

TRANSVERSE

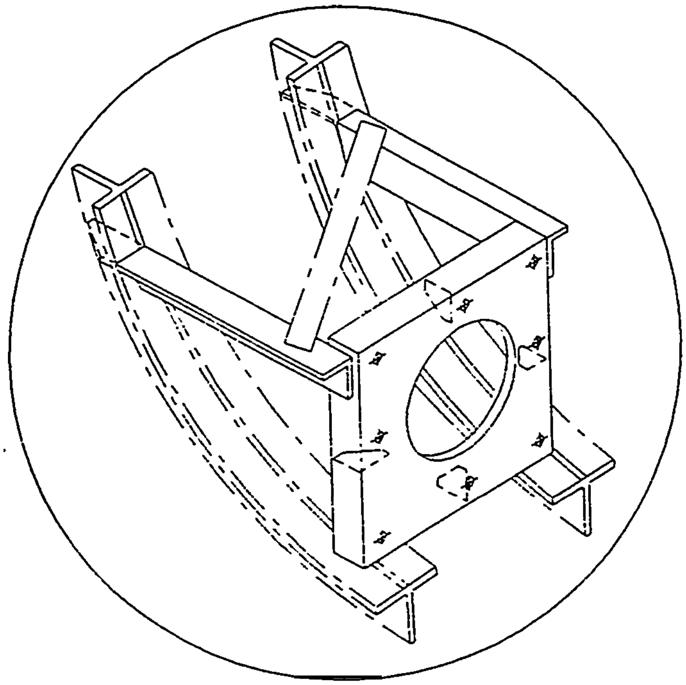


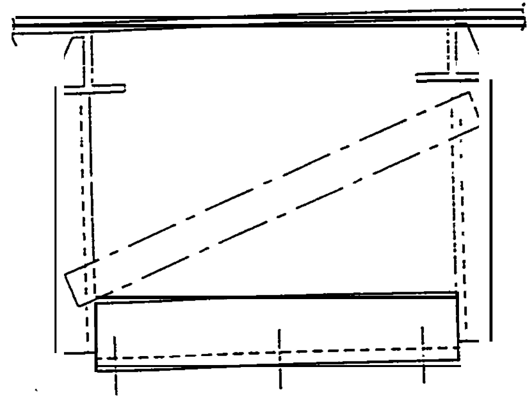
1. CANTILEVER BENDING
2.. FLANGE BENDING

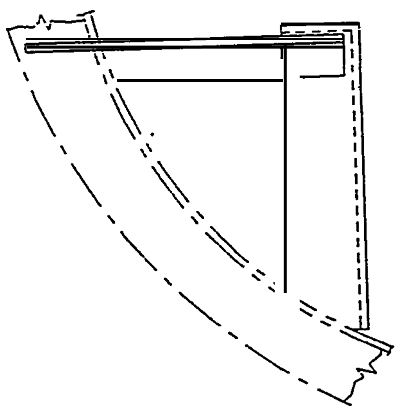
VERTICAL

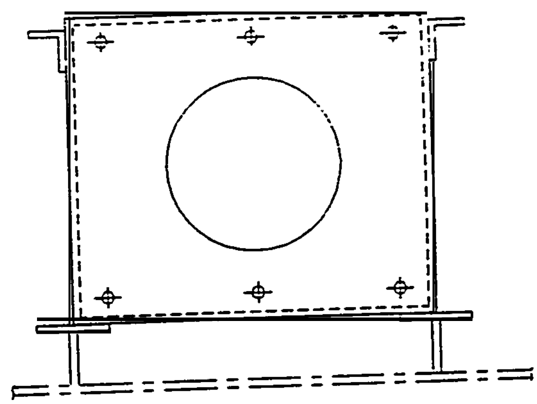
Hull Mounted Side Shell
Shelf Cantilever

STANDARD FOUNDATION TYPE 8		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: P. Vogl CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A

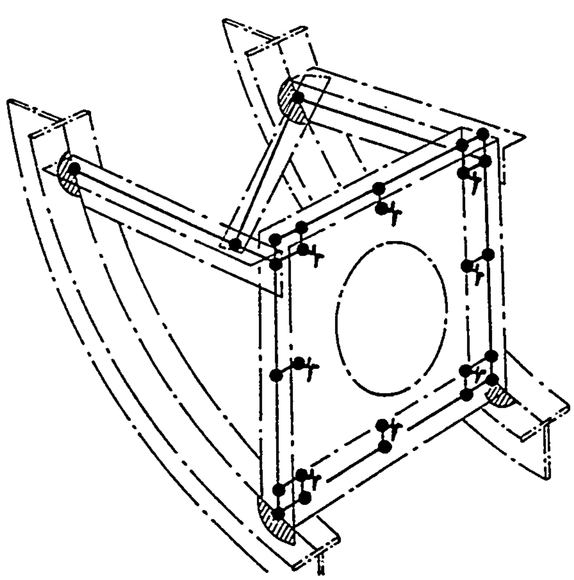








Computer Model

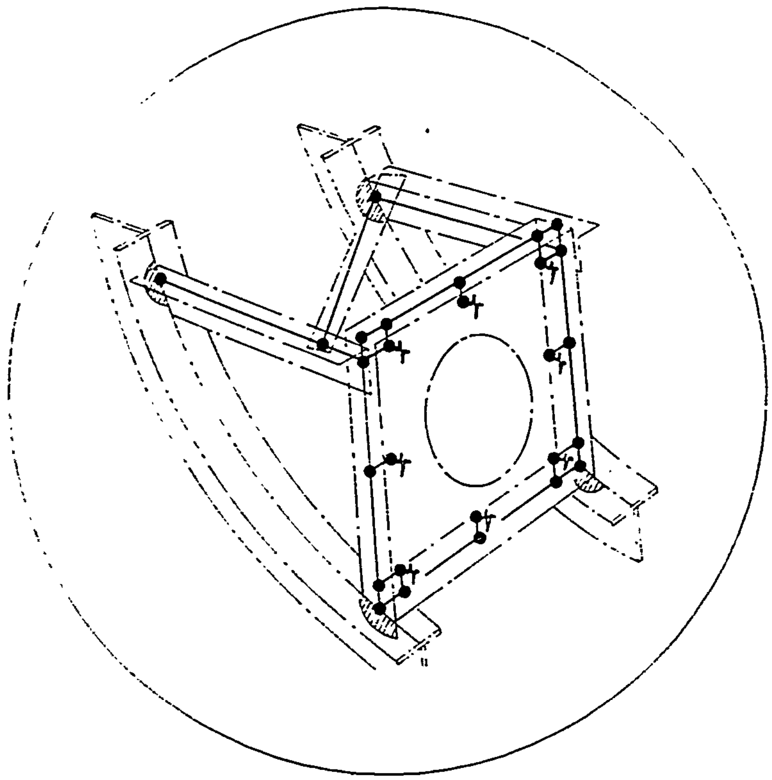


Hull Mounted Side Shell
Panel/Frame

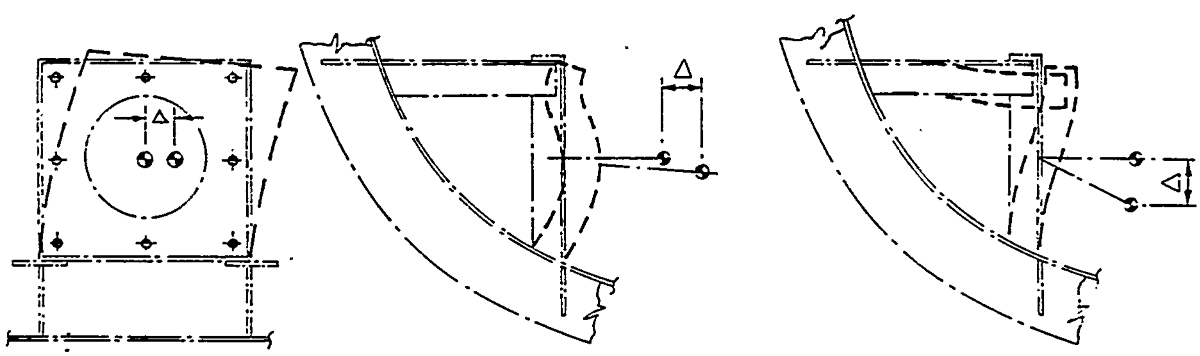
STANDARD FOUNDATION TYPE 9

VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 12 Aug. 95	REV A

Computer **Model**



Load Application and Deflection Characterization



1. PANEL SHEAR DEFLECTION
2. FLANGE BENDING
3. BEAM FLEXURE

LONGITUDINAL

1. FLANGE BENDING
2. BEAM FLEXURE
3. LEG FLEXURE

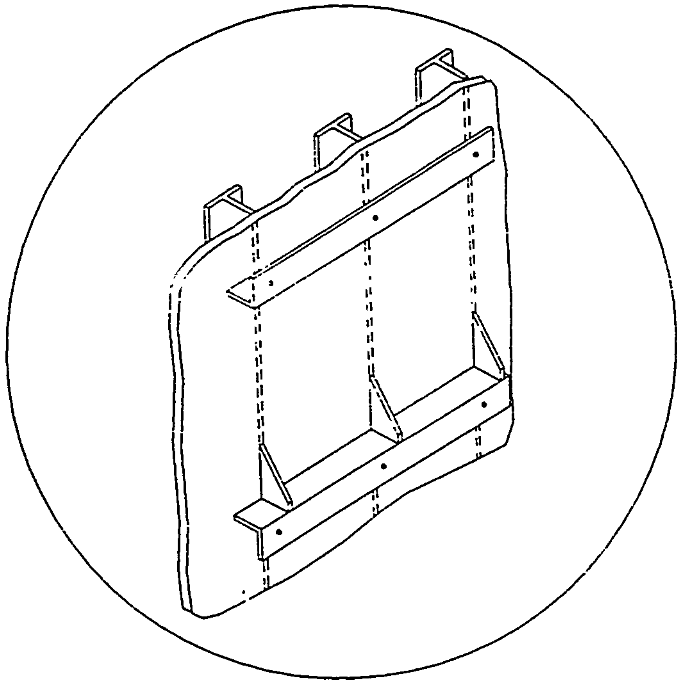
TRANSVERSE

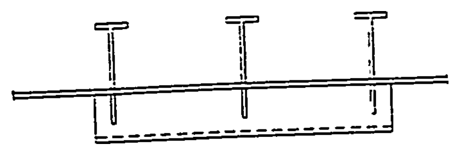
1. FLANGE BENDING
2. BEAM FLEXURE
3. FRAME FLEXURE

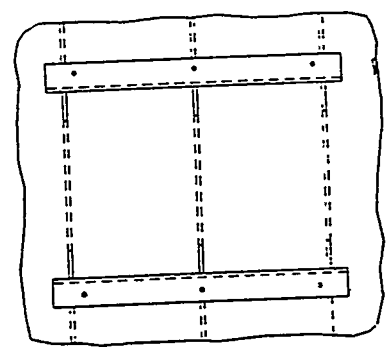
VERTICAL

Hull Mounted Side Shell Panel/Frame

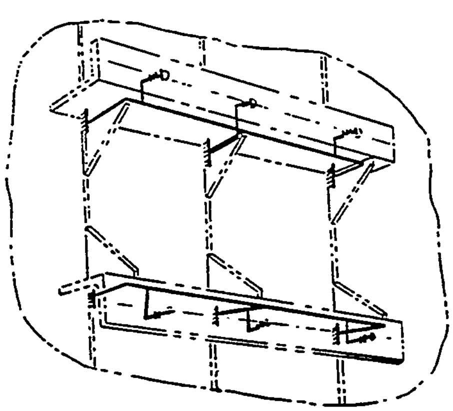
STANDARD FOUNDATION TYPE 9		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 12 Aug. 95	REV A







Computer Model



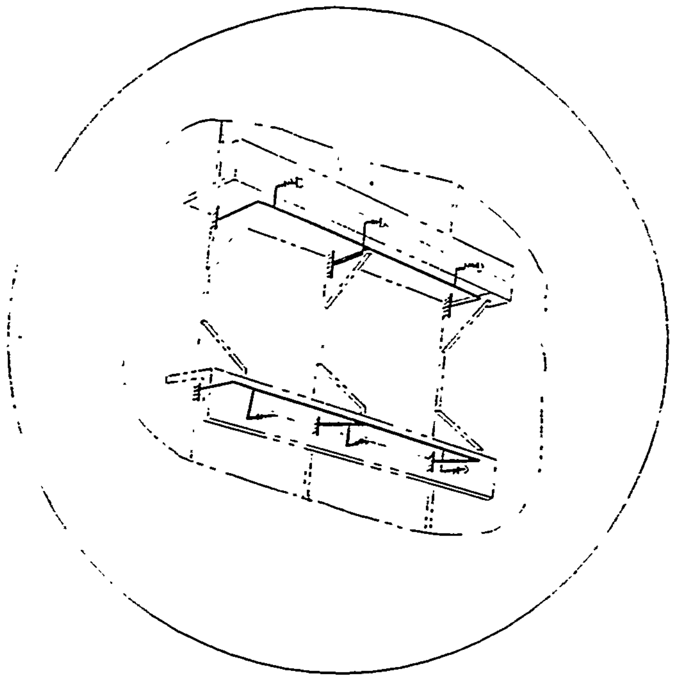
Bulkhead Mounted Grillage

STANDARD FOUNDATION TYPE 10

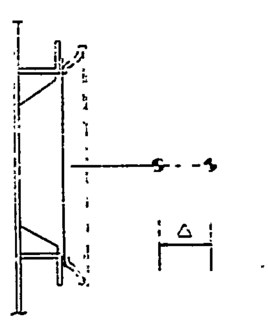
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY:	S. Ducharme
CHCK BY:	M. Gupta
APPR BY:	JJH
SCALE: NONE	DATE: 19 Aug. 95
REV	A

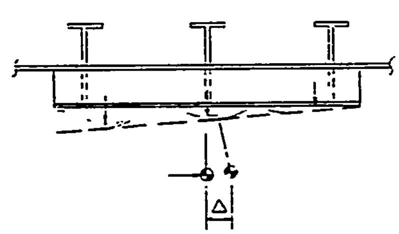
Computer Model



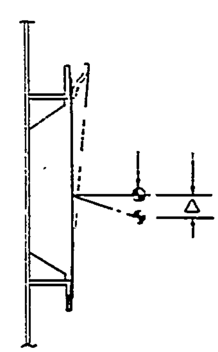
Load Application and Deflection Characterization



1. FLANGE BENDING
LONGITUDINAL



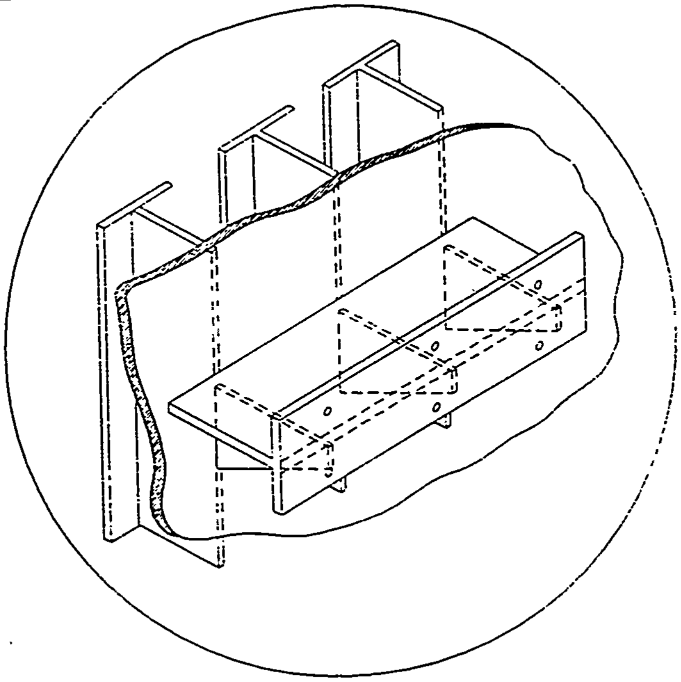
1. FLANGE BENDING
TRANSVERSE

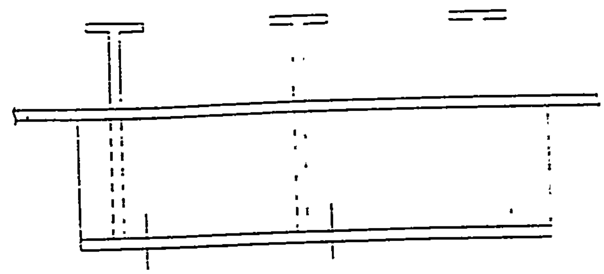


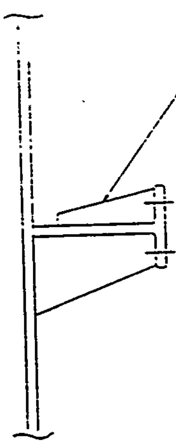
1. FLANGE BENDING
VERTICAL

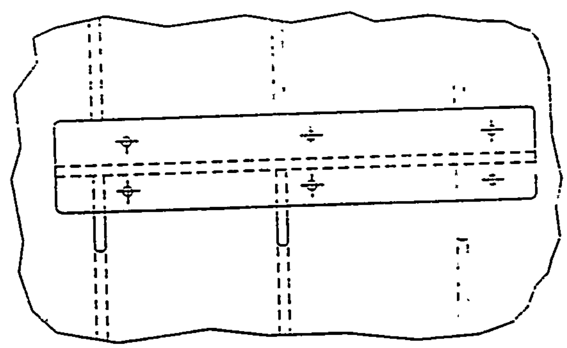
Bulkhead Mounted Grillage

STANDARD FOUNDATION TYPE 10		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: DATE:	REV A

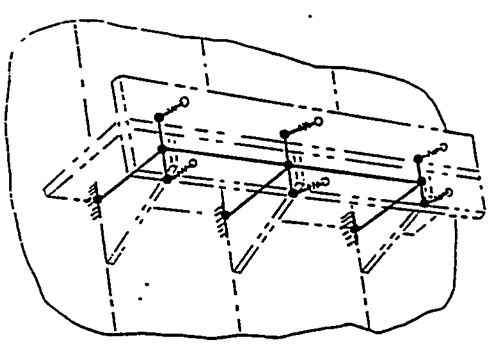








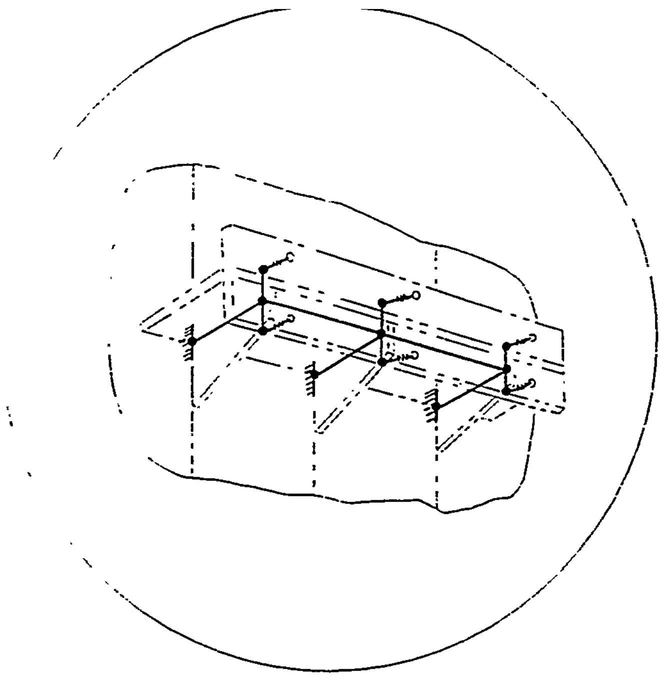
Computer Model



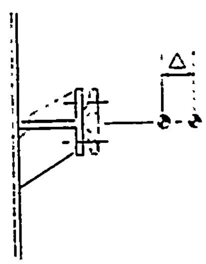
Bulkhead Mounted Torque Be

STANDARD FOUNDATION TYP		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY M. Gupta APPR BY: JJH	
	SCALE: NONE	DATE: 16 AUG 95

Computer Model

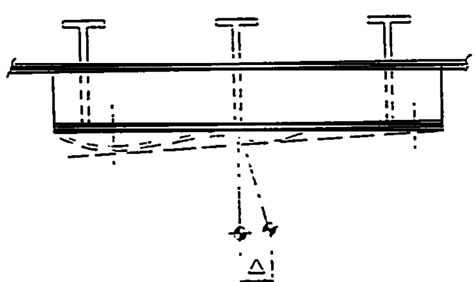


Load Application and Deflection Characterization



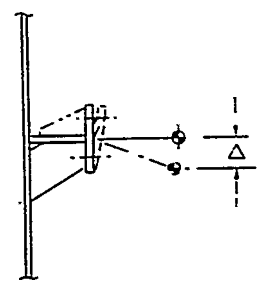
1. FLANGE BENDING

LONGITUDINAL



1. FLANGE BENDING

TRANSVERSE



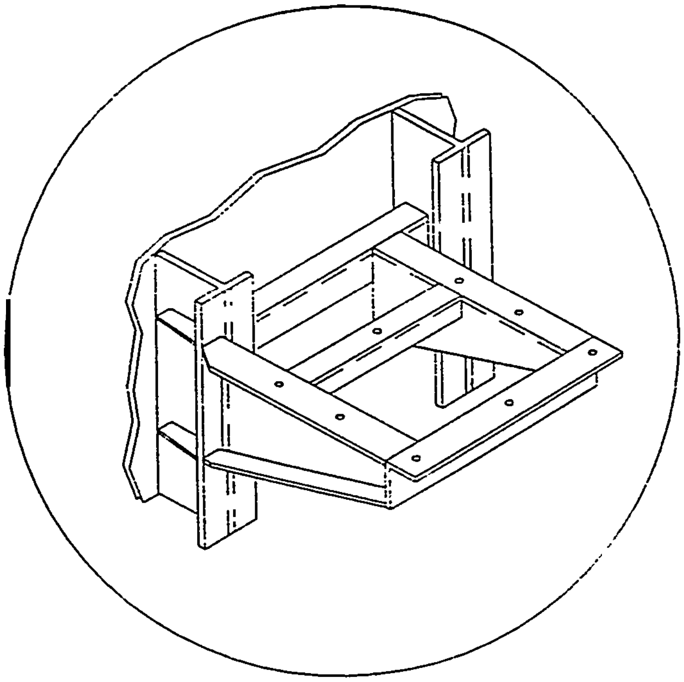
1. FLANGE BENDING

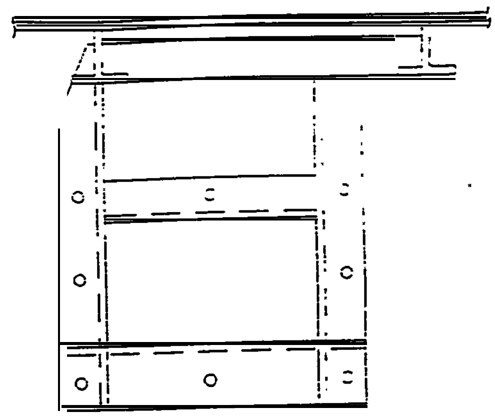
VERTICAL

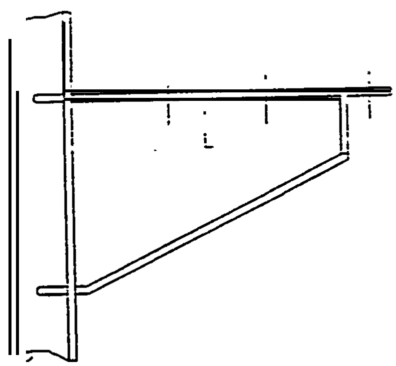
Bulkhead Mounted Torque Beam

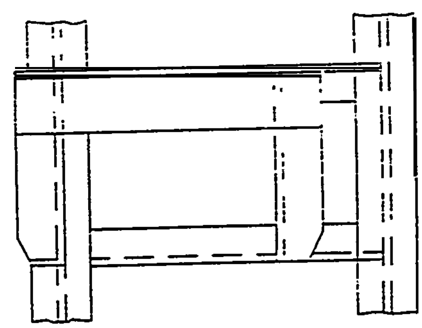
STANDARD FOUNDATION TYPE 11

VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH		REV A

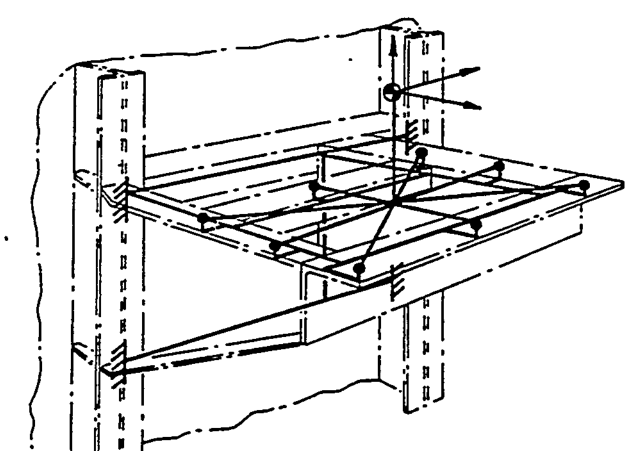








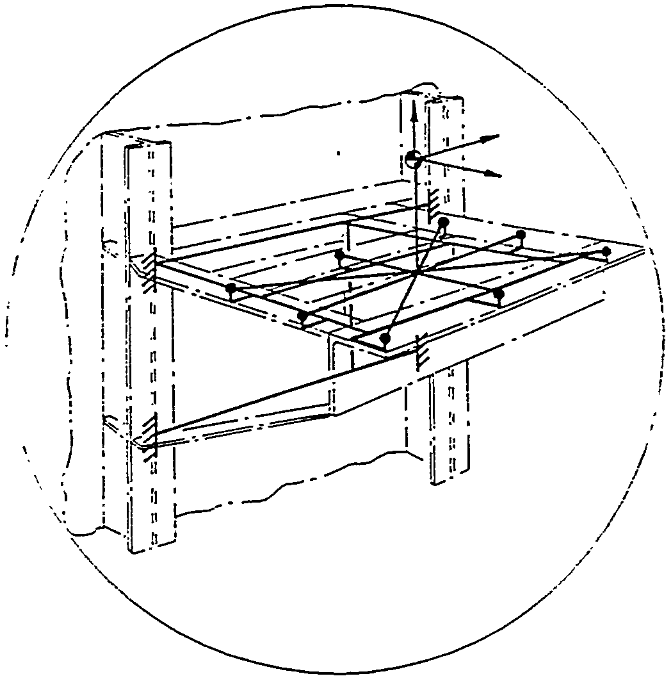
Computer Model



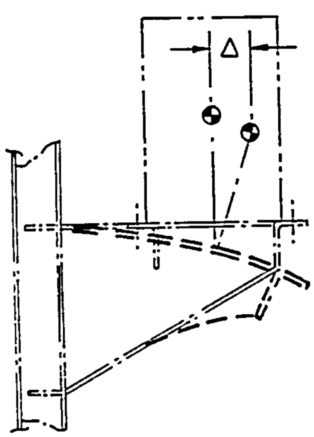
Bulkhead Mounted Shelf

STANDARD FOUNDATION TYPE	
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH

Computer Model

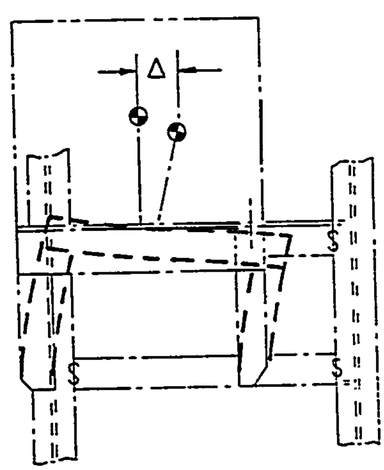


Load Application and Deflection Characterization



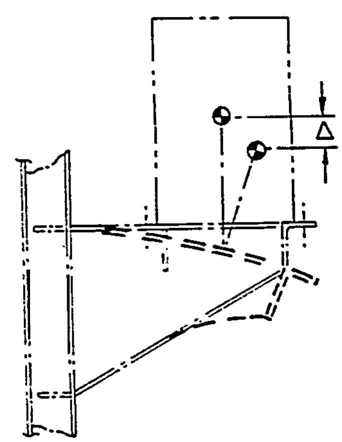
1. FLANGE BENDING
2. CANTILEVER FLEXURE

LONGITUDINAL



1. FLANGE BENDING
2. FRAME BENDING
3. CANTILEVER FLEXURE

TRANSVERSE



1. FLANGE BENDING
2. CANTILEVER FLEXURE

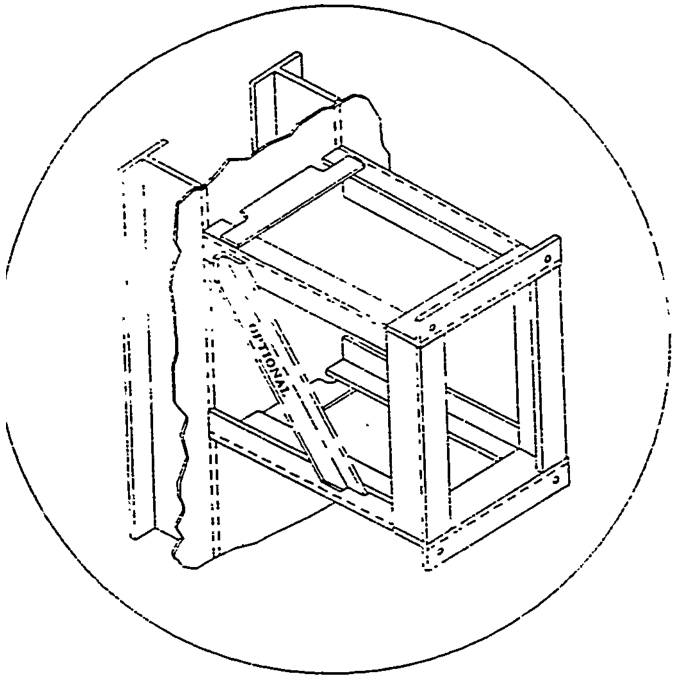
VERTICAL

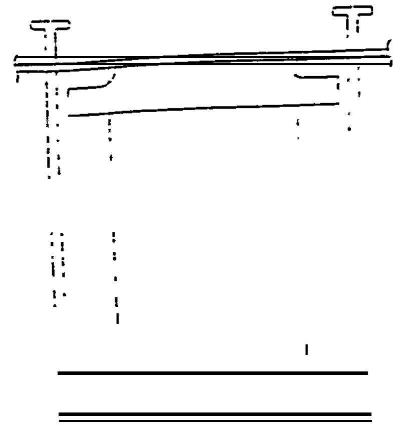
Bulkhead Mounted Shelf

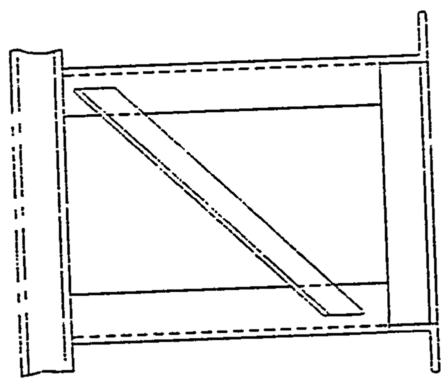
STANDARD FOUNDATION TYPE 12

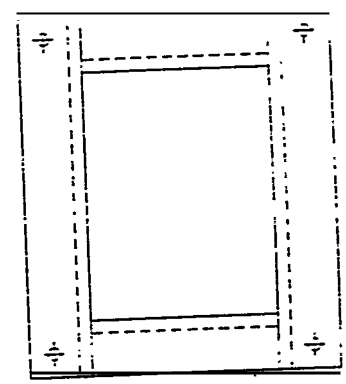
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY:	S. Ducharme	REV
CHCK BY:	M. Gupta	
APPR BY:	JJH	A
SCALE: NONE	DATE: 16 AUG 95	

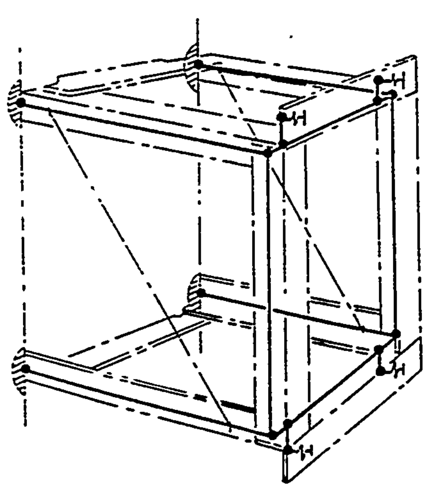








Compututer Model



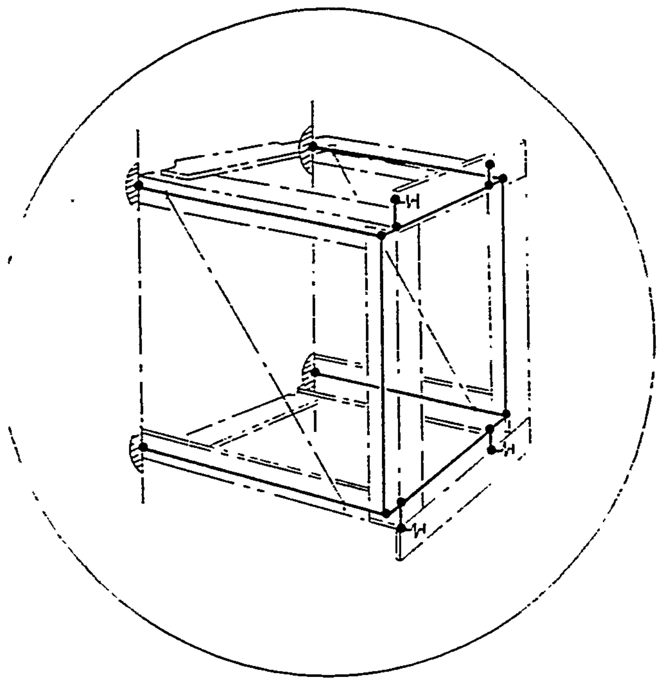
Bulkhead Mounted Frame/Truss

STANDARD FOUNDATION TYPE 13

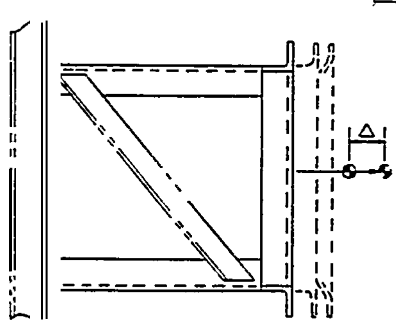
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY: S. Ducharme		REV
CHCK BY: M. Gupta		A
APPR BY: JJH		
SCALE: NONE	DATE: 16 AUG 85	

Computer Model

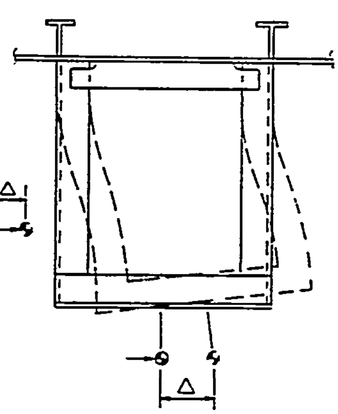


Load Application and Deflection Characterization



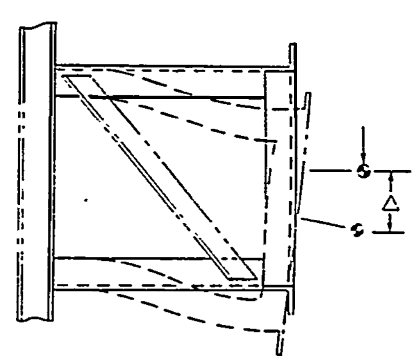
1. FLANGE BENDING
2. LEG FLEXURE

LONGITUDINAL



1. FRAME BENDING
2. FLANGE BENDING

TRANSVERSE



1. FRAME BENDING
2. FLANGE BENDING
3. TRUSS ACTION [OPTIONAL]

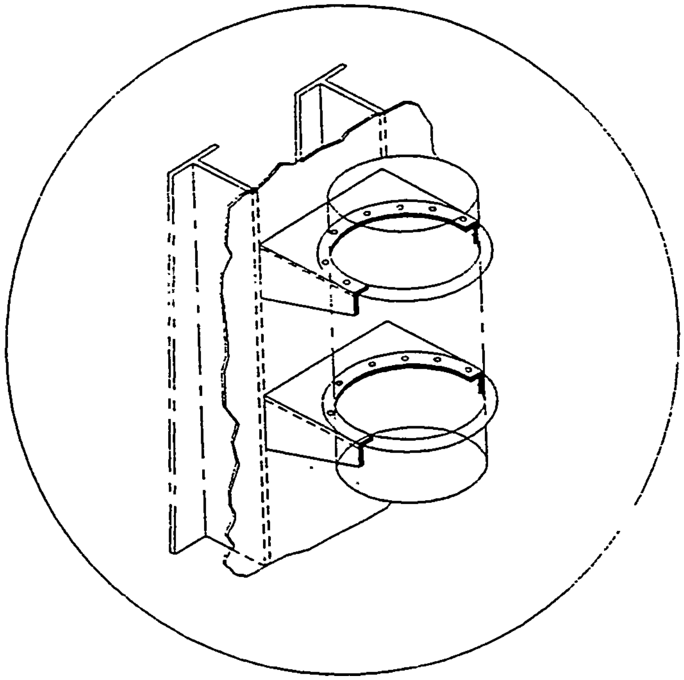
VERTICAL

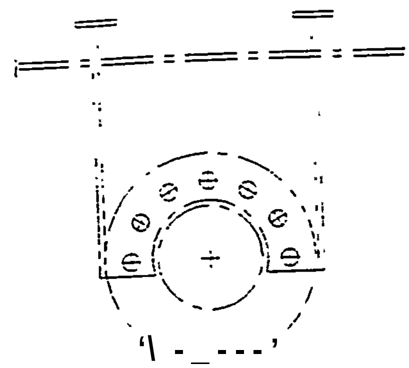
Bulkhead Mounted Frame/Truss

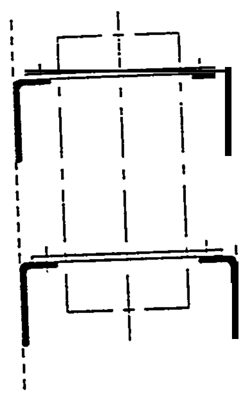
STANDARD FOUNDATION TYPE 13

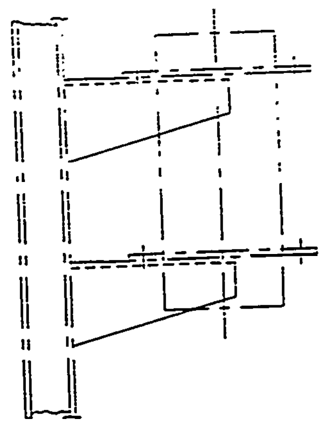
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY: S. Ducharme		REV
CHCK BY: M. Gupta		
APPR BY: JJH		A
SCALE: NONE	DATE: 16 AUG 95	

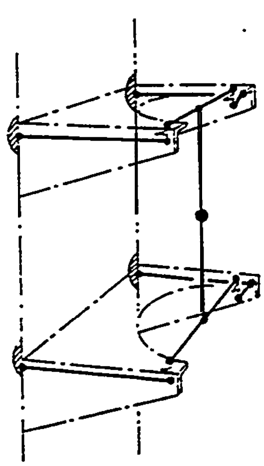








Computer Model



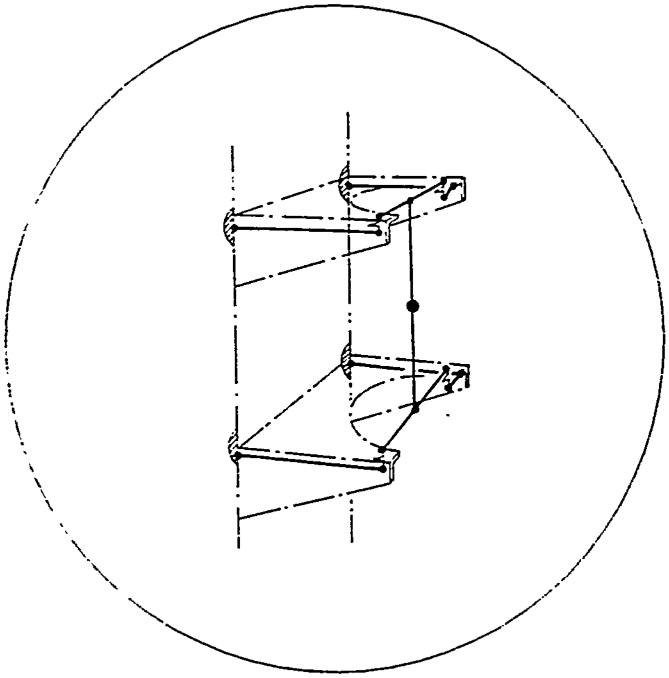
Bulkhead Mounted Shelf/Cantilever

STANDARD FOUNDATION TYPE 14

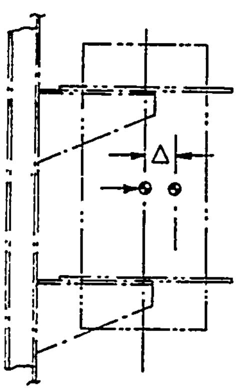
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY:	S. Ducharme	REV
CHCK BY:	M. Gupta	A
APPR BY:	JJH	
SCALE: NONE	DATE: 16 AUG 95	

Computer Model

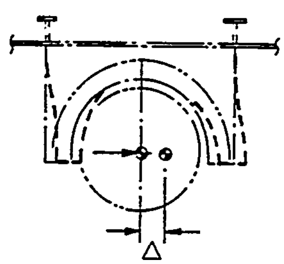


Load Application and Deflection Characterization



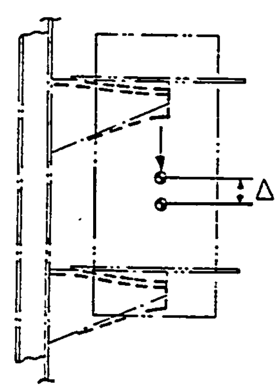
1. PLATE IN PLANE FLEXURE

LONGITUDINAL



1. SHEAR BRACKET

TRANSVERSE

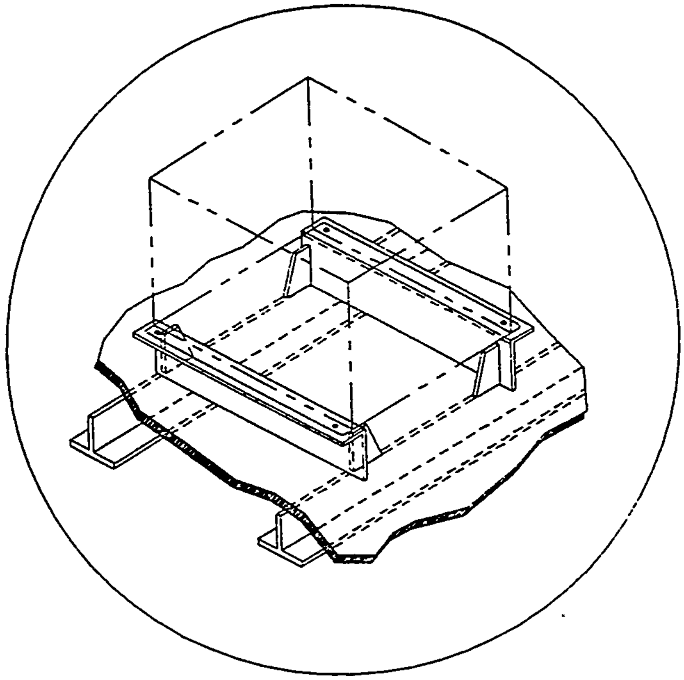


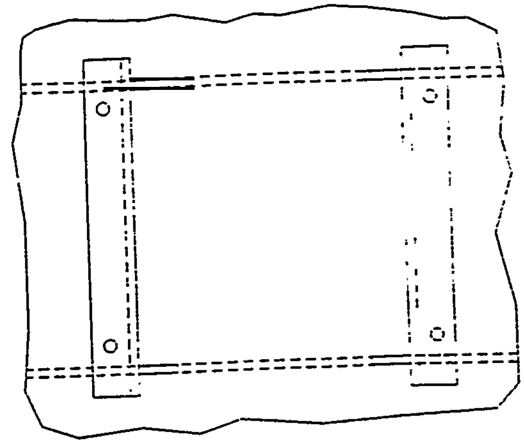
1. FLANGE BENDING
2. BEAM BENDING/TORSION

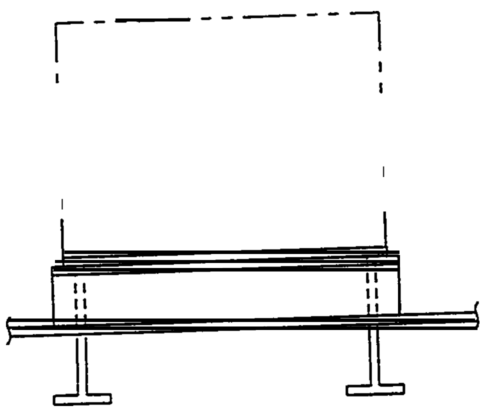
VERTICAL

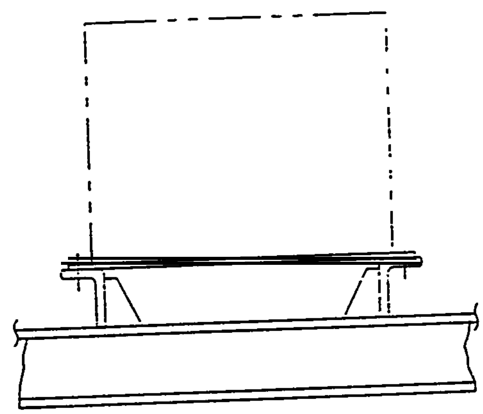
Bulkhead Mounted Shelf/Cantilever

STANDARD FOUNDATION TYPE 14		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A

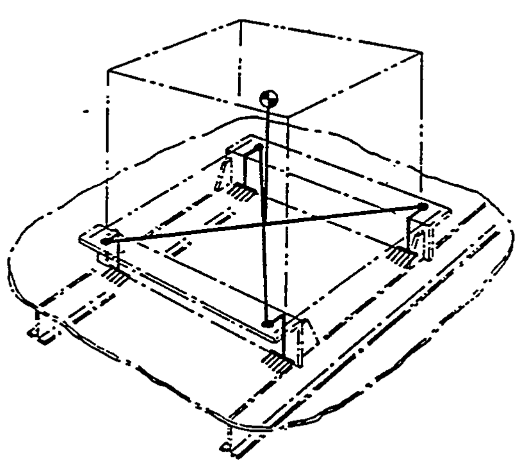








Computer Model

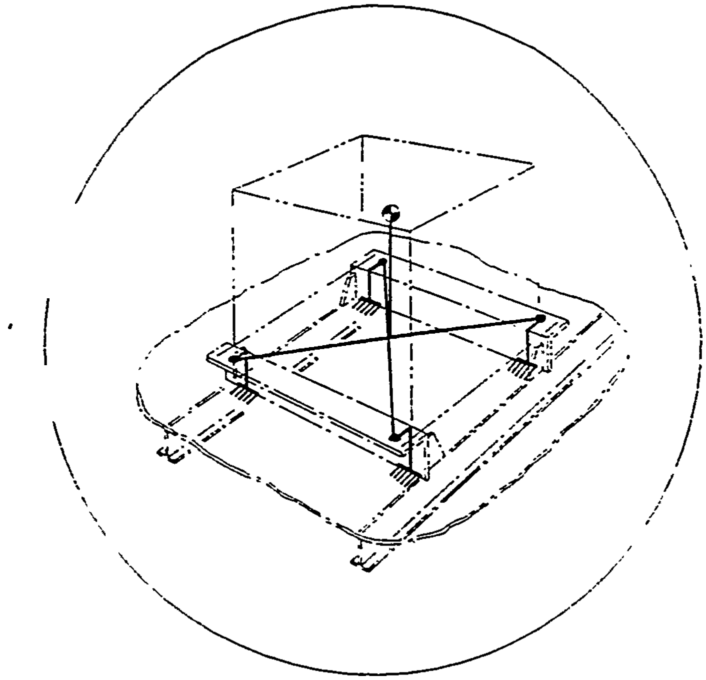


Deck Mounted Grillage

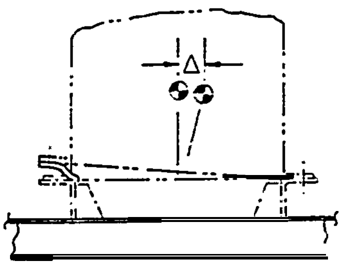
STANDARD FOUNDATION TYPE 15

VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A

Computer Model



Load Application and Deflection Characterization

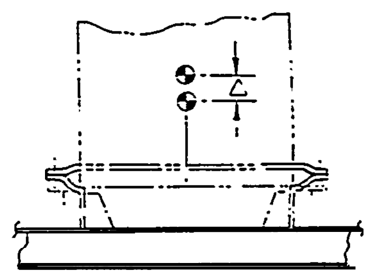


1. FLANGE BENDING

LONGITUDINAL

1. FLANGE BENDING

TRANSVERSE

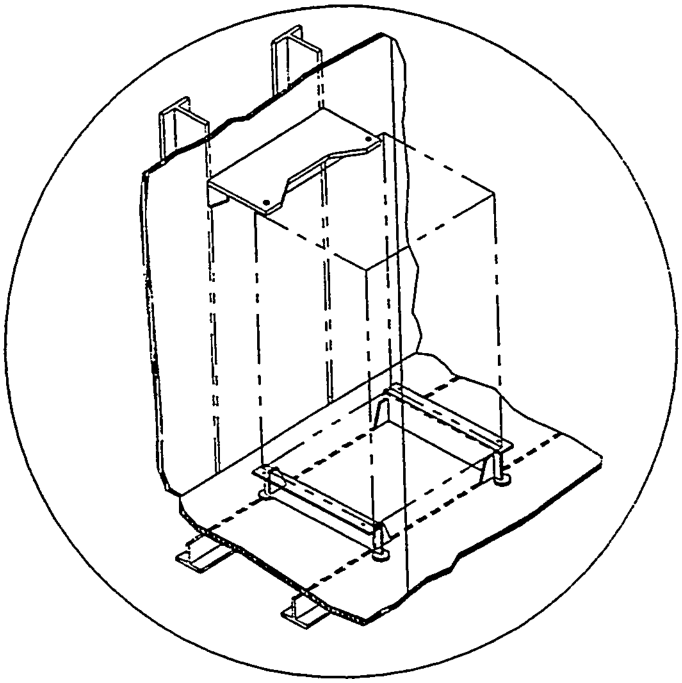


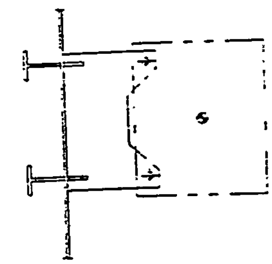
1. FLANGE BENDING

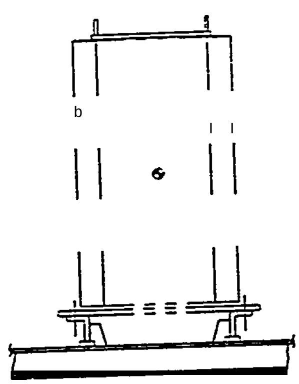
VERTICAL

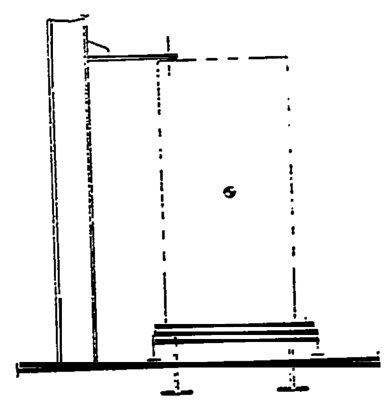
Deck Mounted Grillage

STANDARD FOUNDATION TYPE 15		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A

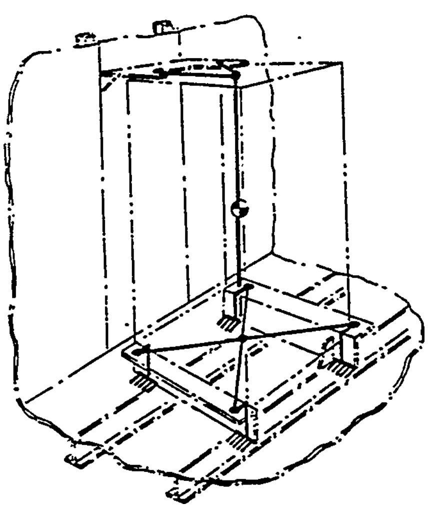








Computer Model



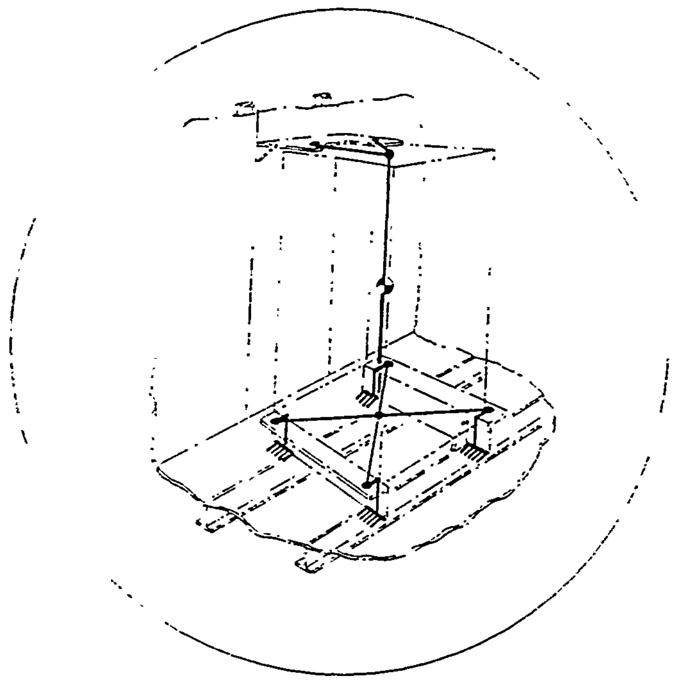
Deck Mounted Grillage
With Upper Support

STANDARD FOUNDATION TYPE 16

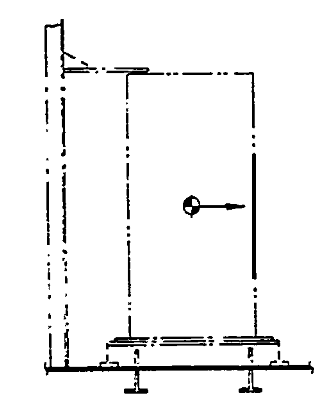
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY:	S. Ducharme	REV
CHCK BY:	M. Gupta	A
APPR BY:	JJH	
SCALE: NONE	DATE: 16 AUG 94	

Computer Model

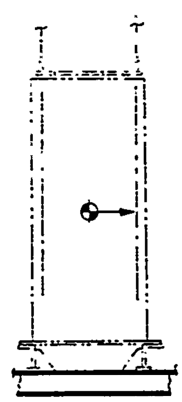


Load Application and Deflection Characterization



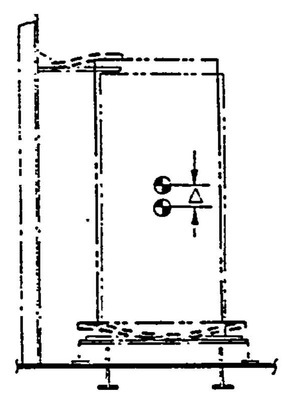
1. HORIZONTAL SHEAR

LONGITUDINAL



1. HORIZONTAL SHEAR

TRANSVERSE

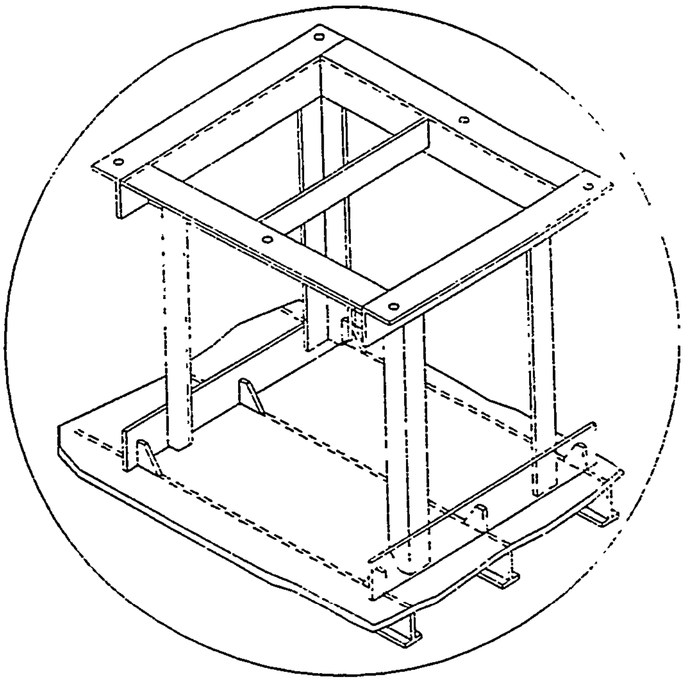


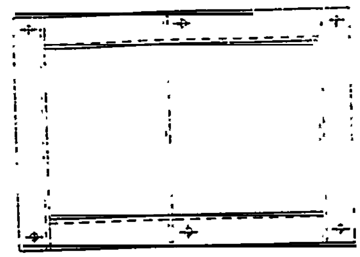
1. FLANGE BENDING

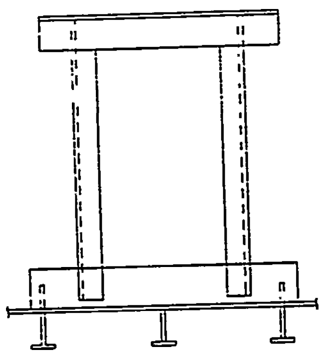
VERTICAL

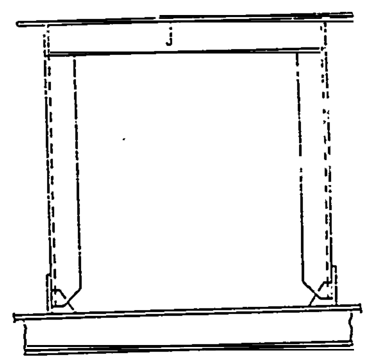
Deck Mounted Grillage
With Upper Support

STANDARD FOUNDATION TYPE 16		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 94	REV A

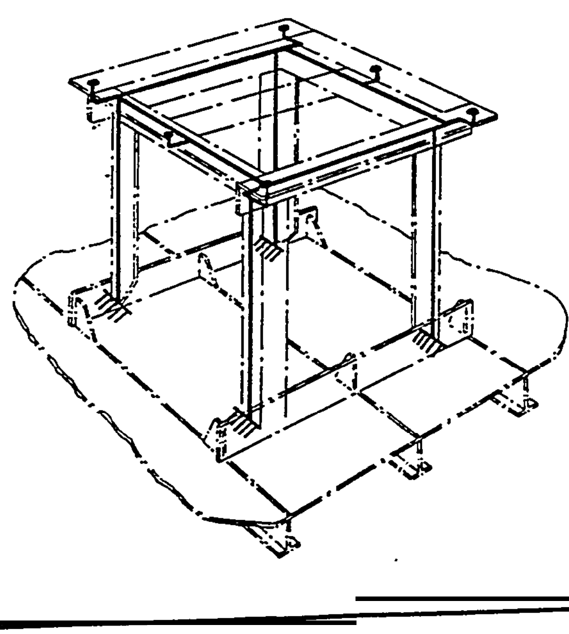








Computer Model



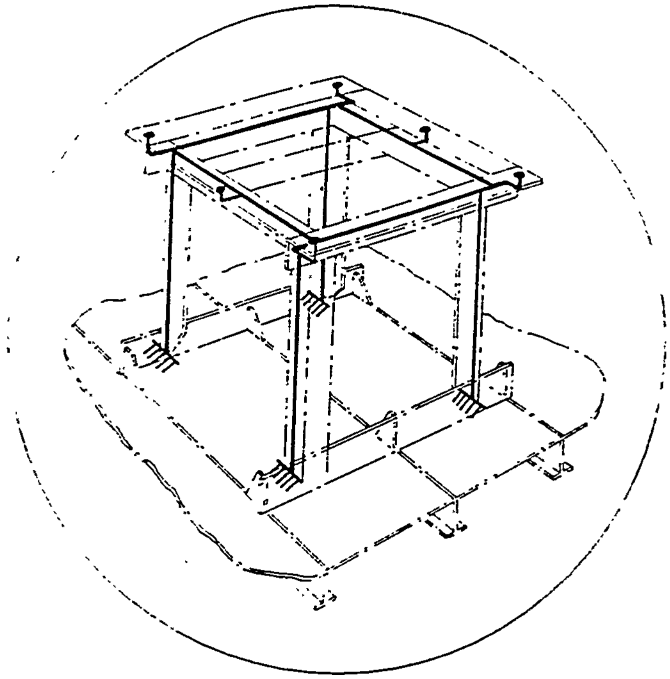
Deck Mounted Frame

STANDARD FOUNDATION TYPE 17

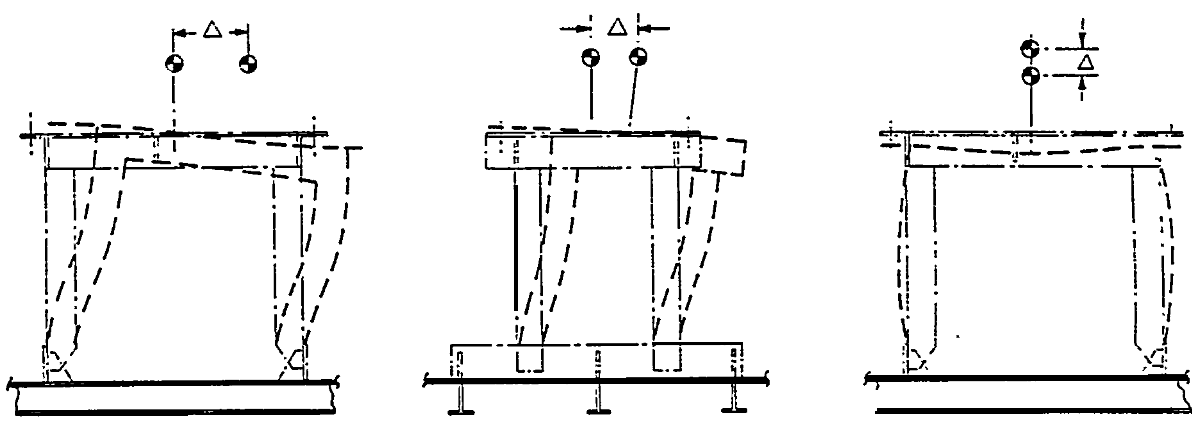
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY:	S. Ducharme		REV
CHCK BY:	M. Cupla		A
APPR BY:	JJH		
SCALE: NONE	DATE: 16 AUG 95		

Computer Model



Load Application and Deflection Characteristics



1. FLANGE BENDING
2. FRAME BENDING

LONGITUDINAL

1. FLANGE BENDING
2. FRAME BENDING

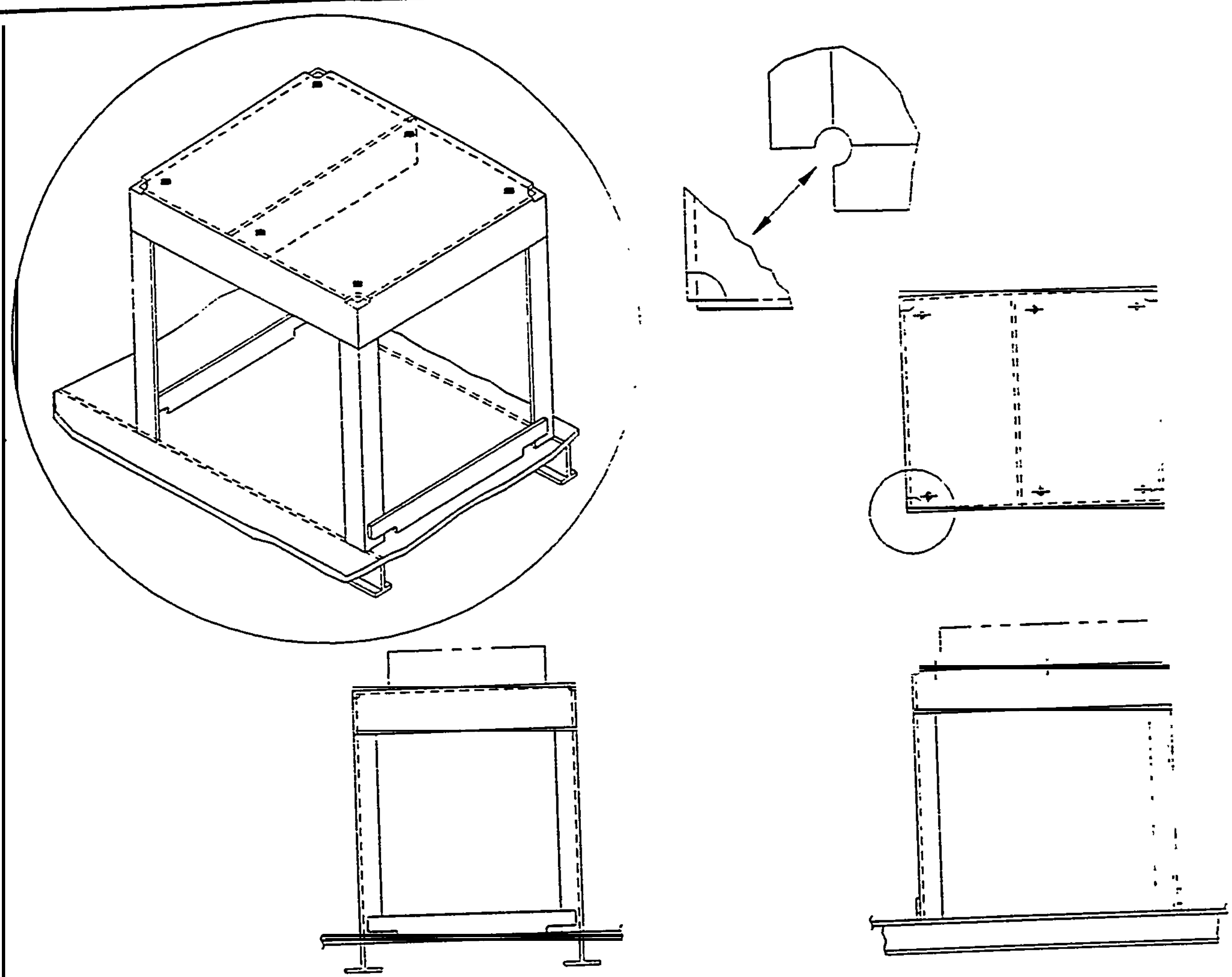
TRANSVERSE

1. FLANGE BENDING
2. BEAM BENDING
3. LEG FLEXURE

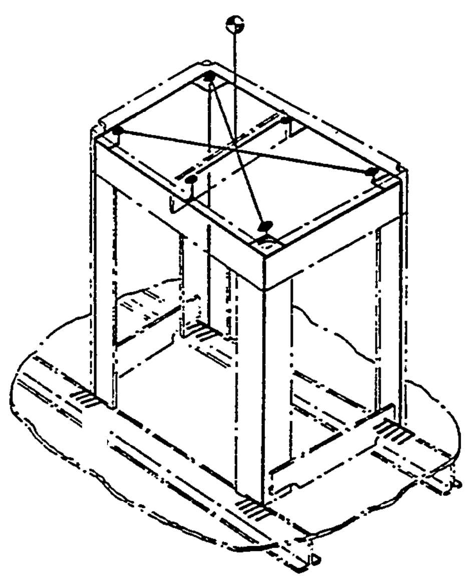
VERTICAL

Deck Mounted Frame

STANDARD FOUNDATION TYPE 17		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Cupla APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A



Computer Model

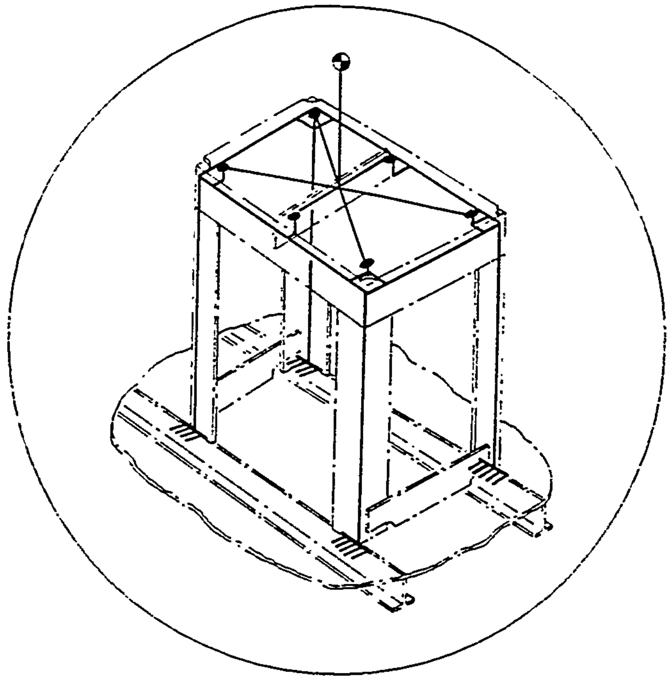


Deck Mounted Frame/Panel

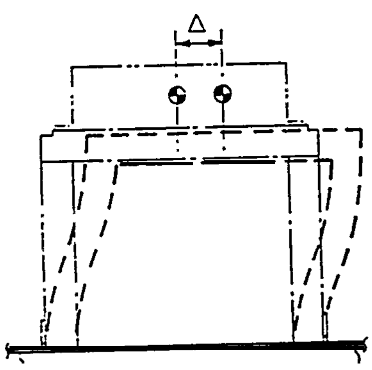
STANDARD FOUNDATION TYPE 18

VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A

Computer Model

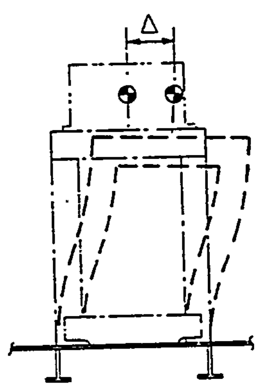


Load Application and Deflection Characterization



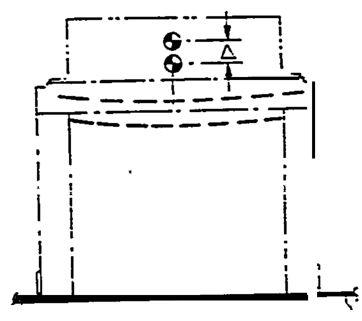
1. FLANGE BENDING
2. FRAME BENDING
3. LEG FLEXURE

LONGITUDINAL



1. FLANGE BENDING
2. FRAME BENDING
3. LEG FLEXURE

TRANSVERSE

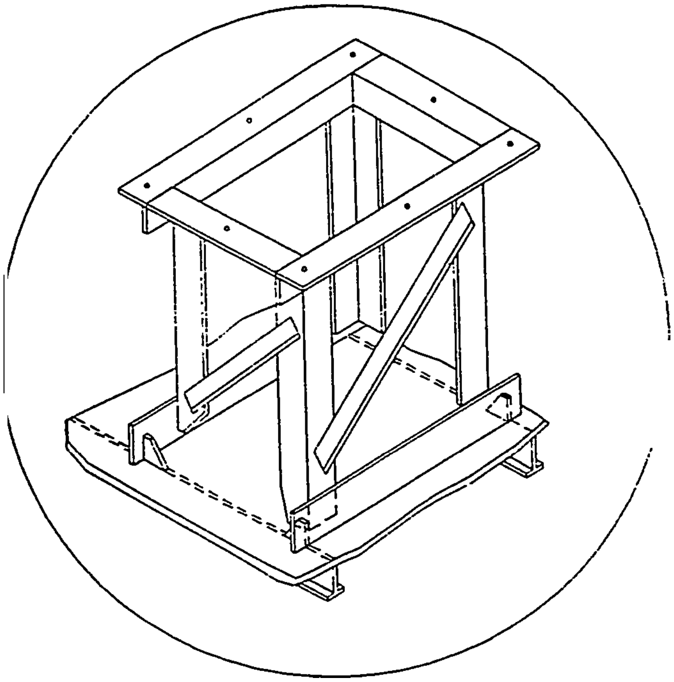


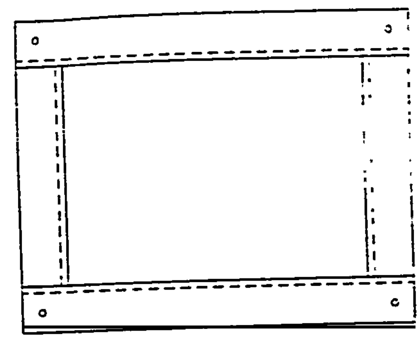
L FLANGE BENDING
2. BEAM BENDING
3. LEG FLEXURE

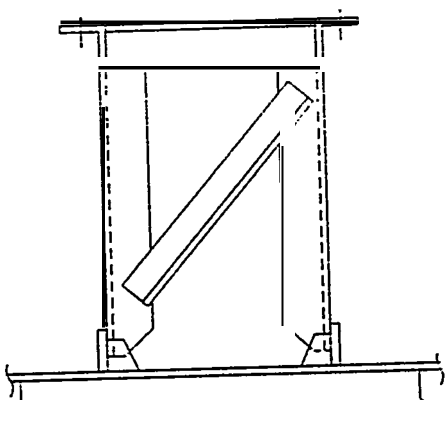
VERTICAL

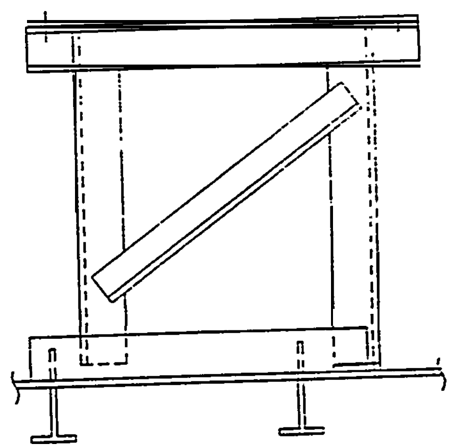
Deck Mounted Frame/Panel

STANDARD FOUNDATION TYPE 18		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 15 AUG 95	REV A

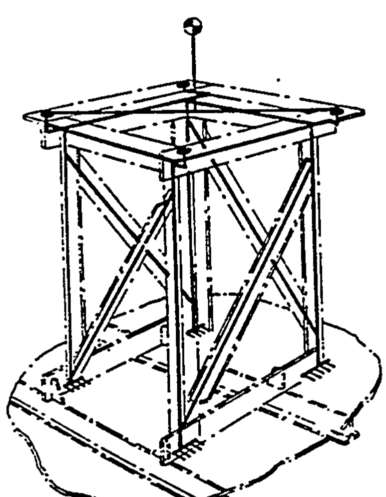








Computer Model



Deck Mounted Truss/Frame

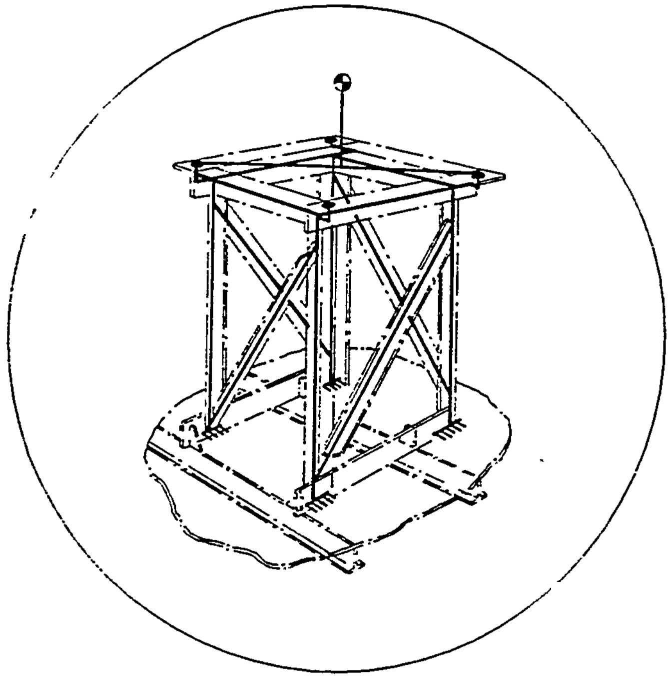
STANDARD FOUNDATION TYPE 19

VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

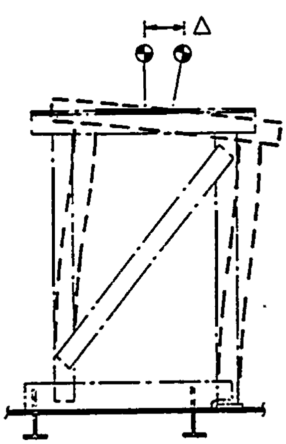
DRWN BY: S. Ducharme
CHCK BY: M. Gupta
APPR BY: JJH
SCALE: NONE
DATE: 16 AUG 95

REV A

Computer Model

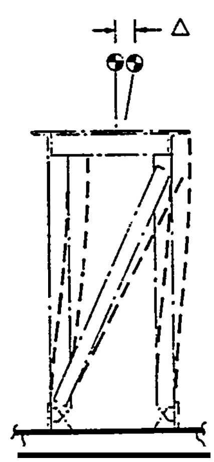


Load Application and Deflection Characterization



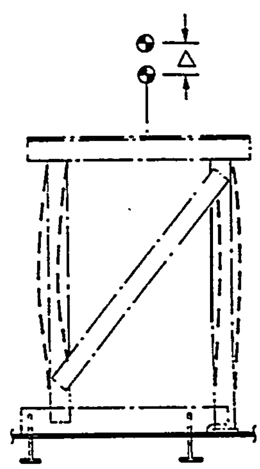
1. FLANGE BENDING
2. TRUSS FLEXURE

LONGITUDINAL



L FLANGE BENDING
2. TRUSS FLEXURE

TRANSVERSE



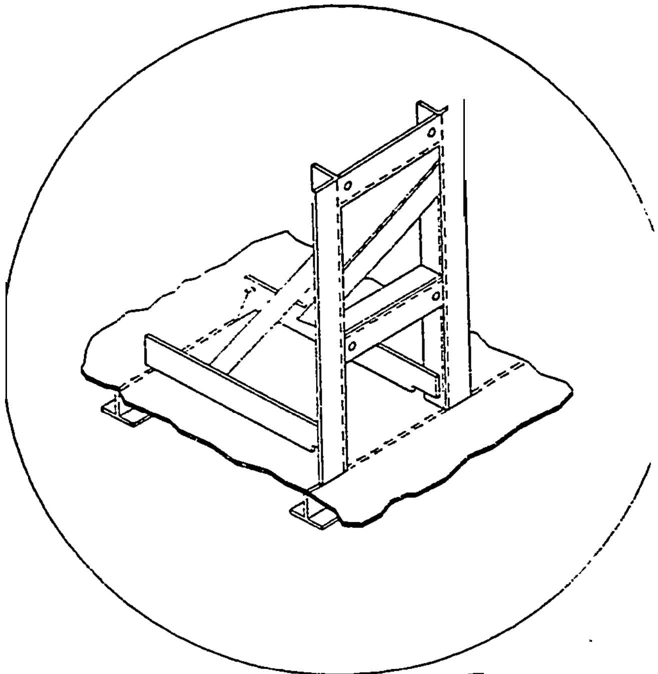
1. FLANGE BENDING
2. LEG FLEXURE

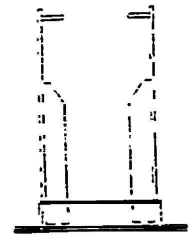
VERTICAL

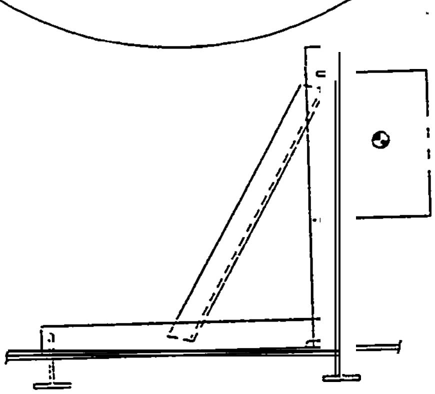
Deck Mounted Truss/Frame

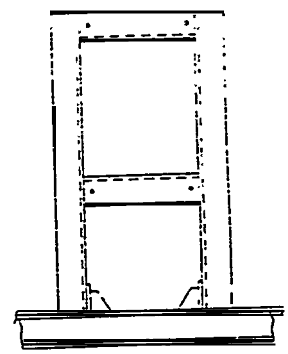
STANDARD FOUNDATION TYPE 19

VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A

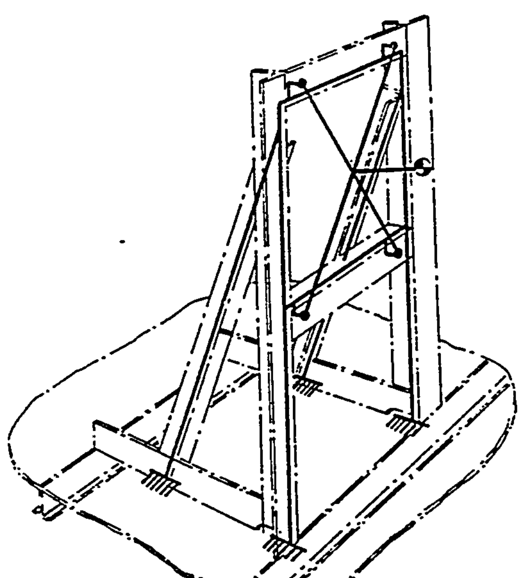








Computer Model



Deck Mounted A-Frame/Truss

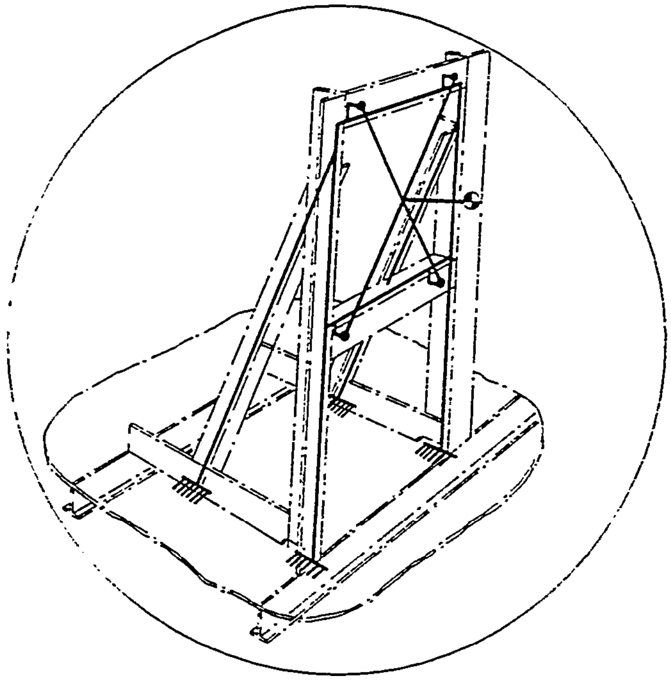
STANDARD FOUNDATION TYPE 20

VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

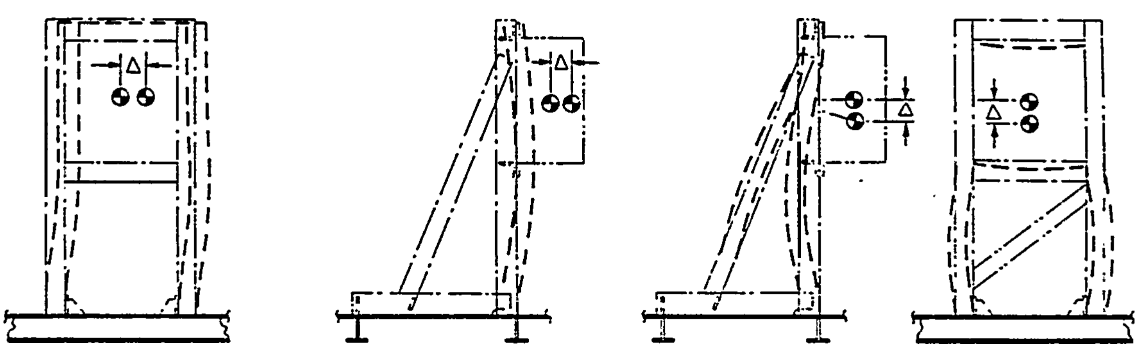
DRWN BY:	S. Ducharme
CHCK BY:	M. Gupta
APPR BY:	JJH
SCALE: NONE	DATE: 16 AUG 95

REV A

Computer Model



Load Application and Deflection Characterization



1. FLANGE BENDING
2. FRAME BENDING

LONGITUDINAL

1. FLANGE BENDING
2. BEAM BENDING

TRANSVERSE

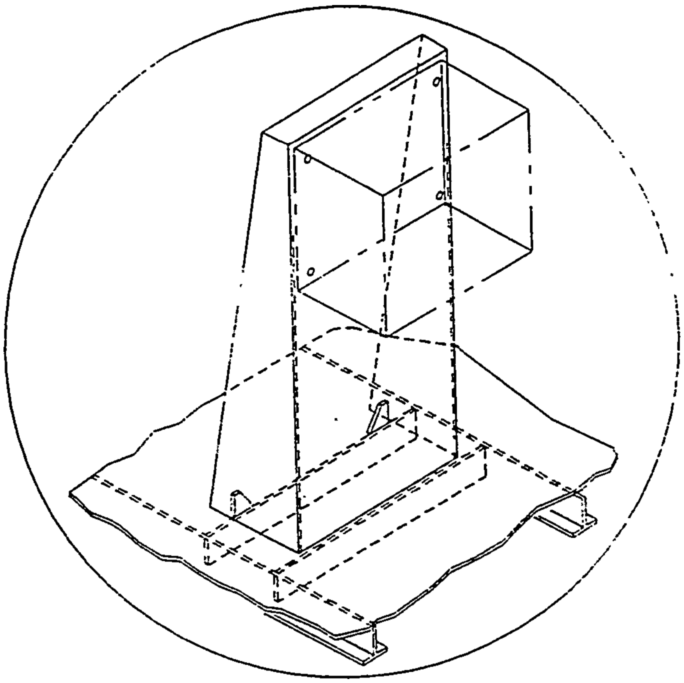
1. FLANGE BENDING
2. BEAM BENDING
3. FRAME BENDING

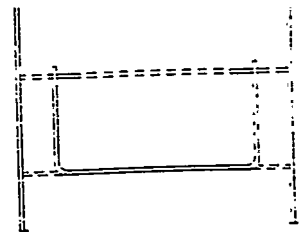
VERTICAL

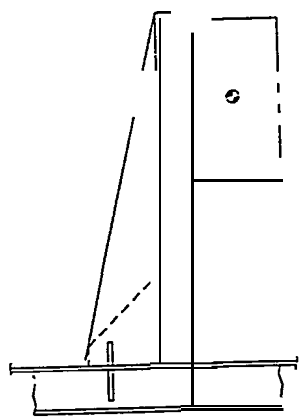
Deck Mounted A–Frame/Truss

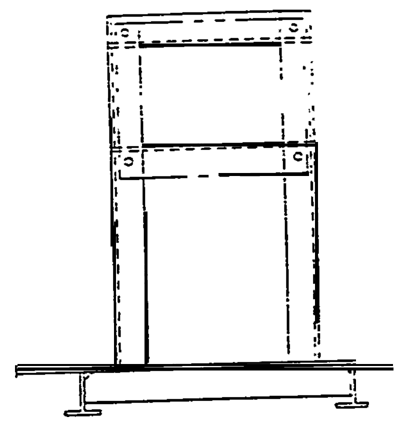
STANDARD FOUNDATION TYPE 20

VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A

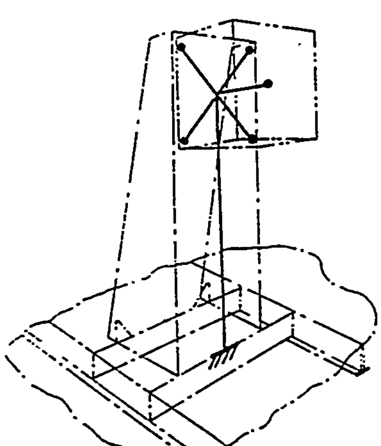








Computer Model



Deck Mounted Panel/Cantilever

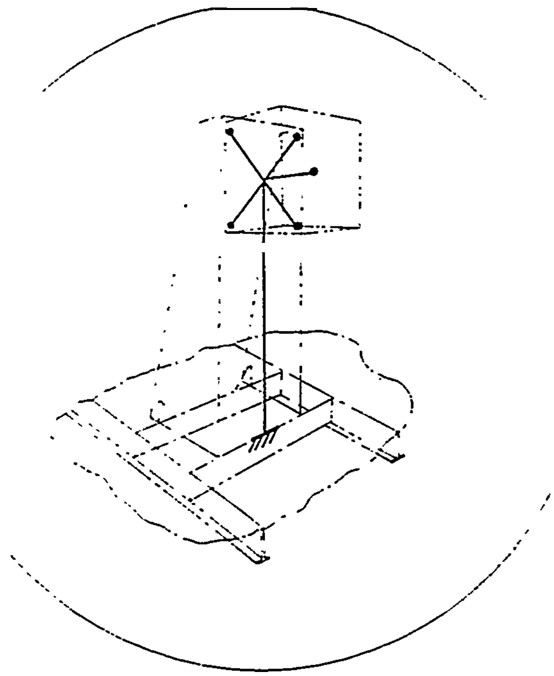
STANDARD FOUNDATION TYPE 21

VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

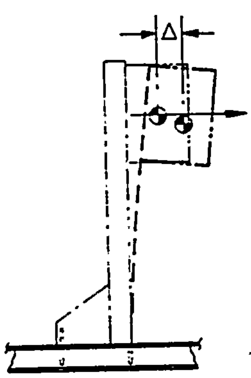
DRWN BY:	S. Ducharme
CHCK BY:	M. Gupta
APPR BY:	JJH
SCALE: NONE	DATE: 07 Aug. 95

REV A

Computer Model

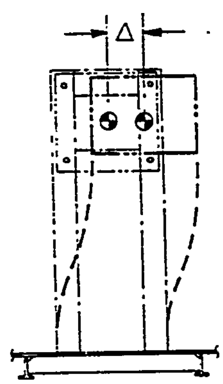


Load Application and Deflection Characterization



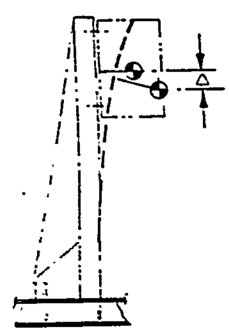
1. FLANGE BENDING
2. CANTILEVER BENDING

LONGITUDINAL



1. FLANGE BENDING
2. FRAME TORSION
3. FRAME BENDING

TRANSVERSE



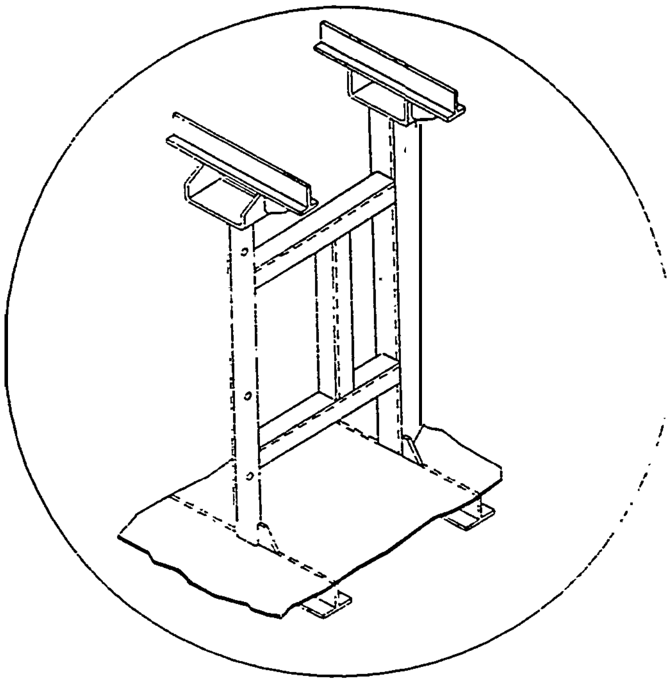
L FLANGE BENDING
2. CANTILEVER BENDING
(TIP MOMENT)

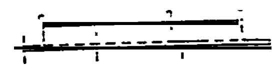
VERTICAL

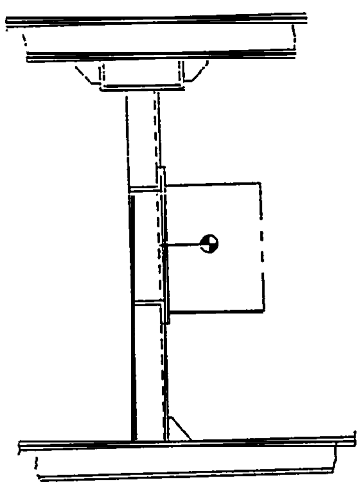
Deck Mounted Panel/Cantilever

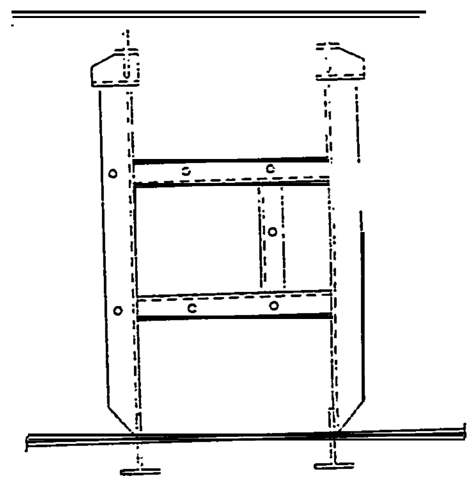
STANDARD FOUNDATION TYPE 21

VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 07 Aug. 95	REV A

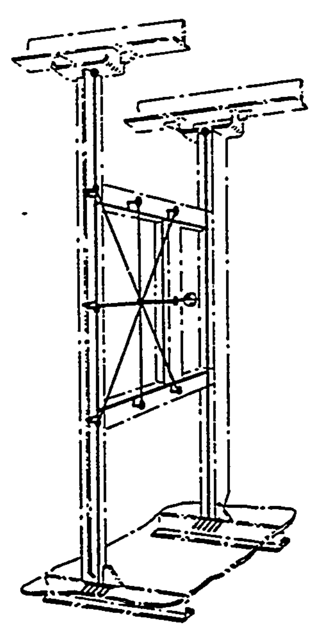








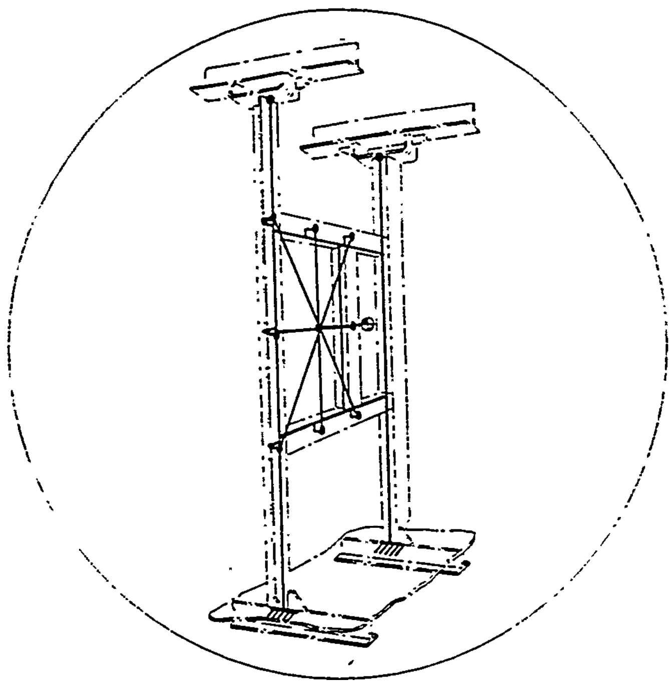
Computer Model



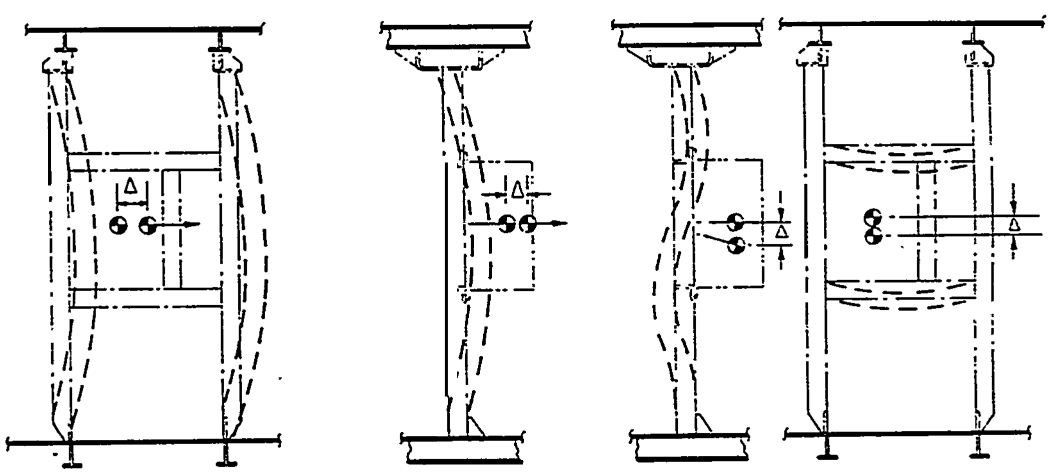
Deck Mounted Deck to Deck
Rack/Panel

STANDARD FOUNDATION TYPE 22		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 07 Aug. 95	REV A

Computer Model



Load Application and Deflection Characterization



1. FLANGE BENDING
2. BEAM BENDING
3. LEG FLEXURE

LONGITUDINAL

1. FLANGE BENDING
2. BEAM BENDING

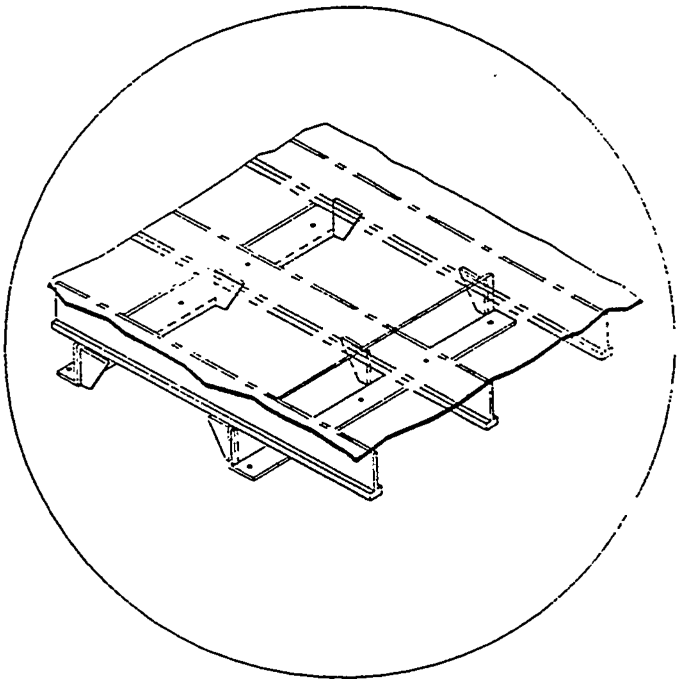
TRANSVERSE

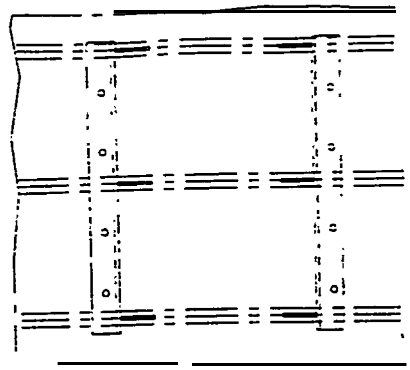
1. FLANGE BENDING
2. BEAM BENDING
3. LEG FLEXURE

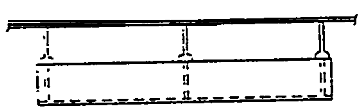
VERTICAL

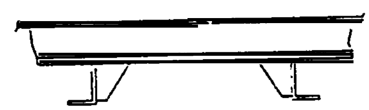
Deck Mounted Deck to Deck Rack/Panel

STANDARD FOUNDATION TYPE 22		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 07 Aug. 95	REV A

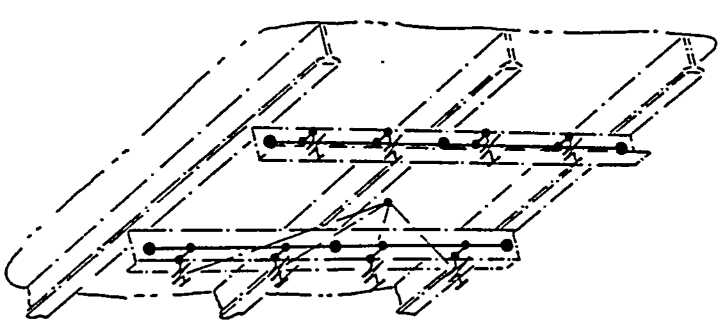








Computer Model

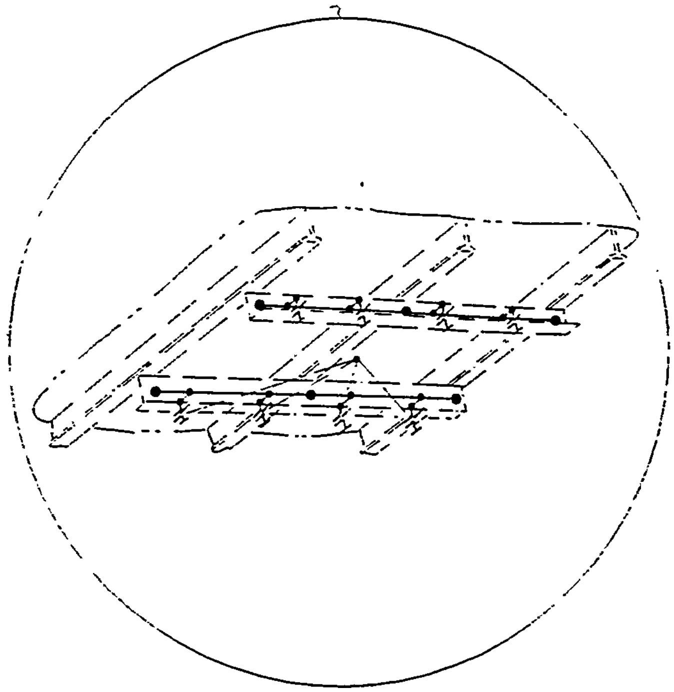


Deck Mounted Overhead Grillage

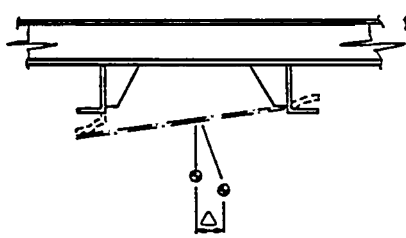
STANDARD FOUNDATION TYPE 23

VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A

Computer Model

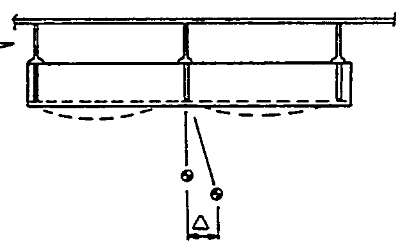


load Application and Deflection Characterization



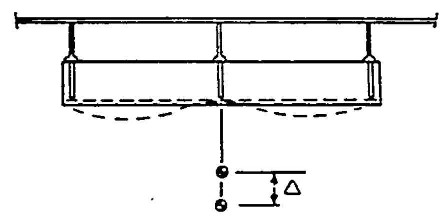
1. FLANGE BENDING
2. BEAM BENDING/TORSION

LONGITUDINAL



1. FLANGE BENDING
2. BEAM BENDING/TORSION

TRANSVERSE

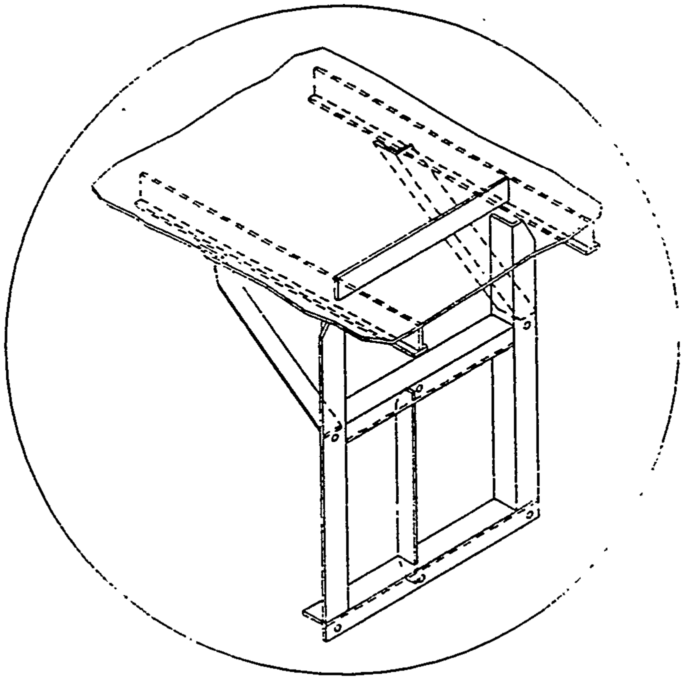


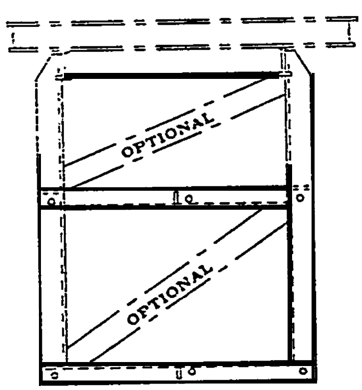
1. FLANGE BENDING
2. BEAM BENDING/TORSION

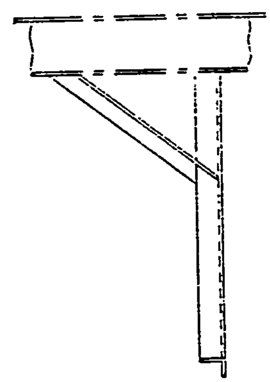
VERTICAL

Deck Mounted Overhead Grillage

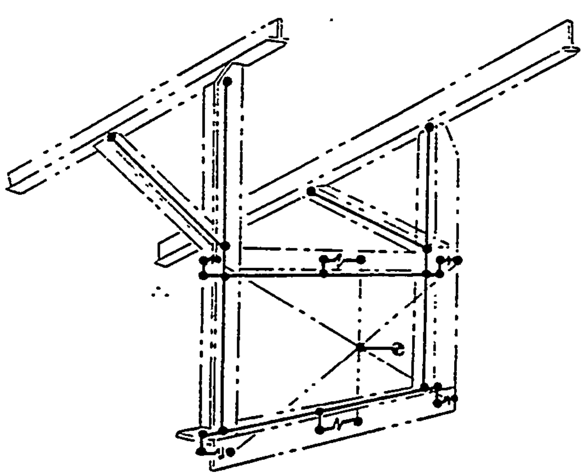
STANDARD FOUNDATION TYPE 23		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A







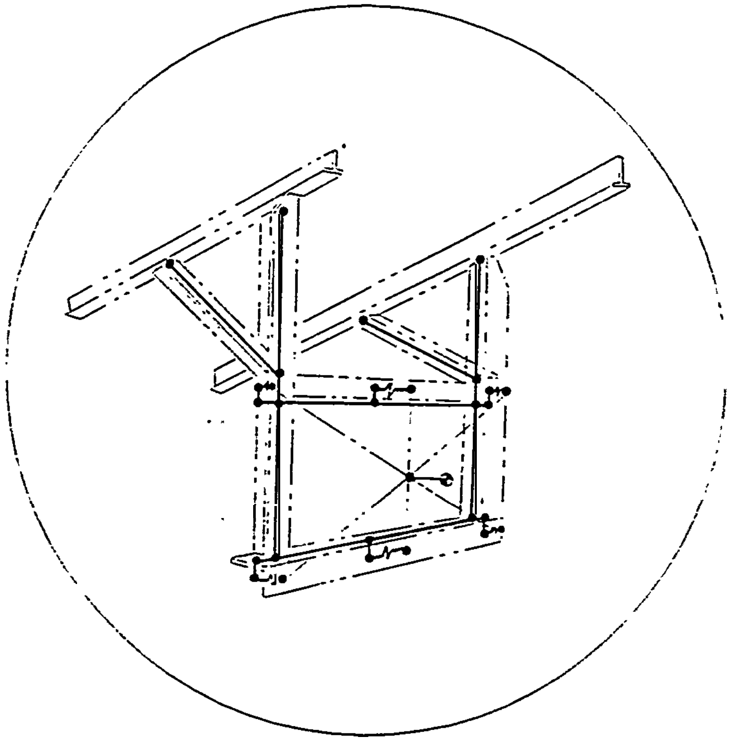
Computer **Model**



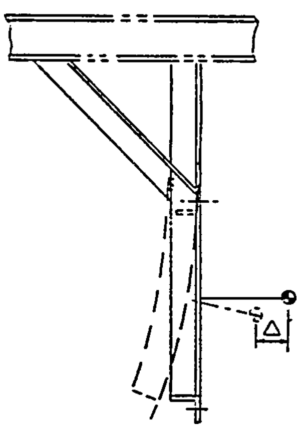
Deck Mounted Overhead
Truss/Cantilever

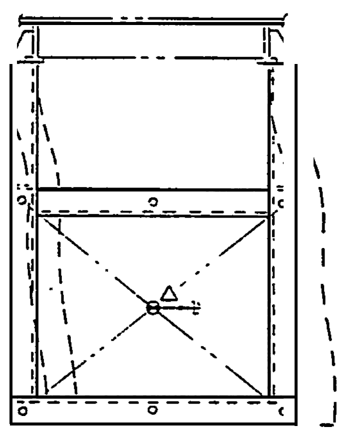
STANDARD FOUNDATION TYPE 24		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A

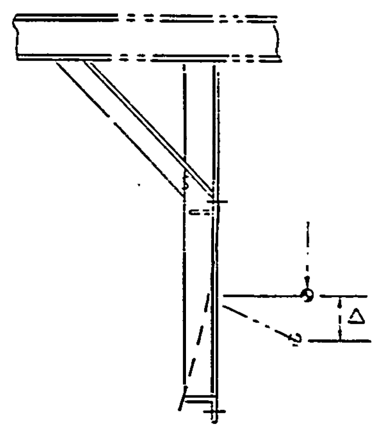
Computer Model



Load Application and Deflection Characterization







1. FRAME BENDING
2. BEAM BENDING
3 FLANGE BENDING

1 BEAM BENDING
2 FLANGE BENDING

LONGITUDINAL

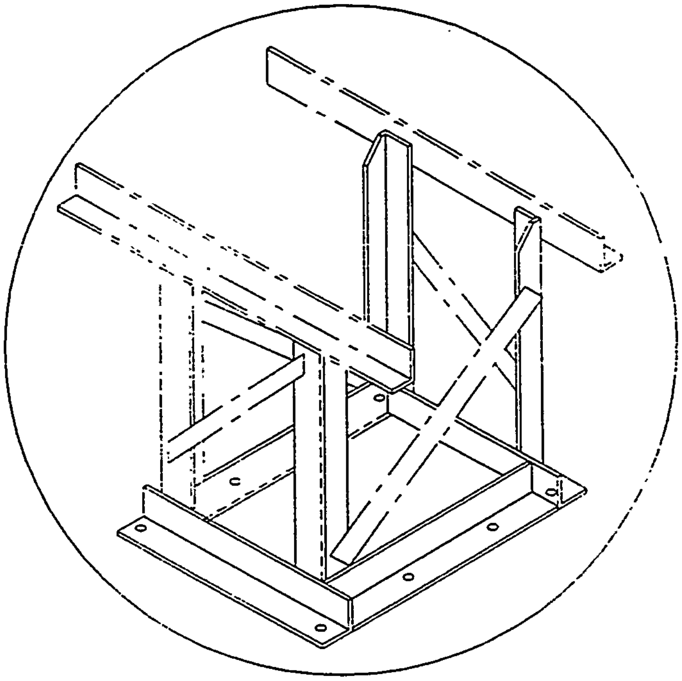
TRANSVERSE

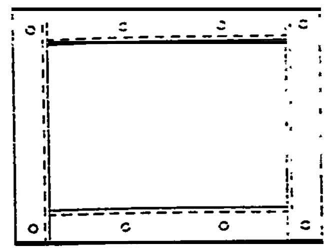
VERTICAL

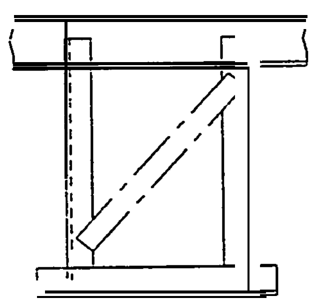
Deck Mounted Overhead Truss/Cantilever

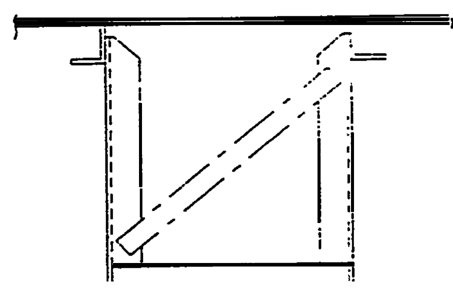
STANDARD FOUNDATION TYPE 24

VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 93	REV A

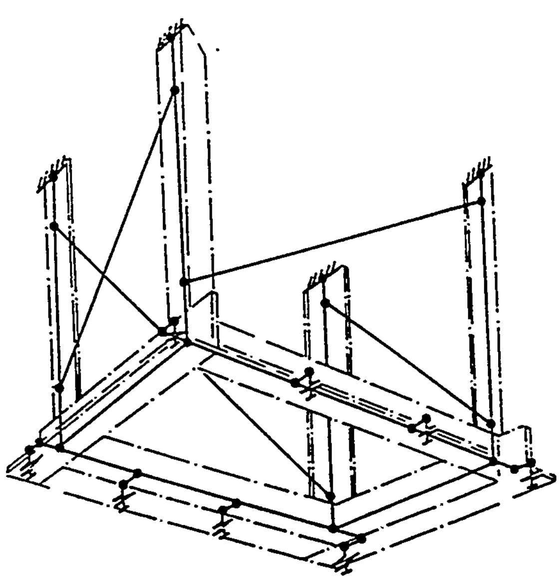








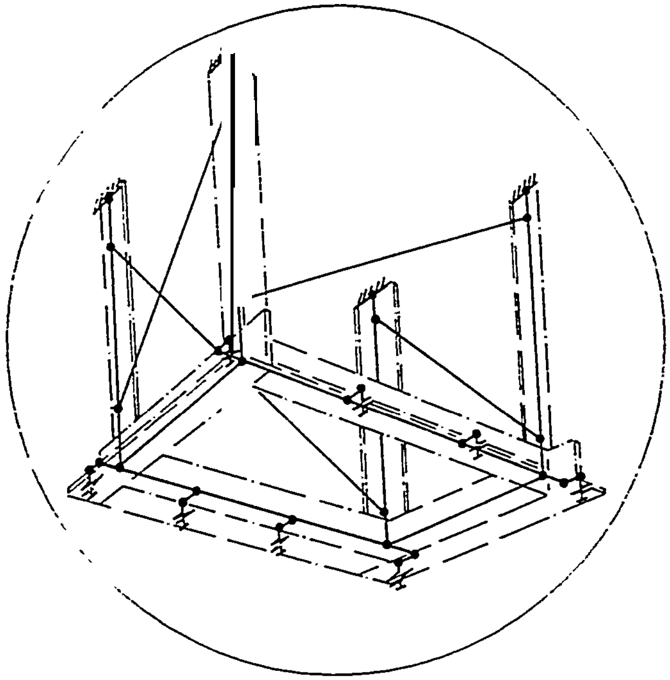
Computer Model



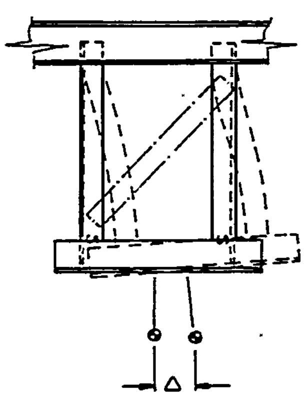
Deck Mounted Overhead Truss

STANDARD FOUNDATION TYPE 25		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupla APPR BY: JJH SCALE: NONE DATE. 16 AUG 95	REV A

Computer Model

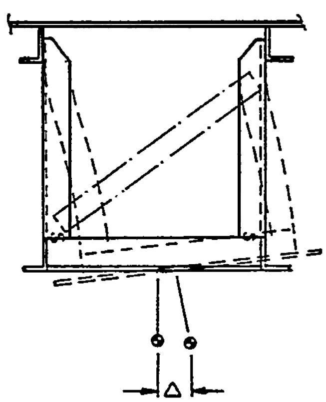


Load application and Deflection Characterization



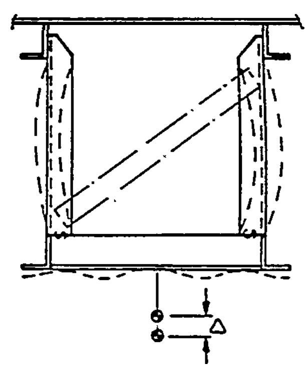
1. FRAME FLEXURE
2. FLANGE FLEXURE
3. LEG FLEXURE

LONGITUDINAL



1. FRAME FLEXURE
2. FLANGE FLEXURE
3. LEG FLEXURE

TRANSVERSE



1. FLANGE FLEXURE/BEAM TORSION
2. BEAM BENDING
3. LEG FLEXURE

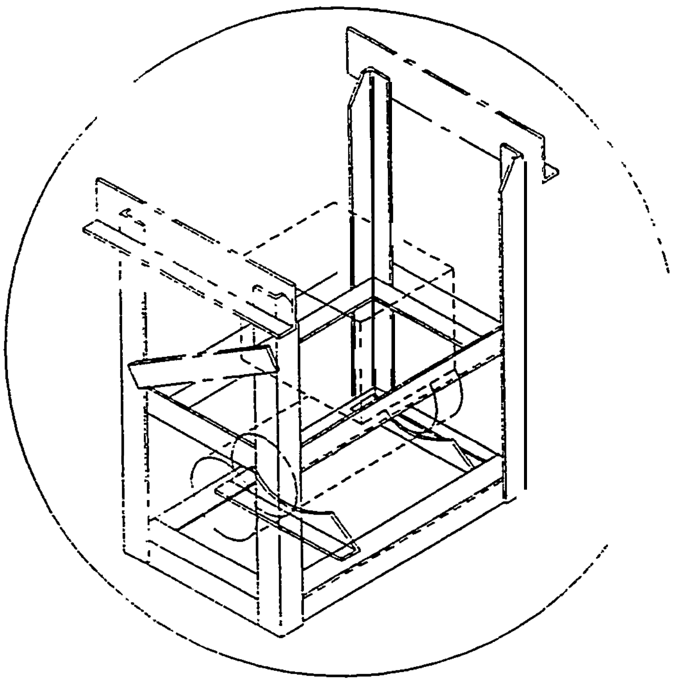
VERTICAL

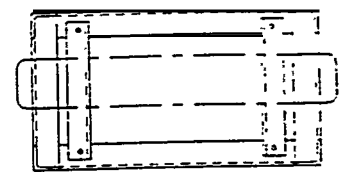
Deck Mounted Overhead Truss

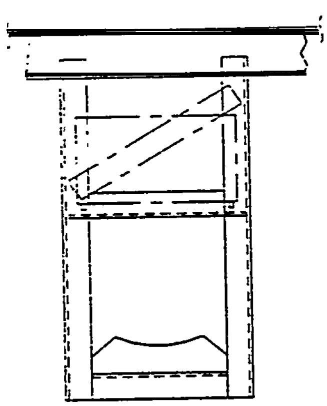
STANDARD FOUNDATION TYPE 25

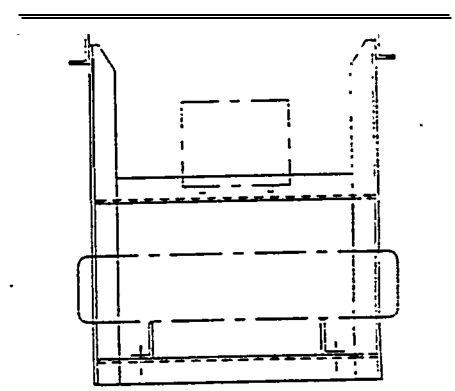
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY:	S. Ducharme	REV
CHCK BY:	M. Gupta	
APPR BY:	JJH	A
SCALE: NONE	DATE: 16 AUG 93	

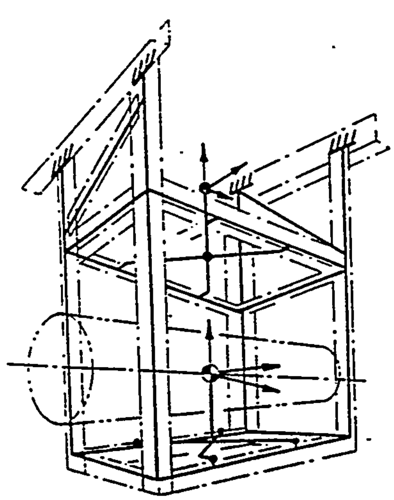








Computer Model



Deck Mounted Overhead Frame/Truss

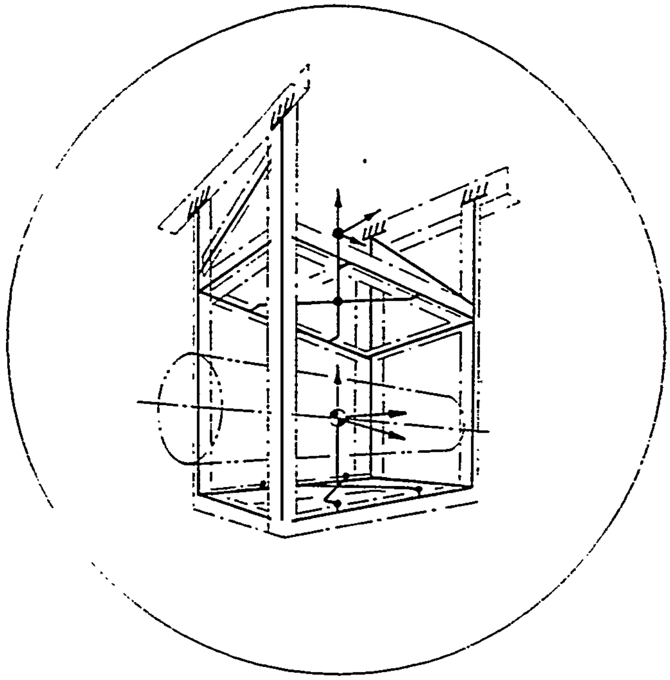
STANDARD FOUNDATION TYPE 26

VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

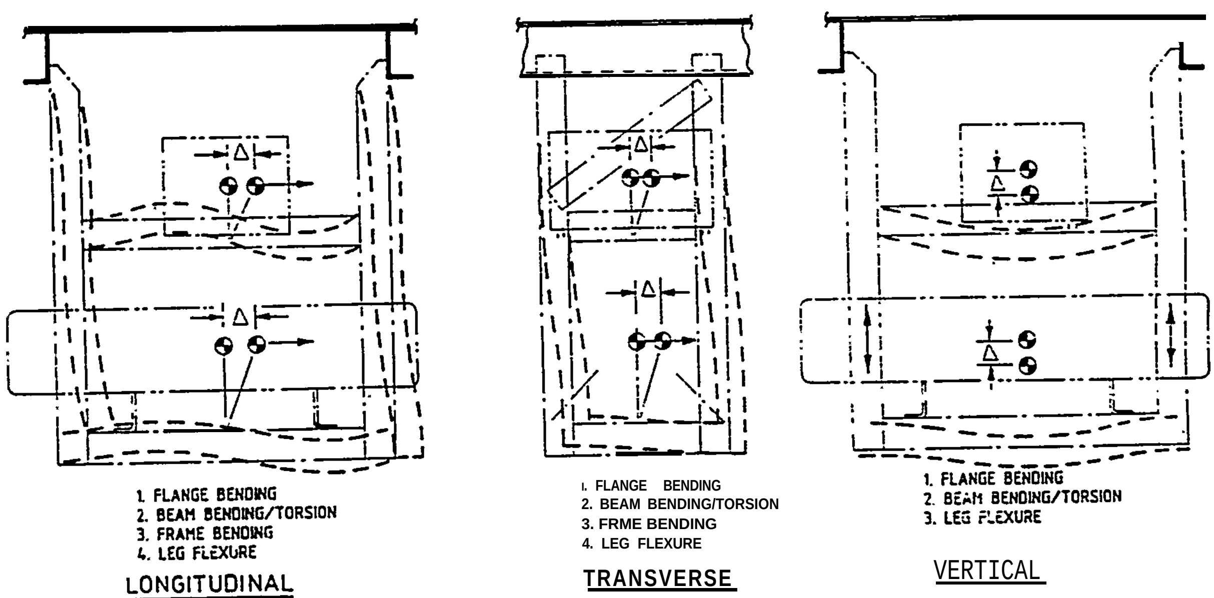
DRWN BY:	S. Ducharme
CHCK BY:	M. Gupta
APPR BY:	JJH
SCALE: NONE	DATE: 16 AUG 95

REV A

Computer Model



Load Application and Deflection Characterization

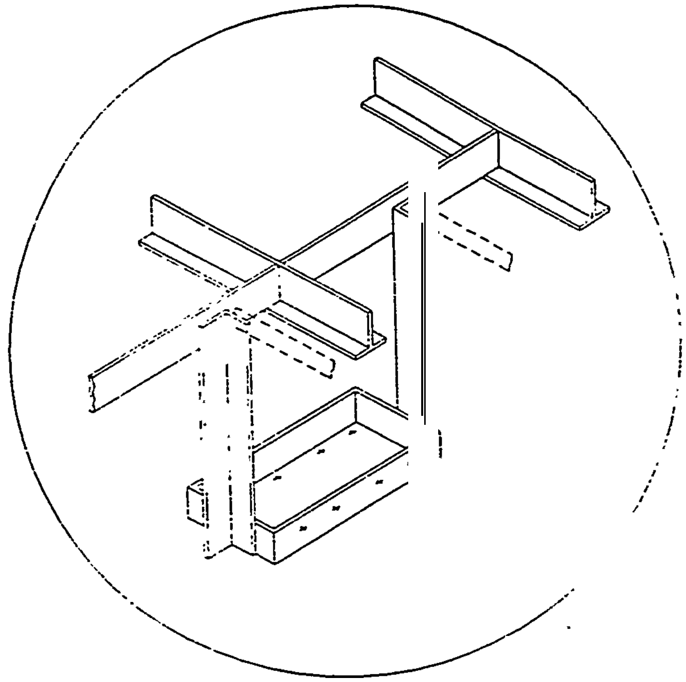


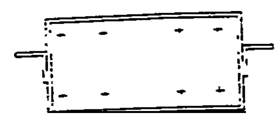
Deck Mounted Overhead Frame/Truss

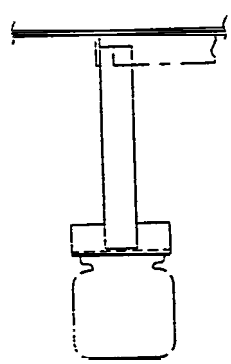
STANDARD FOUNDATION TYPE 26

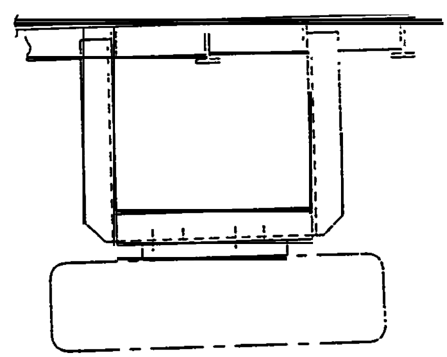
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY: S. Ducharme
CHCK BY: M. Gupta
APPR BY: JJH
SCALE: NONE
DATE: 16 AUG 95
REV A

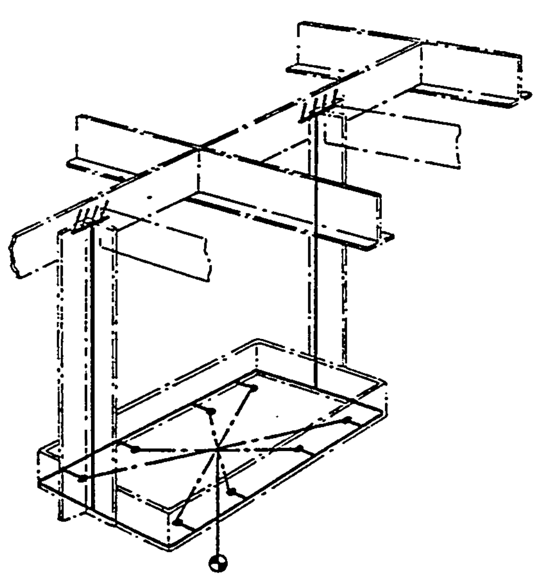








Computer Model

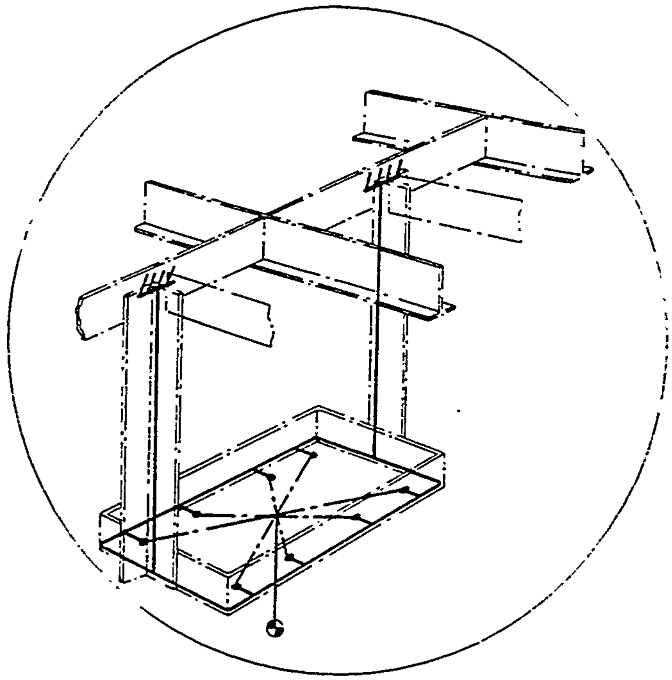


Deck Mounted Overhead
Cantilever/Panel

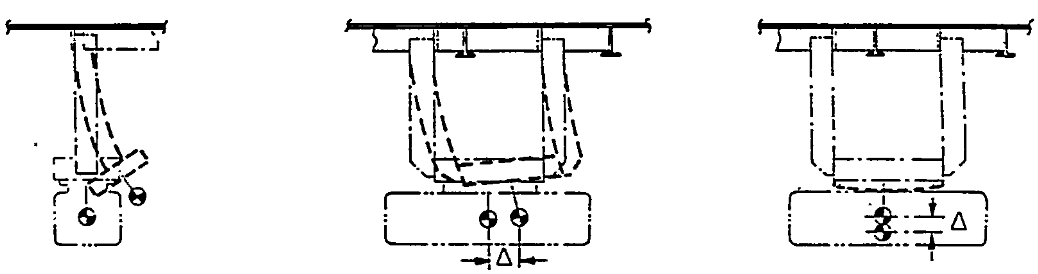
STANDARD FOUNDATION TYPE 27

VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 08 Aug. 95	REV A

Computer Model



Load Application and Deflection Characterization



1 FLANGE BENDING
2. CANTILEVER BENDING

LONGITUDINAL

1. FLANGE BENDING
2. FRAME BENDING

TRANSVERSE

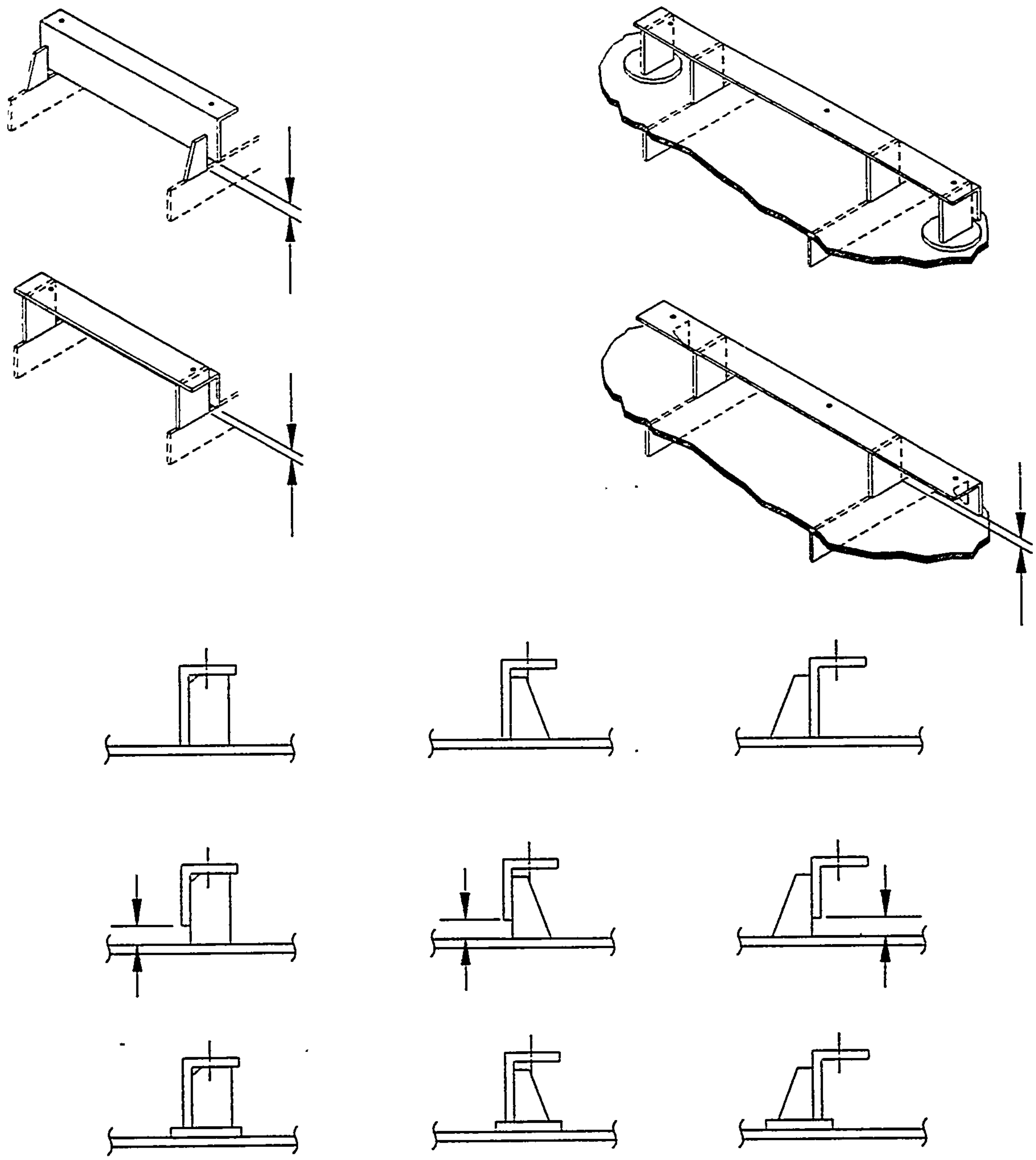
1. FLANGE BENDING
2. BEAM BENDING
3. LEG FLEXURE

VERTICAL

Deck Mounted Overhead
Cantilever/Panel

STANDARD FOUNDATION TYPE 27		
VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 08 Aug. 95	REV A

Standard Attachment Techniques



Notes: These Attachments Techniques Are Applicable to Foundation Types 1, 5, 10, **15, 16, 23 and Method Mounts**

Attachment Technique A

VIBTECH, INC. P.O. BOX 435 NORTH KINGSTOWN, RI 02852 TEL: 401/294-1590 FAX: 401/295-2592	DRWN BY: S. Ducharme CHCK BY: M. Gupta APPR BY: JJH SCALE: NONE DATE: 16 AUG 95	REV A

9.2 Typical Scantlings for Standard Foundations

Enclosed are design view-graphs & data tables for the 3 most frequently used foundation configurations. These design tables provide the scantling sizes for foundations suitable for equipments having certain defined limits, capable of meeting normal environmental, noise and vibration requirements. These design data tables were computed with a very conservative approach, the worst combination of sea-loads along with the worst orientation of foundation and minimum bolting attachments were adopted. Described below is a generic procedure to use these design data tables for foundation design:

- Obtain equipment information (VFI) of the equipment/machinery to be installed, equipment weight, height of CG (eccentricity) and bolting pattern are required. For grillages, mounting plate thickness information on which the foundation will be attached, is required.

- Compute the ratio e/h, where e is the eccentricity and h is the spacing between extreme bolts in the direction of maximum seaway load. (See attached graphical illustration)

- Compute the required load bearing capacity per bolting attachment by dividing the equipment weight by the number of bolts given in the bolting pattern.

- The load bearing capacity per bolting attachment is checked off on the Design Data Table corresponding to the Mounting Plate thickness in case of grillages, or corresponding to Mounting Angle span length in case of frames/trusses, and the minimum scantling size which gives the allowable load higher than the required load bearing capacity is selected for mounting scantling.

- For frames/trusses compute the required load bearing capacity per leg by dividing the equipment weight by the number of legs required in the foundation. The minimum scantling size corresponding to the frame/truss leg length which gives the allowable load higher than the required load bearing capacity per leg, is selected for foundation legs.

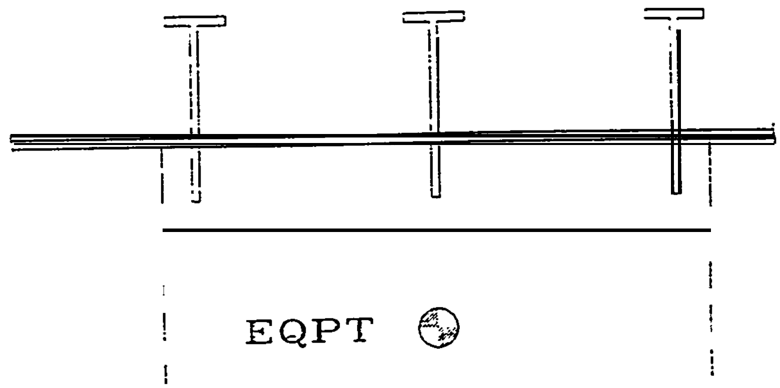
- Develop fret-cut foundation sketch with the foundation configuration and select scantlings.

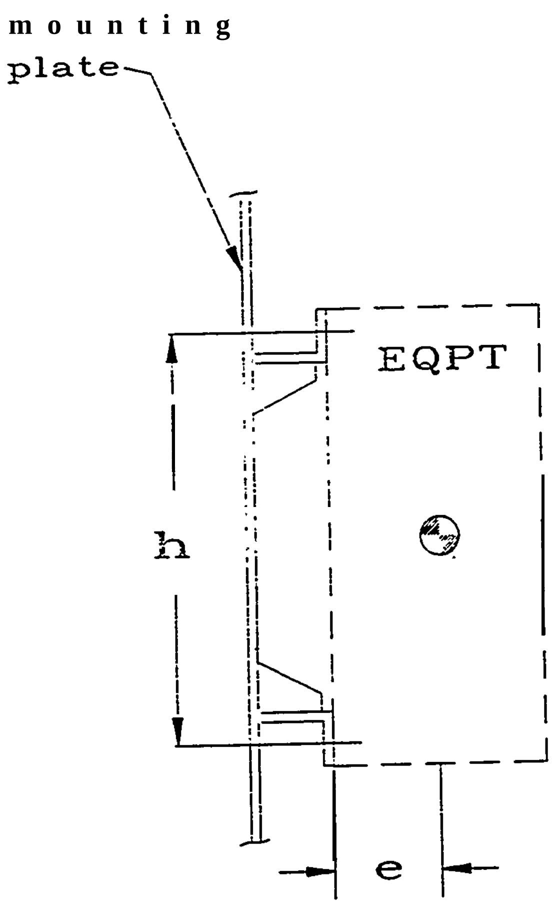
- Perform interference check.

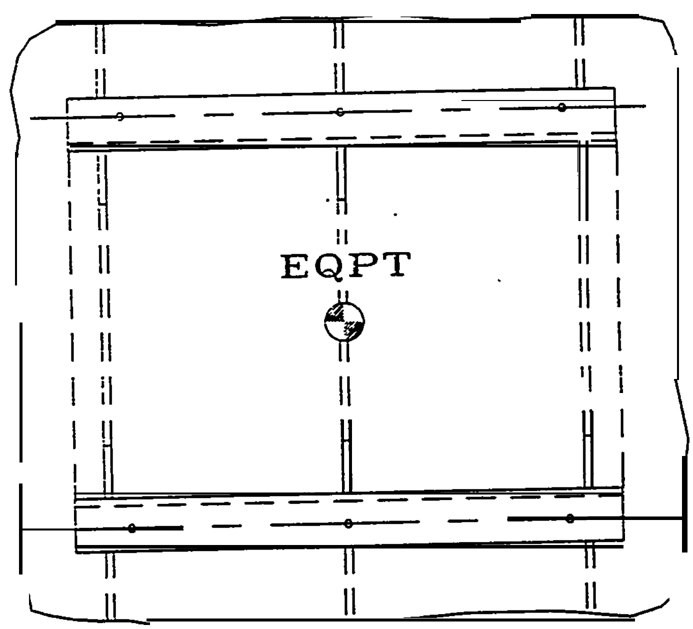
- Re-develop the foundation sketch if required. Producibility and cost-saving methods should be incorporated at every design step.

- Validate the final Foundation Design.

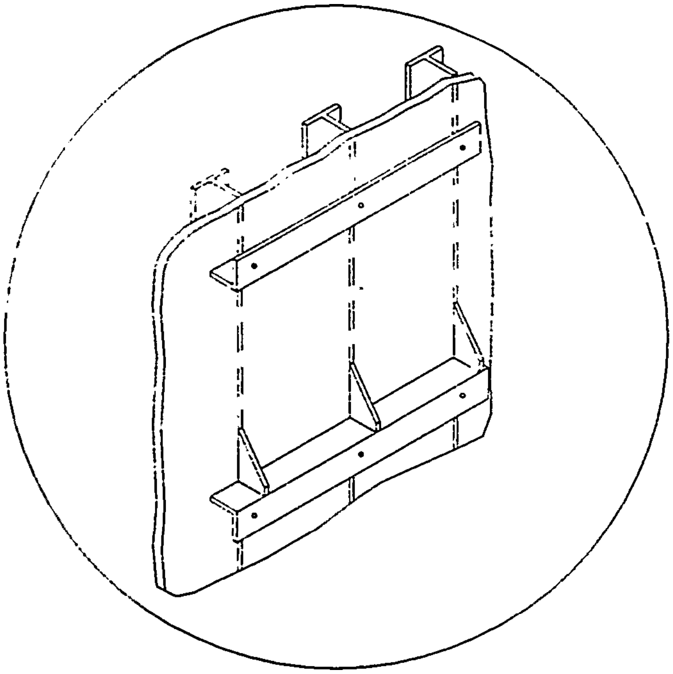
GRILLAGE

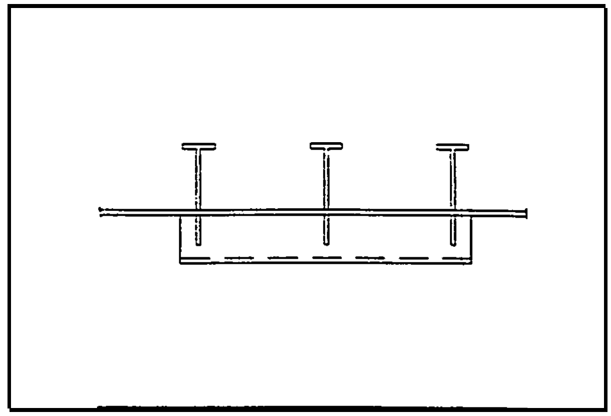


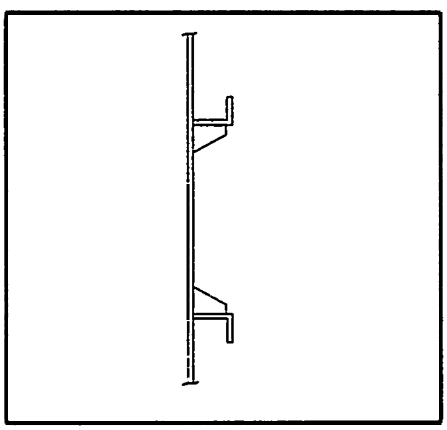


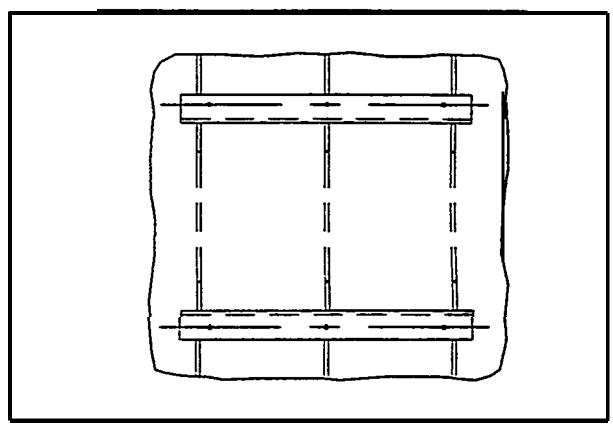


GRILLAGE









Design Data of Limit Load in Lbs.

Scantling Sizes (in.)	e/h	Mounting Plate Thickness (in) 0.1875	0.25	0.375	0.5	0.625
2x2x3/16	0.5	112	258	258	258	258
	1	28	65	139	139	139
2.5x2 .5xl/4	0.5	112	266	459	459	459
	1	28	66	247	247	247
3x3x 1/4	0.5	112	262	449	449	449
	1	28	66	242	242	242
3x3x3/8	0.5	113	266	887	965	966
	1	28	67	222	520	520
3.5x3.5x3/8	0.5	113	266	866	1038	1036
	1	28	67	217	485	558
4x4xl/2	0.5	113	267	889	1813	1813
	1	28	67	222	515	968

Notes: Design Data Table not Applicable to Grillages Lifted-Off Mounting Plate. Refer to Design Data of Appropriate Method Mount.

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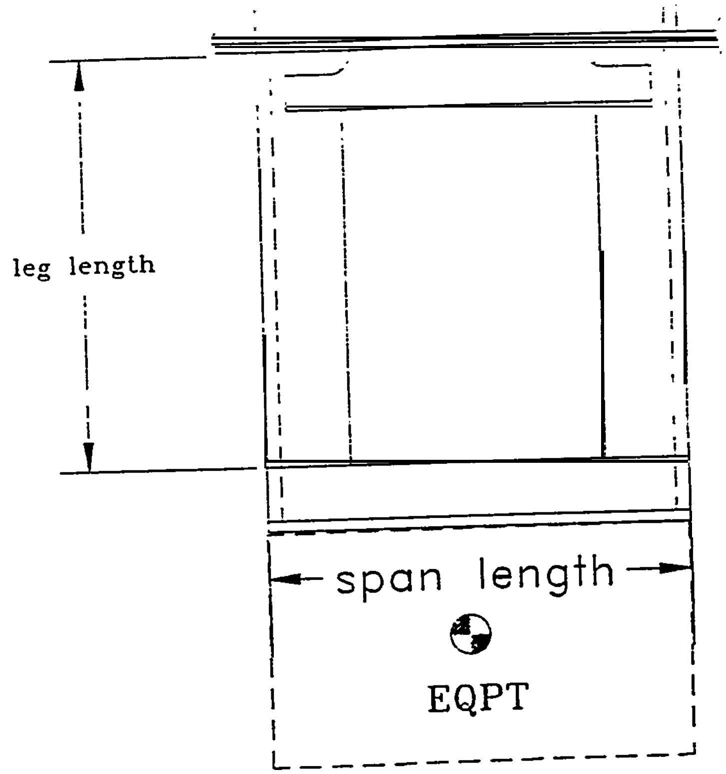
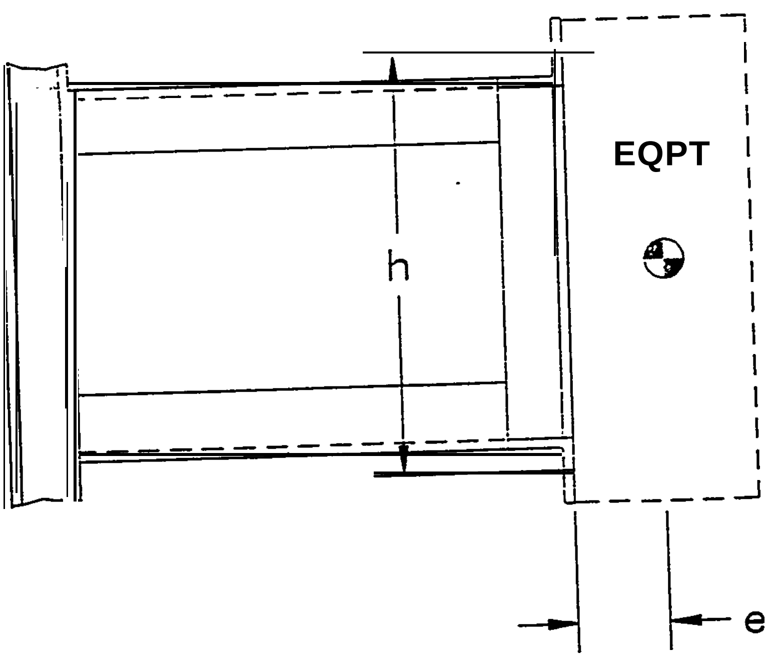
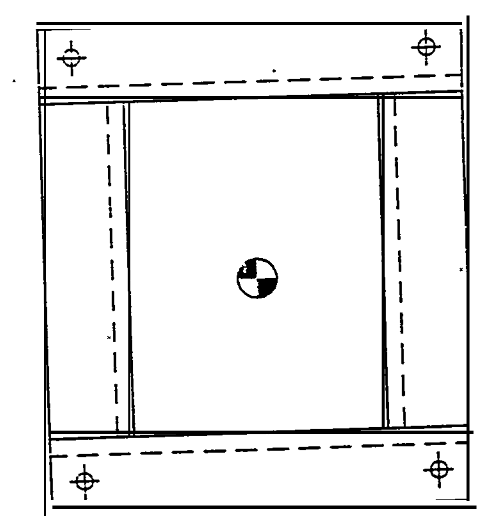
FRAME







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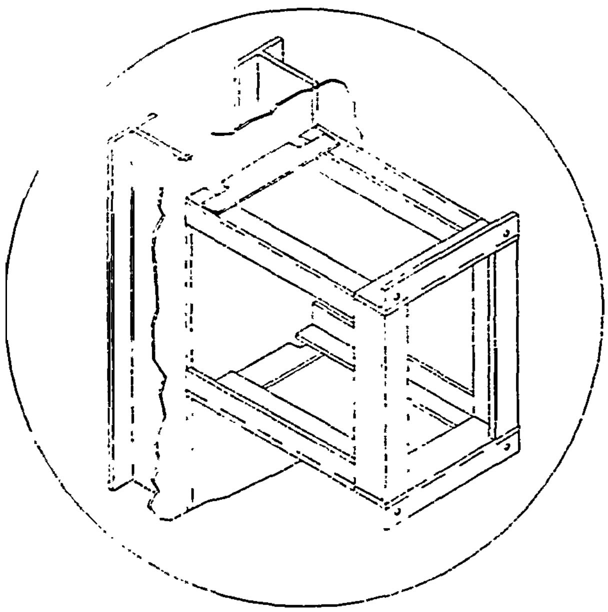

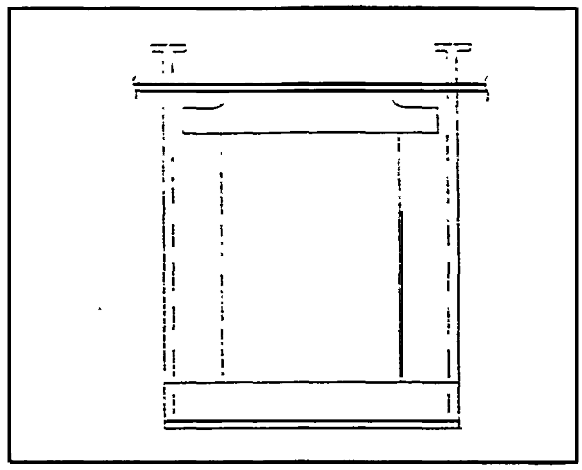

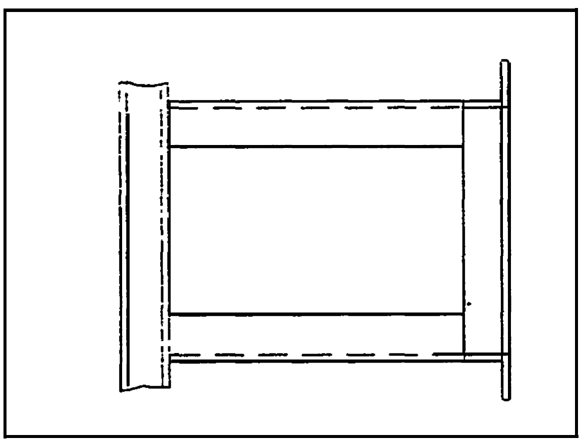

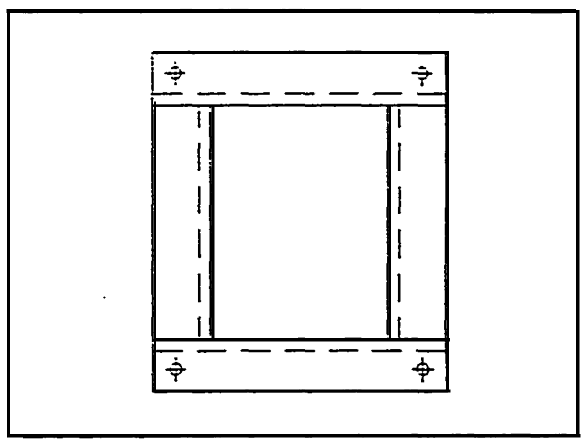

Design Data of Limit Load in Lbs.

Scantling Sizes (in.)	e/h	Mounting Angle Span Length (in) 10	20	30	40	50
2 x 2 x 3 / 1 6	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	338
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776

Scantling Sizes (in.)	e/h	Frame Leg Lenglh (in) 6	12	18	24	30	36
2x2x3/16	0.5	1000	550	350	---	---	---
	1	900	500	325	---	---	---
2.5x2.5xl/4	0.5	2CO0	1150	775	575	---	---
	1	1800	1100	750	550	---	---
3x3xl/4	0.5	2900	1650	1125	875	700	---
	1	2650	1550	1100	850	675	
3.5x3.5x3/8	0.5	---	3300	2300	1800	1450	1225
	1	---	3100	2200	1750	1400	1200
4x4x1/2	0.5	---	5500	3900	3050	2475	2100
	1	---	5100	3750	2950	2400	2050

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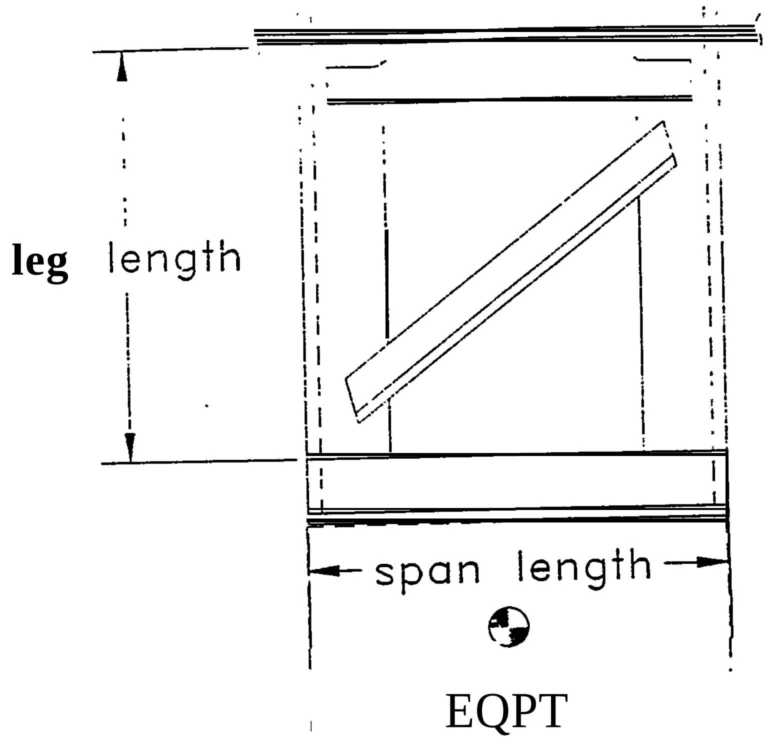
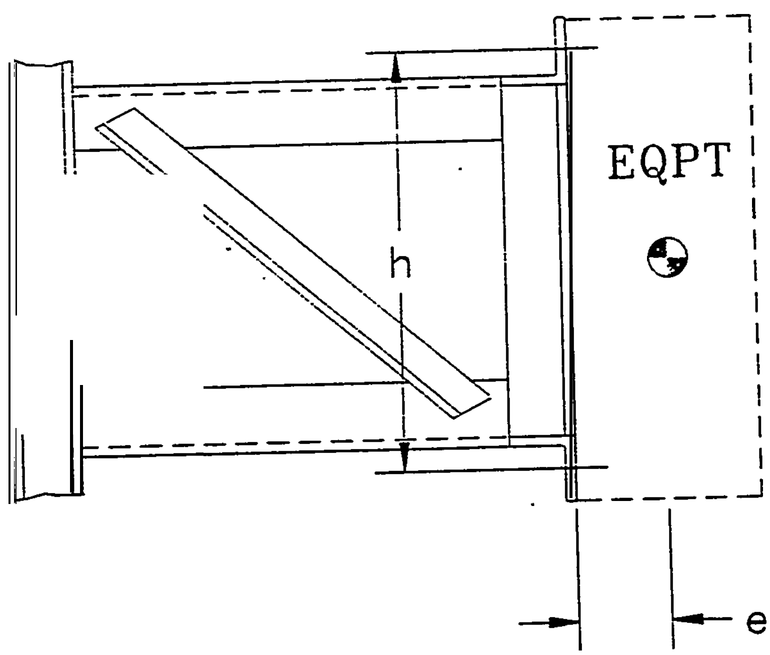
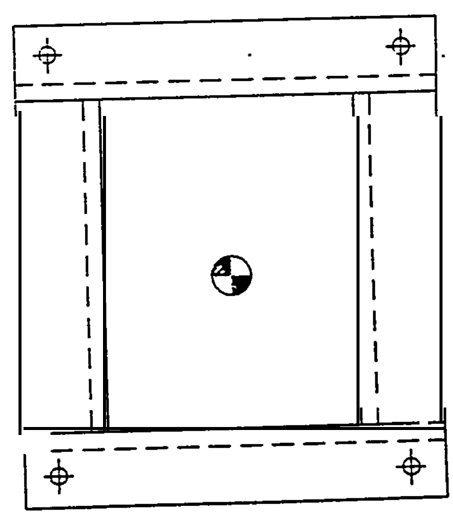
TRUSS







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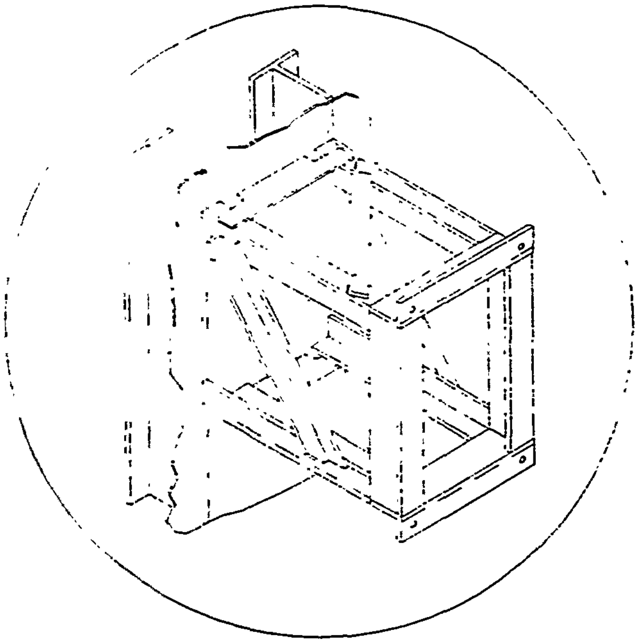

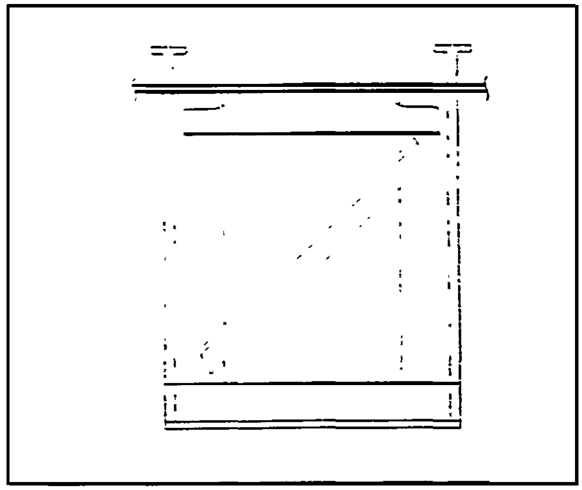

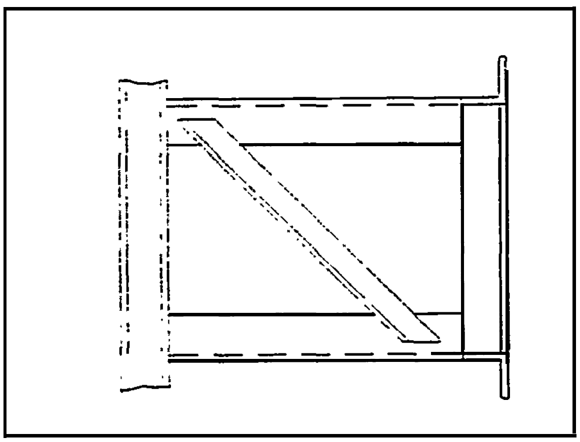

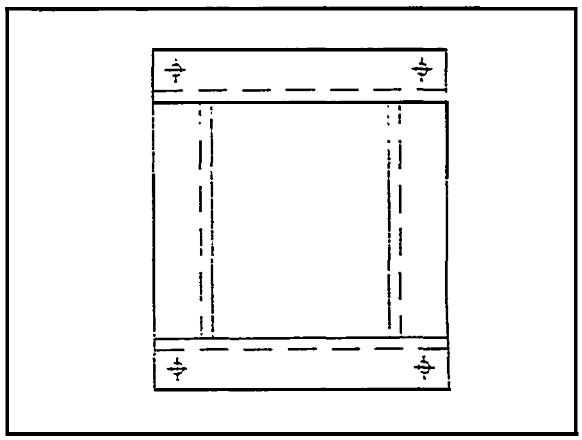

Design Data of Limit Load in Lbs.

Scantling Sizes (in.)	e/h	Mounting Angle Span Length (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	338
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	559	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776

Scantling Sizes (in.)	e/h	Truss Leg Length (in) 6	12	18	24	30	36
2x2x3/16	0.5	1650	1275	1025	800	650	- - -
	1	1400	1150	950	775	625	- - -
2.5x2.5x1/4	0.5	2950	2375	2000	1650	1375	1175
	1	2550	2100	1825	1550	1300	1125
3X3X1/4	0.5	3800	3075	2700	2275	1975	1700
		3200	2700	2425	2100	1850	1650
3.5x3.5x3/8	0:5	- - -	5675	5025	4300	3825	3400
	1	- - -	4975	4525	3950	3550	3175
4x4x1/2	0.5	- - -	- - -	- - -	6950	6300	5600
	1	- - -	- - -	- - -	6325	5800	5200

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NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

DRWN BY:	S. Ducharme	REV	A
CHCK BY:	M. Gupta		
APPR BY:	JJH		
SCALE: NONE	DATE: 16 AUG 95		

9.3 Typical Configurations & Scantlings for Foundation Method Mounting

Method or standard mounting is based on the observation that equipment mountings can be standardiized based on several factors:

- Where engineering methodology is applied in a consistent manner, consistent results can be expected.

- Where equipment can be characterized by geometry, weight and bolting attachment design, then parametric analysis of these variables can yield standard designs suitable for equipment that are within the bounds of the parametric limits.

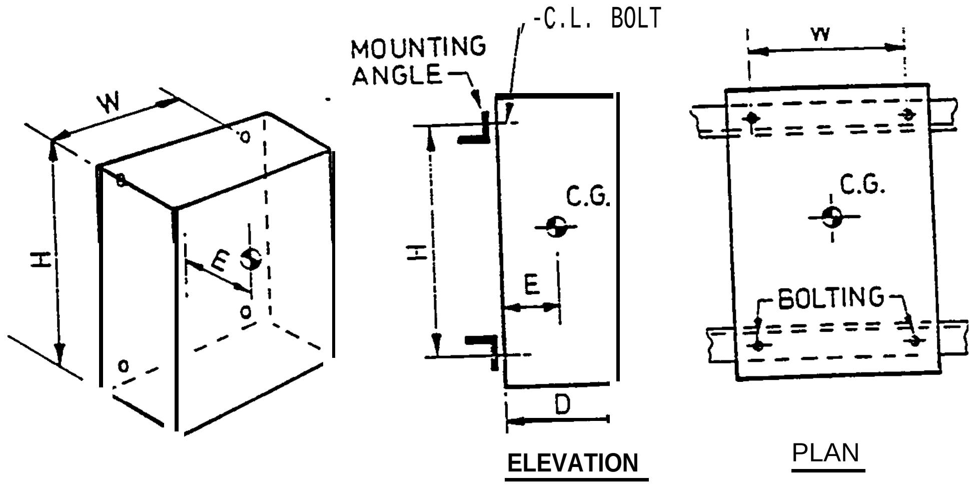
- Parametric analysis of the equipment and mounting methods is comprehensive and time consuming to ensure that all equipment falling within the parametric limits imposed on a specific design can be mounted on the foundations without requiring further analysis.

There are hundreds of lightweight power panels, controllers, transformers, (black boxes), etc., for which a standard mounting approach could be used for installation. These designs are lightweight and cost effective because they are optimized using producibility design inputs and they are engineered to reduce welding to the minimum required. Thus standard mounting foundation solutions are suitable for equipment within the defined weight limits and are capable of meeting normal environmental, noise and vibration requirements.

Once having performed the generalized engineering and parametric analyses, the engineers selecting the proper standard mounting need only compare the particular equipment being supported to the standard mounting design parametric limits defined for each design in order to select a suitable method. This, of course, will reduce engineering time to a minimum for these applications. The approach used in developing an engineering approach to standard mounting is as follows:

- Characterize equipment to be supported. Statistics for equipment dimensions, i.e. height, width, depth, center of gravity (eccentricities), bolt pattern dimensions, and equipment weight must be evaluated parametrically.

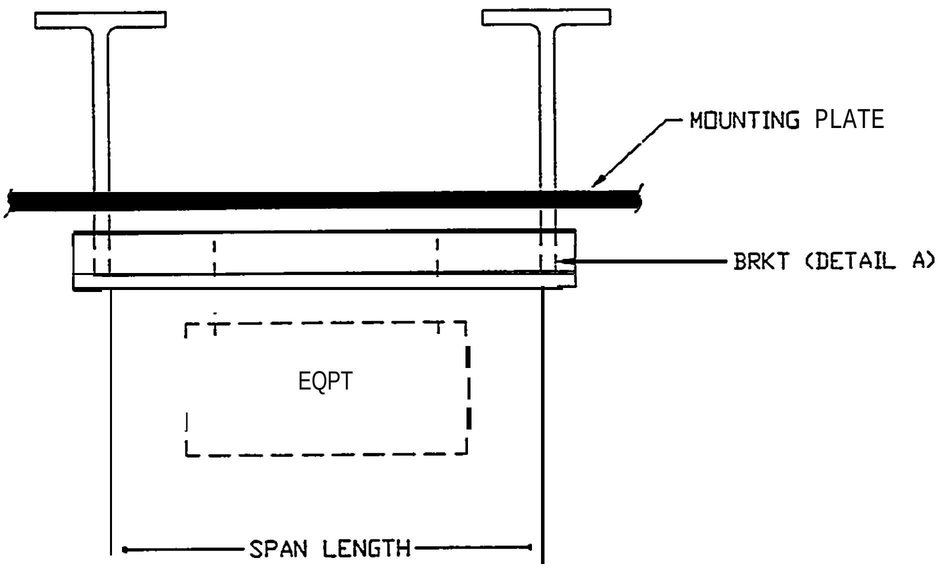
- Develop computer/hand calculation math models to investigate each candidate standard mounting method order to determine equipment geometry or weight limits versus the standard mounting scantling sizes.

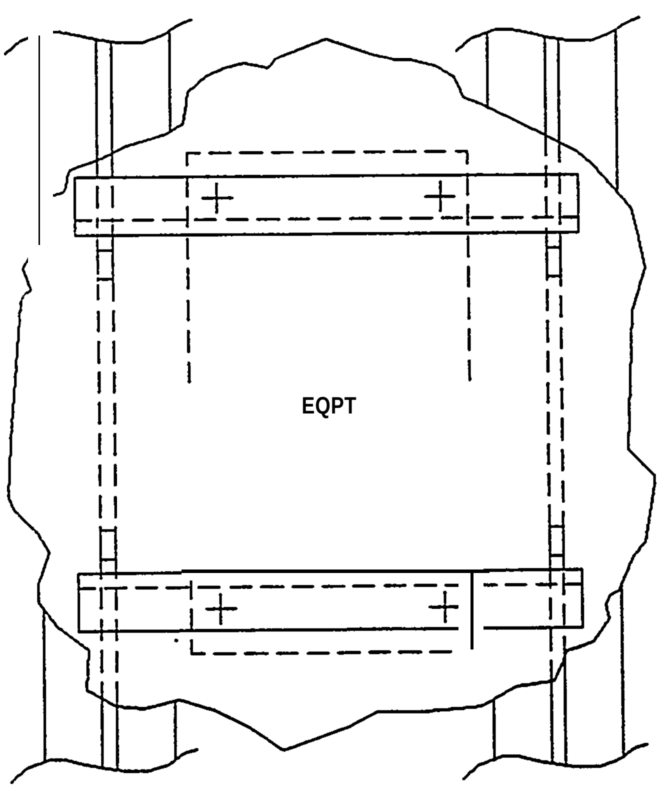


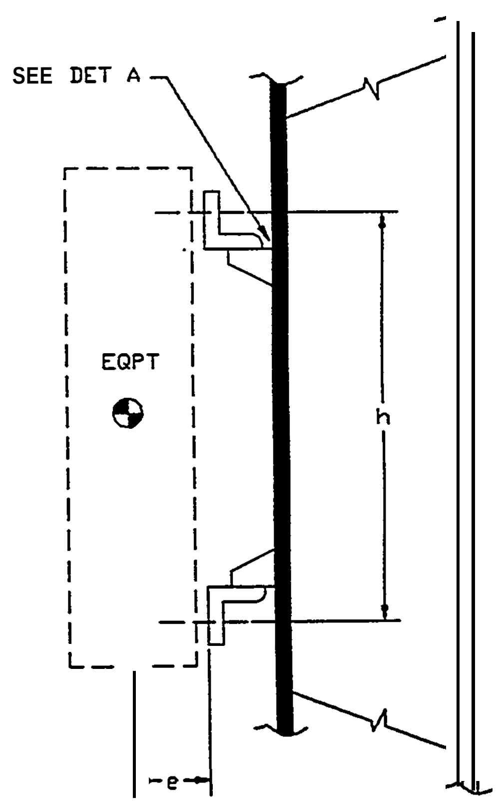
- Select limiting equipment characteristics such as E/H or E/W and summarize in a form which compares these values with acceptable scantling sizes to facilitate engineering selection of the material.

Enclosed are design data tables for 18 different configurations of method mounts along with the scantling sizes and their parametric limits.

METHOD MOUNT ILLUSTRATION

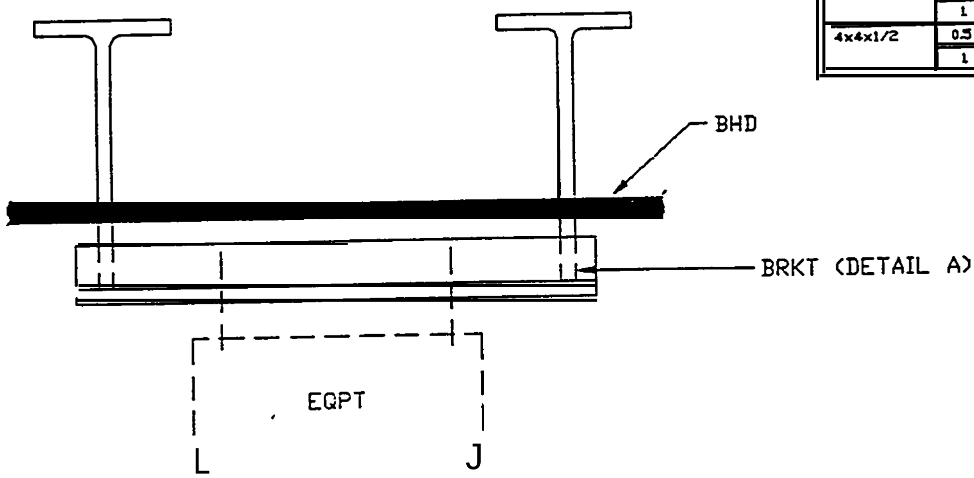


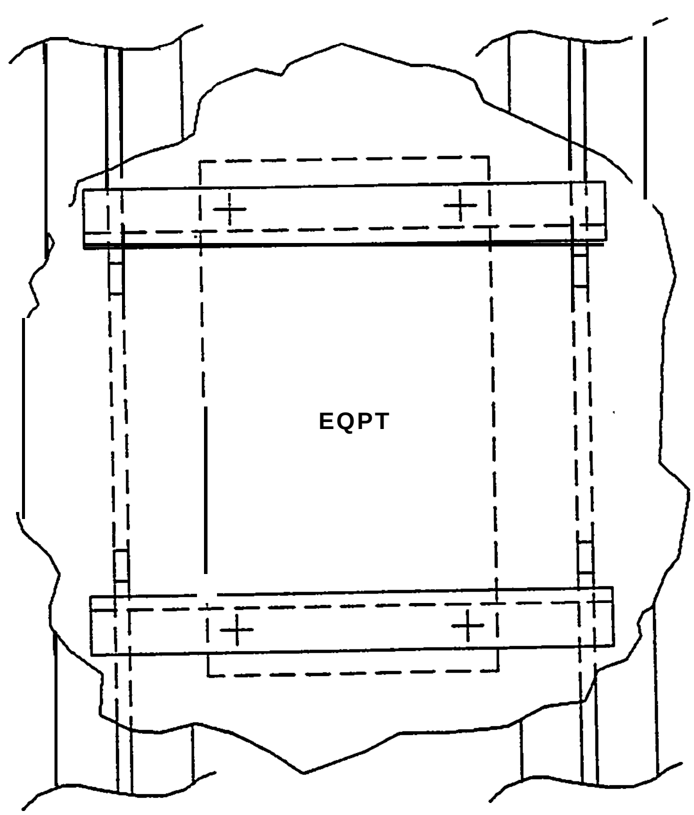


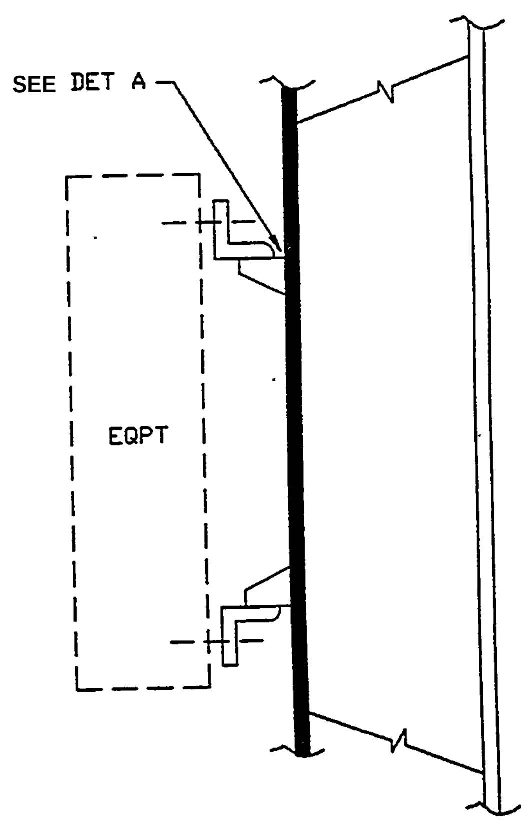


METHOD 1

SCANTLING SIZES (in)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776



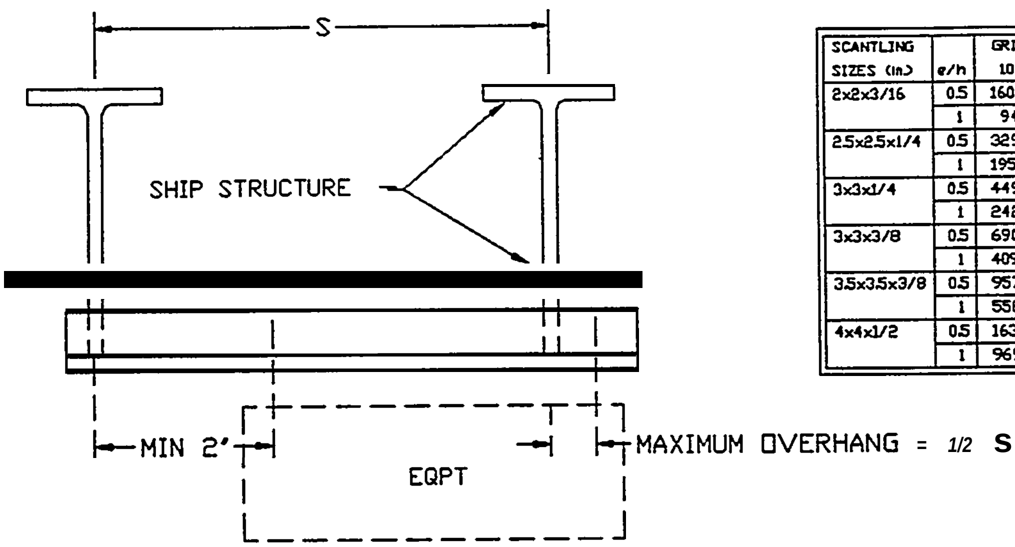


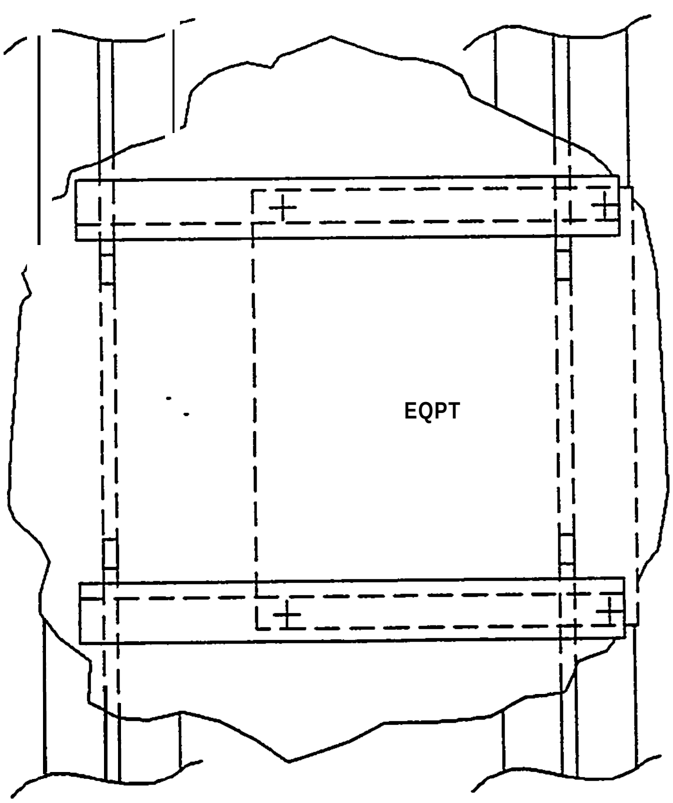


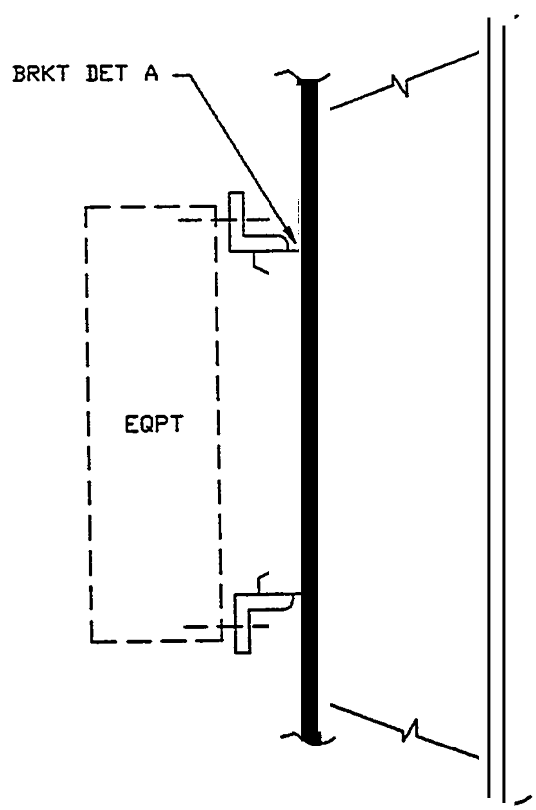
SCANTLING SIZES (in.)	e/h	GRILLAGES SPAN LENGTH On 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776

METHOD 2

SCANTLING SIZES (in.)	e/h	GRILLAGE OVERHANG LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	160	80	53	26	13
	1	94	47	25	10	5
2.5x2.5x1/4	0.5	329	165	110	67	34
	1	195	98	63	27	14
3x3x1/4	0.5	449	243	162	118	61
	1	242	143	96	47	24
3x3x3/8	0.5	690	346	217	92	47
	1	409	205	87	37	19
3.5x3.5x3/8	0.5	957	481	321	241	140
	1	558	284	190	109	56
4x4x1/2	0.5	1630	820	548	411	271
	1	969	486	324	211	108







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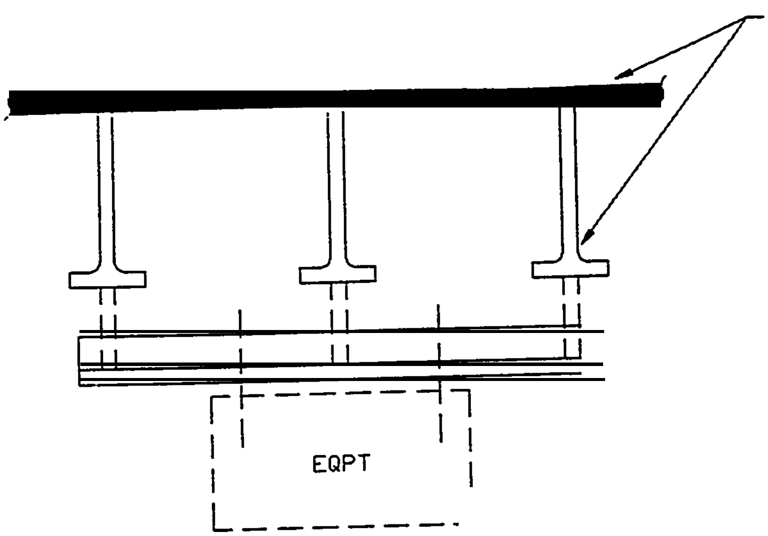
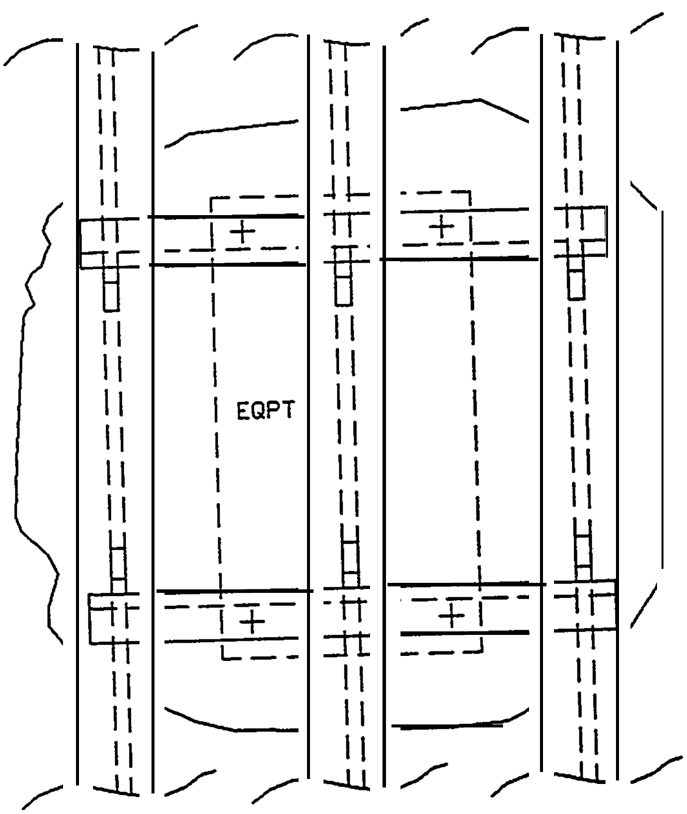
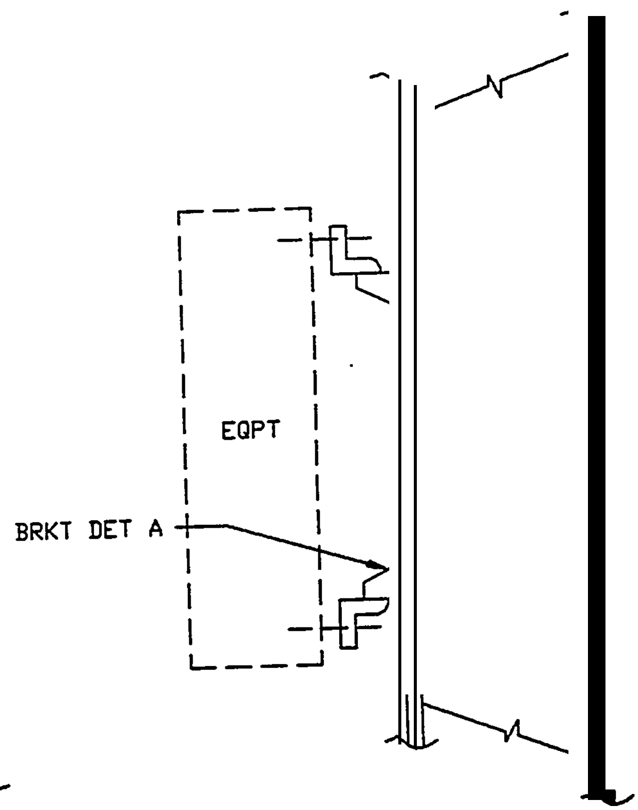


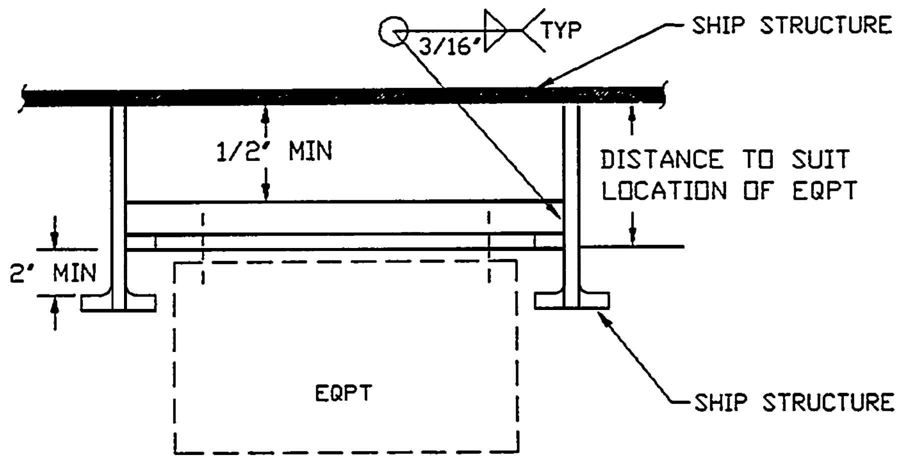
SCANTLING SIZES (in)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776

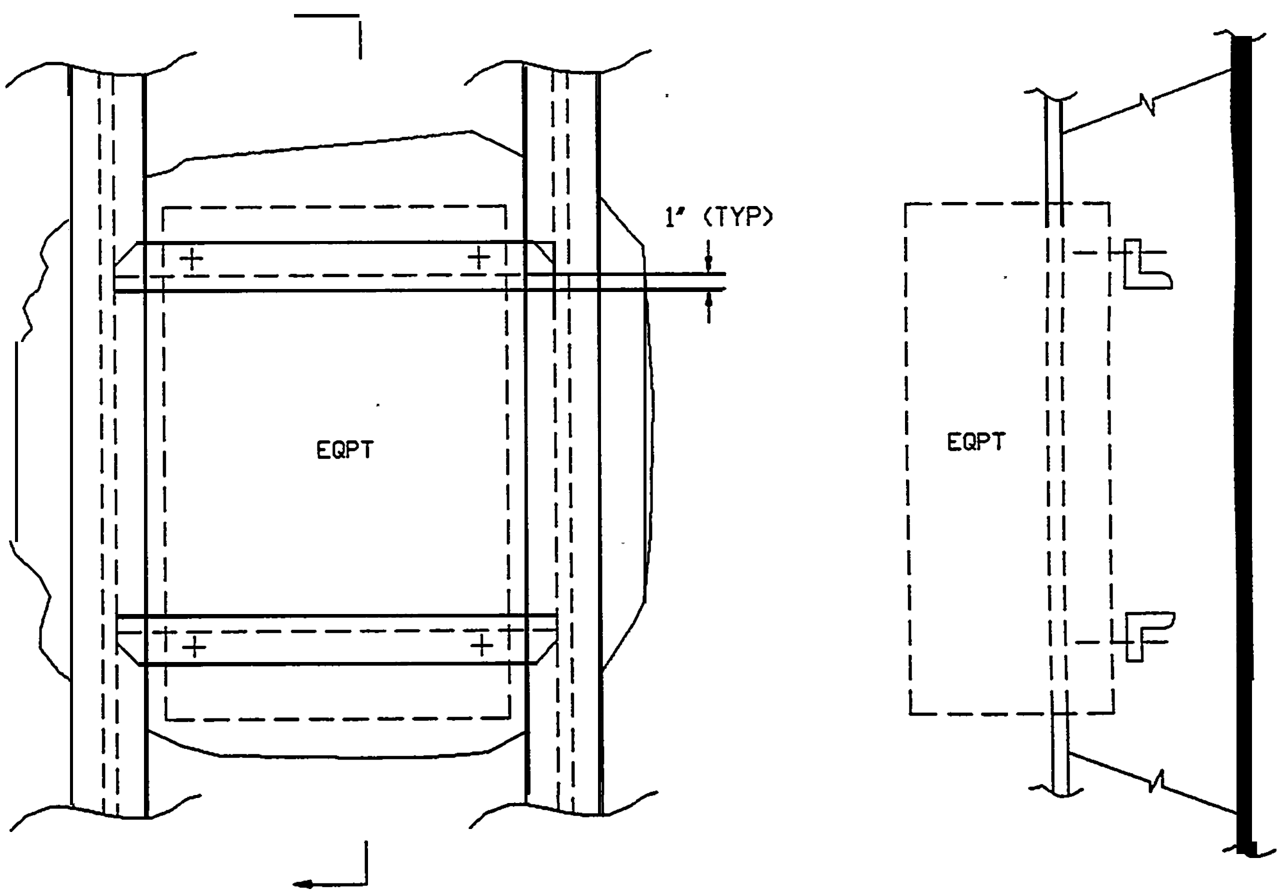




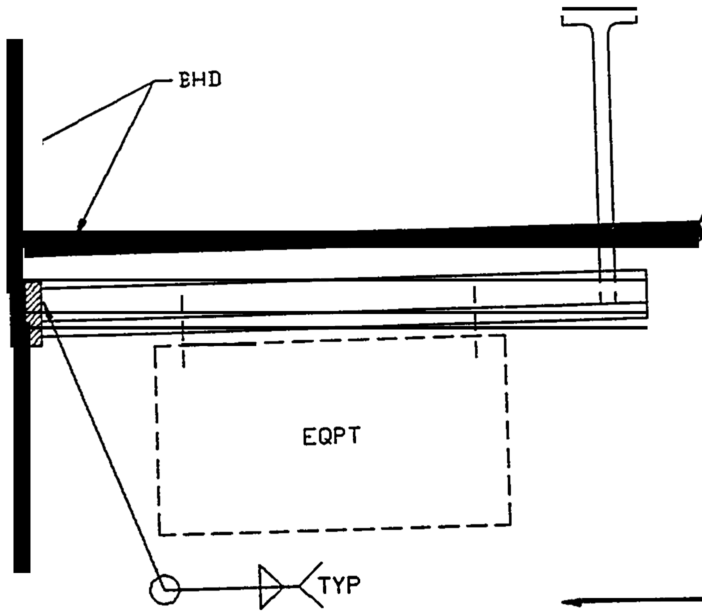
METHOD 4

SCANTLING SIZES (n)	e/h	GRILLAGE SPAN LENGTH (n)				
		10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776

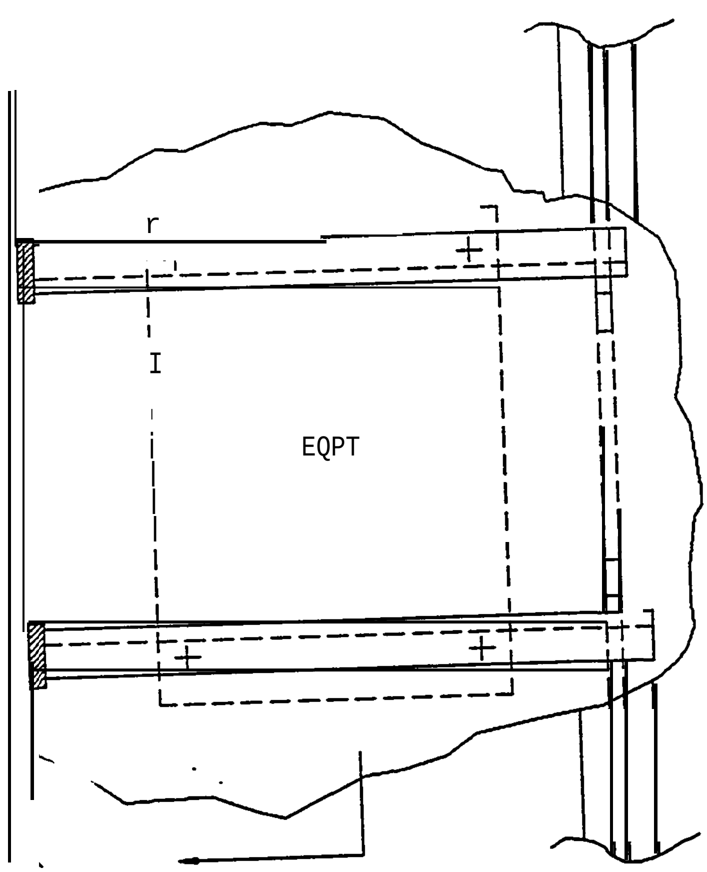


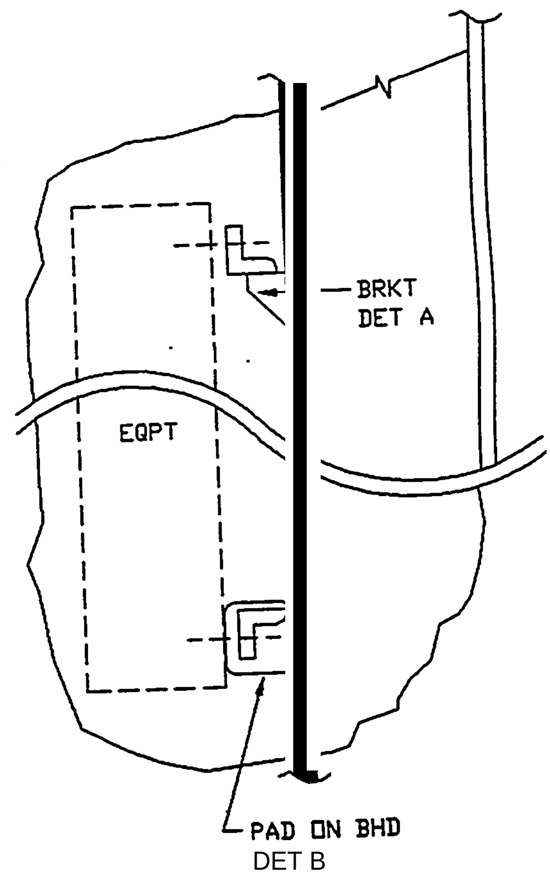


METHOD 5



SCANTLING SIZES (in)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776





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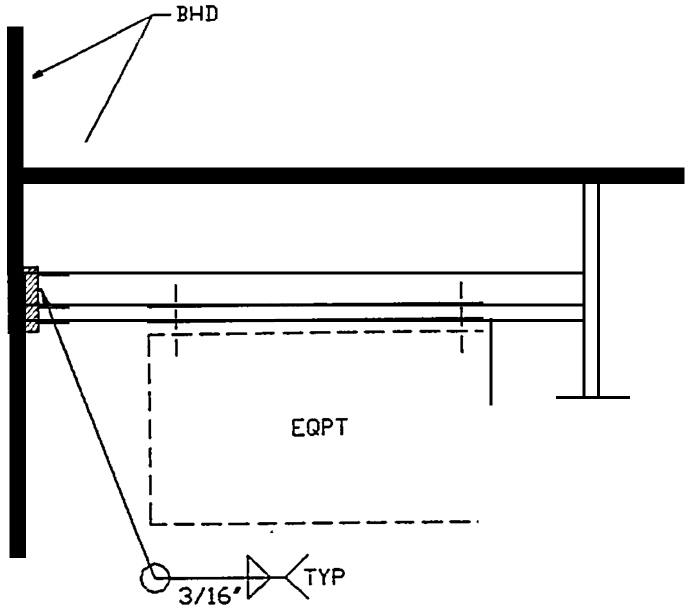
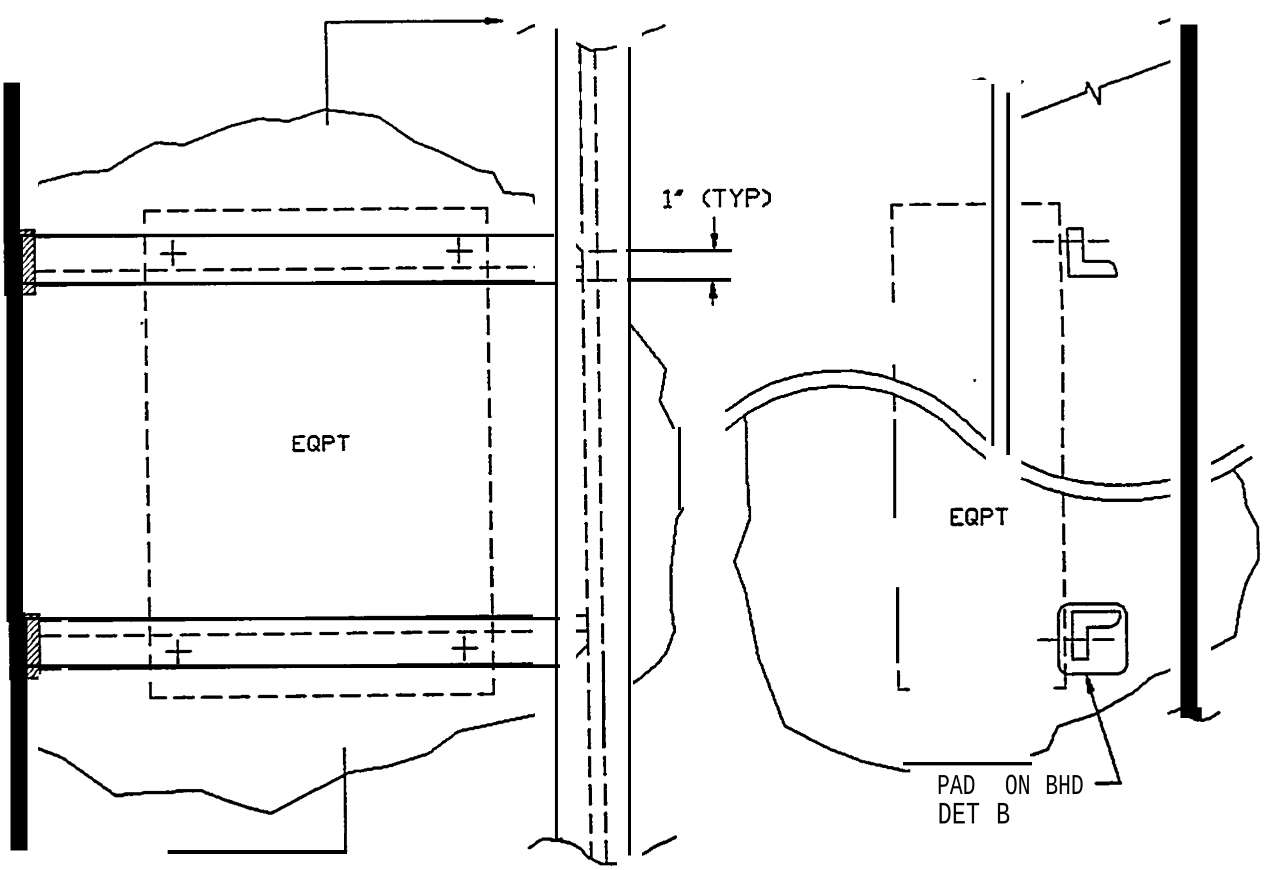
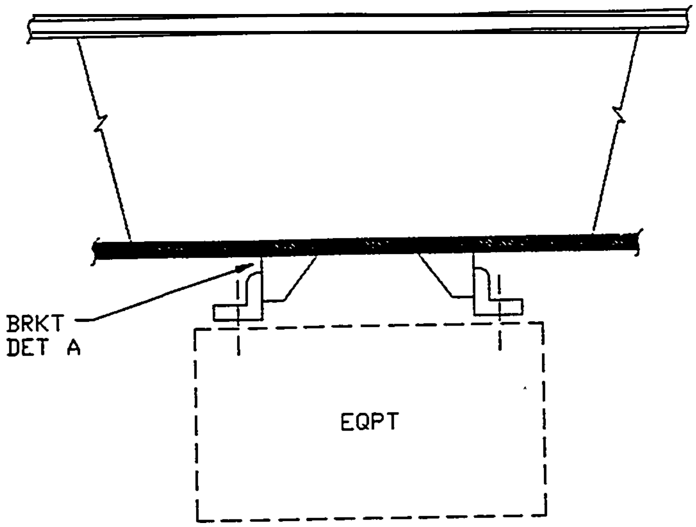


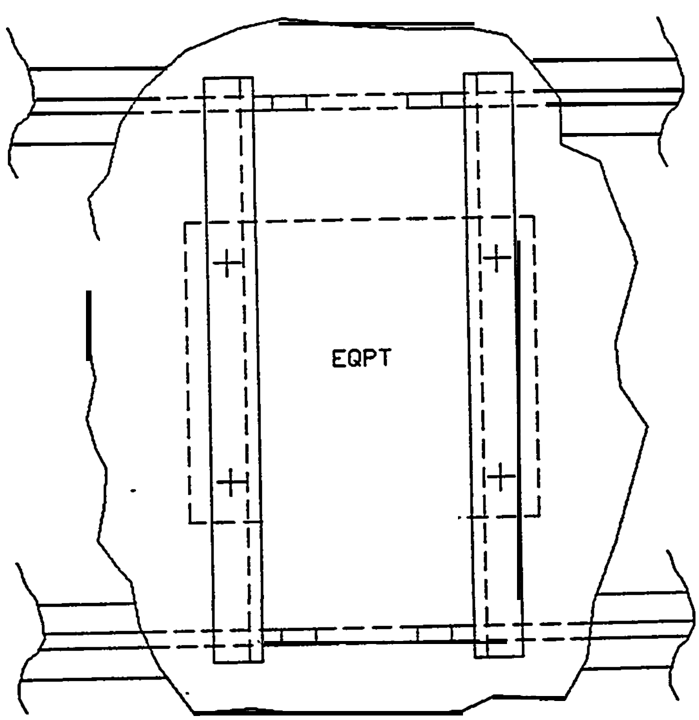
SCANTLING SIZES (in.)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776

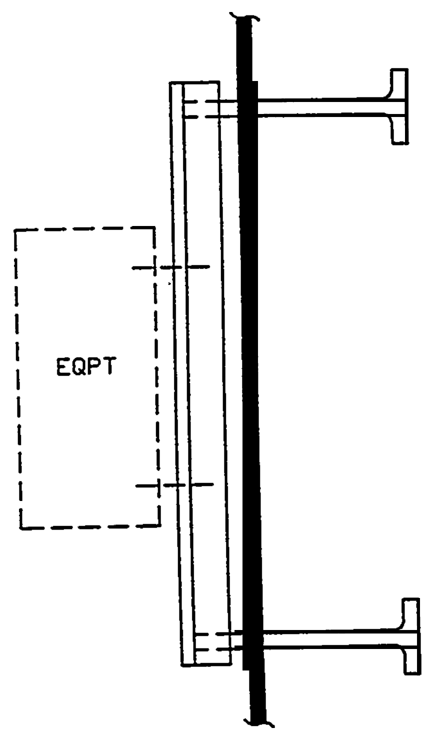


METHOD 7

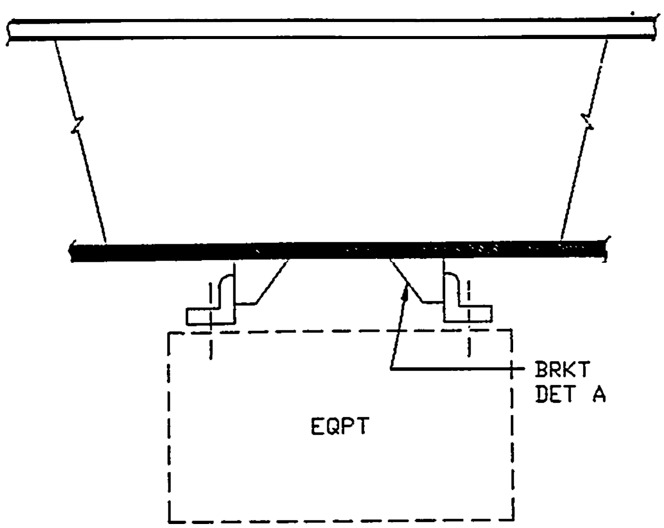


SCANTLING SIZES (in)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776



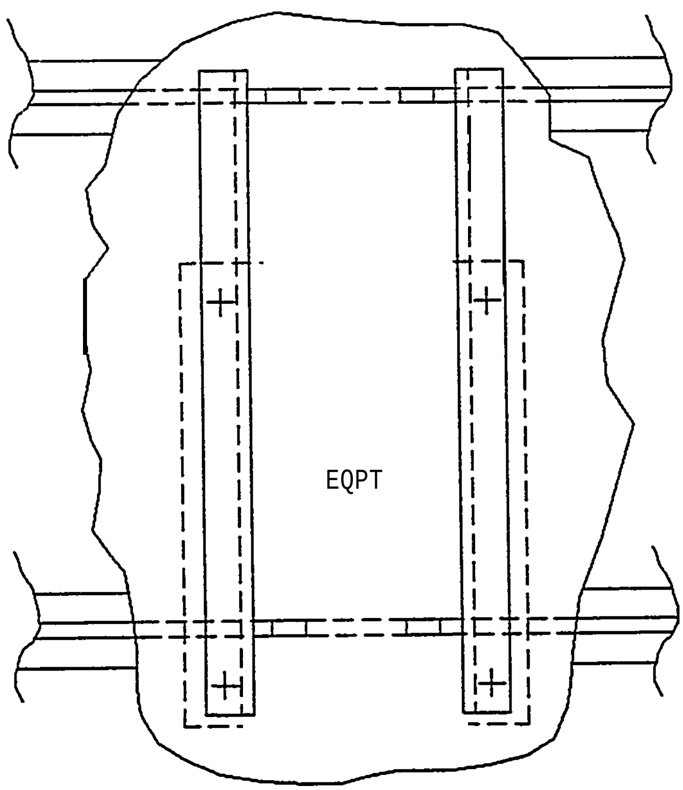


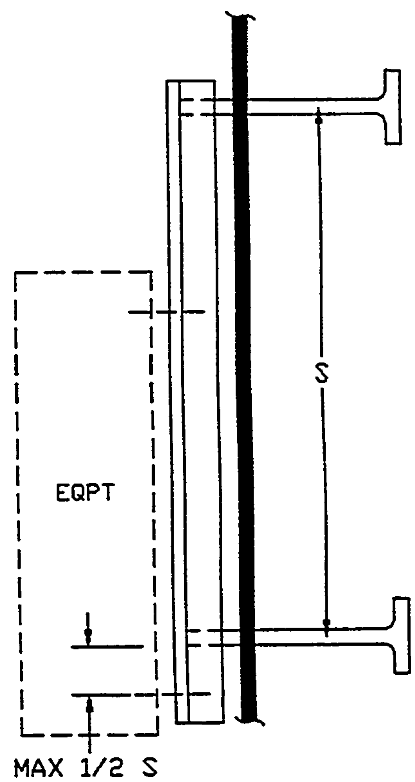
METHOD 8



SCANTLING SIZES (in.)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776

SCANTLING SIZES (in.)	e/h	GRILLAGE OVERHANG LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	160	80	53	26	13
	1	94	47	25	10	5
2.5x2.5x1/4	0.5	329	165	110	67	34
	1	195	98	63	27	14
3x3x1/4	0.5	449	243	162	118	61
	1	242	143	96	47	24
3x3x3/8	0.5	690	346	217	92	47
	1	409	205	87	37	19
3.5x3.5x3/8	0.5	957	481	321	241	140
	1	558	284	190	109	56
4x4x1/2	0.5	1630	820	548	411	271
	1	969	486	324	211	108

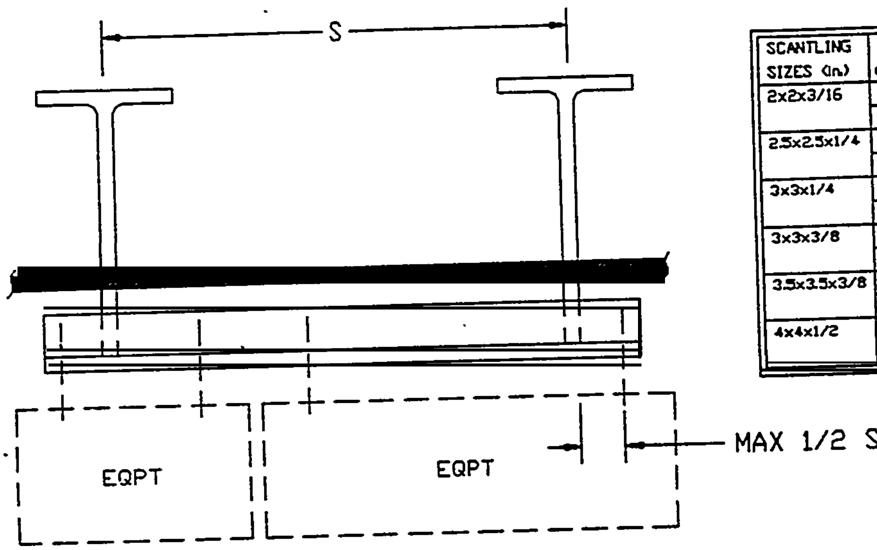


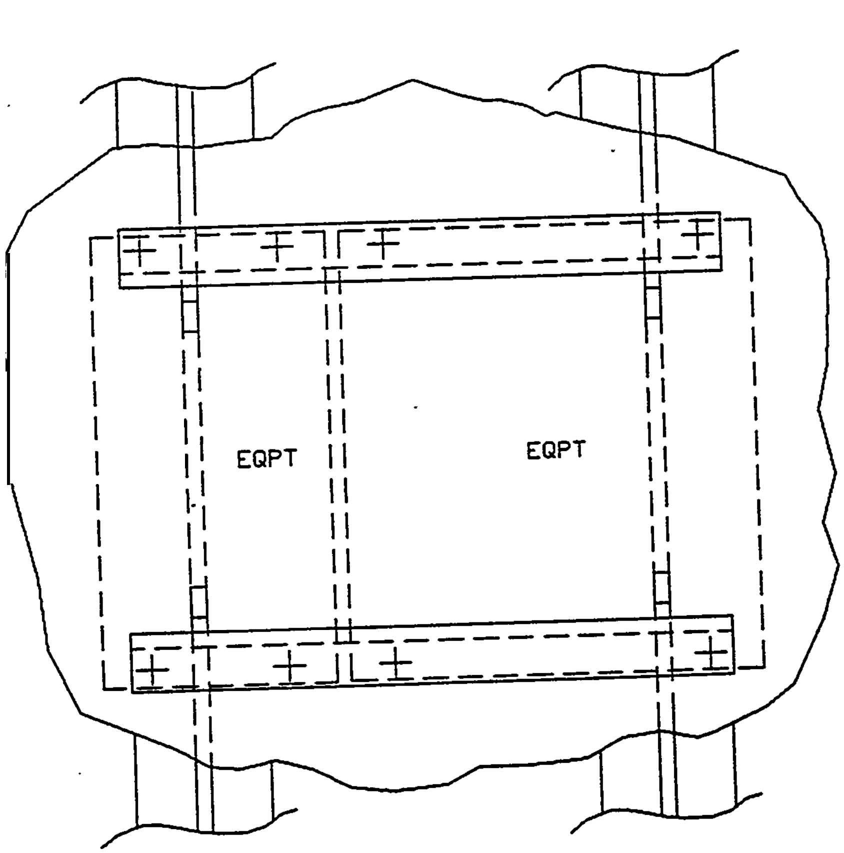


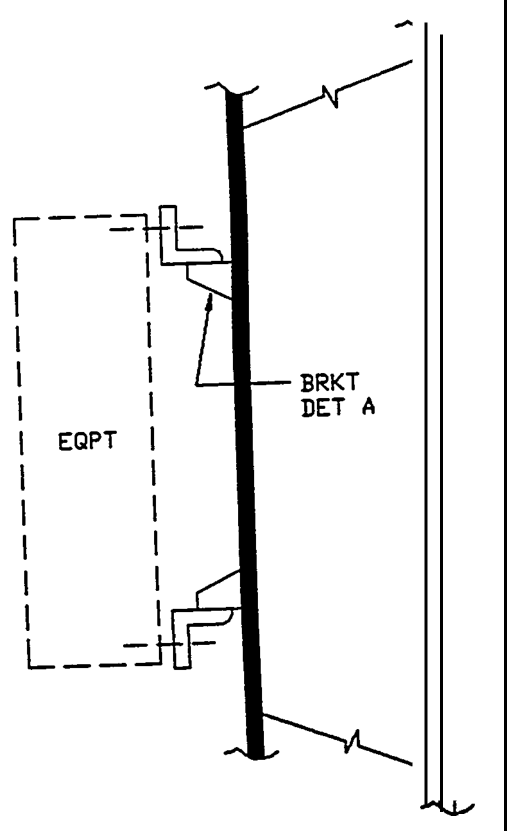
METHOD 9

SCANTLING SIZES (in)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776

SCANTLING SIZES (in)	e/h	GRILLAGE OVERHANG LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	160	80	53	26	13
	1	94	47	25	10	5
2.5x2.5x1/4	0.5	329	165	110	67	34
	1	195	98	63	27	14
3x3x1/4	0.5	449	243	162	118	61
	1	242	143	96	47	24
3x3x3/8	0.5	690	346	217	92	47
	1	409	205	87	37	19
3.5x3.5x3/8	0.5	957	481	321	241	140
	1	558	284	190	109	56
4x4x1/2	0.5	1630	820	548	411	271
	1	969	486	324	211	108

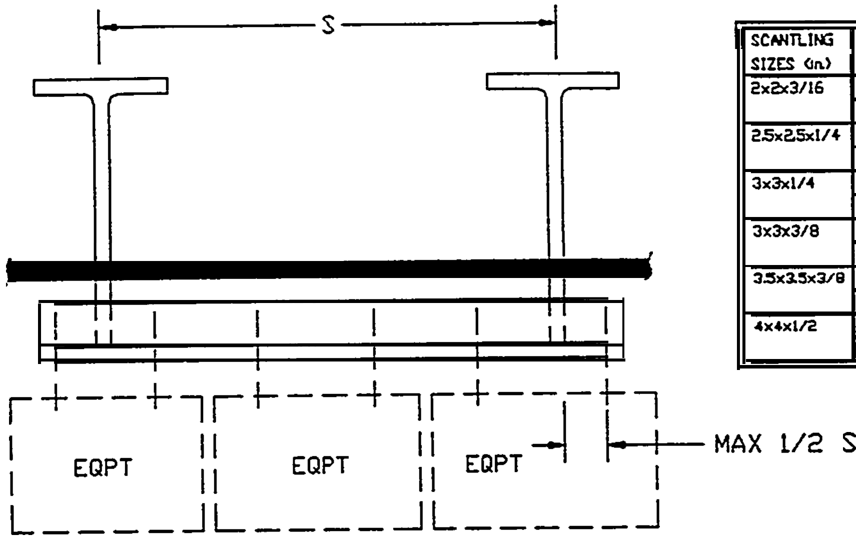




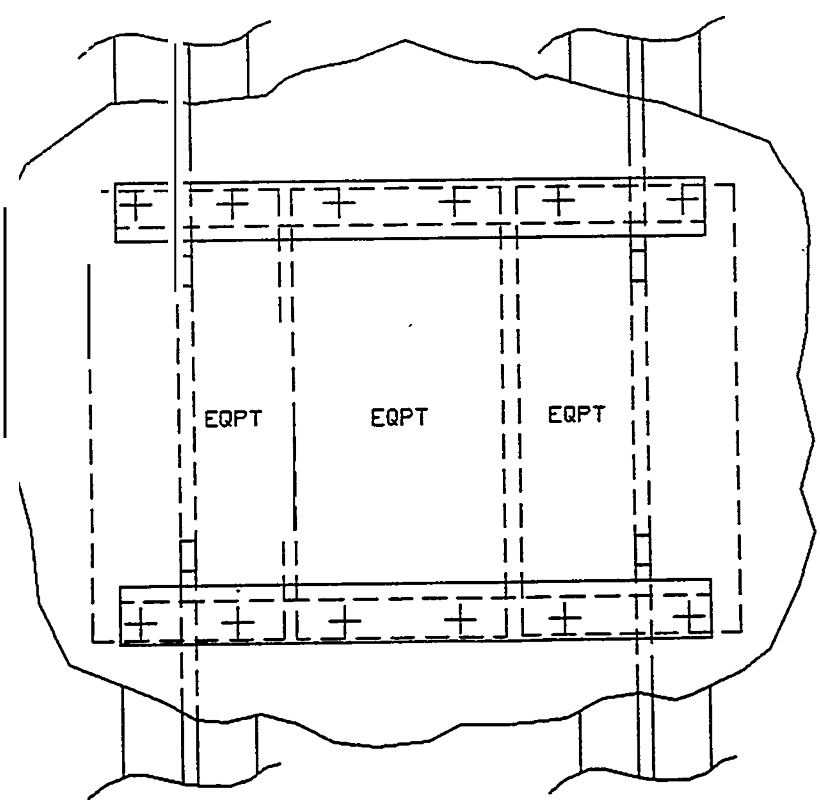


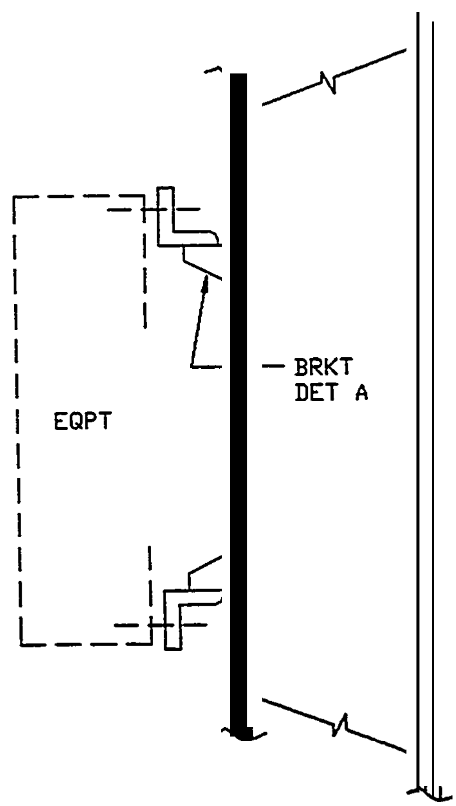
METHOD 10

SCANTLING SIZES (in)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776



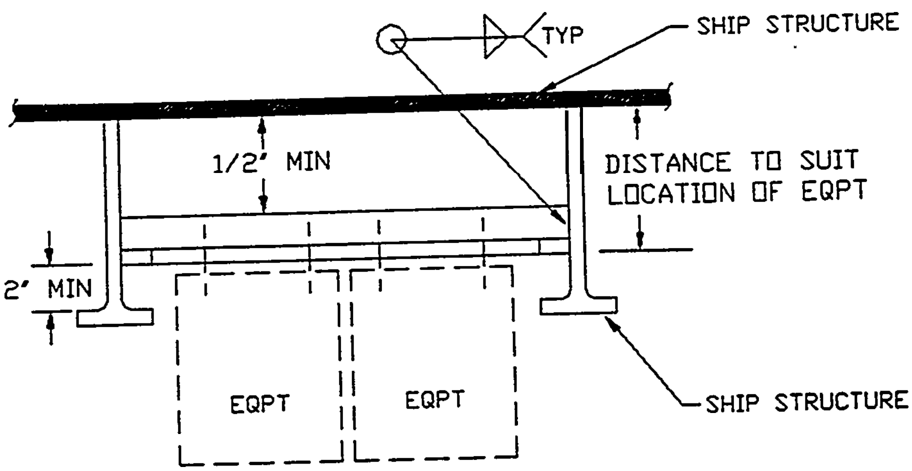
SCANTLING SIZES (in)	e/h	GRILLAGE OVERHANG LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	160	80	53	26	13
	1	94	47	25	10	5
2.5x2.5x1/4	0.5	329	165	110	67	34
	1	195	98	63	27	14
3x3x1/4	0.5	449	243	162	118	61
	1	242	143	96	47	24
3x3x3/8	0.5	690	346	217	92	47
	1	409	205	87	37	19
3.5x3.5x3/8	0.5	957	481	321	241	140
	1	558	284	190	109	56
4x4x1/2	0.5	1630	820	548	411	271
	1	969	486	324	211	108

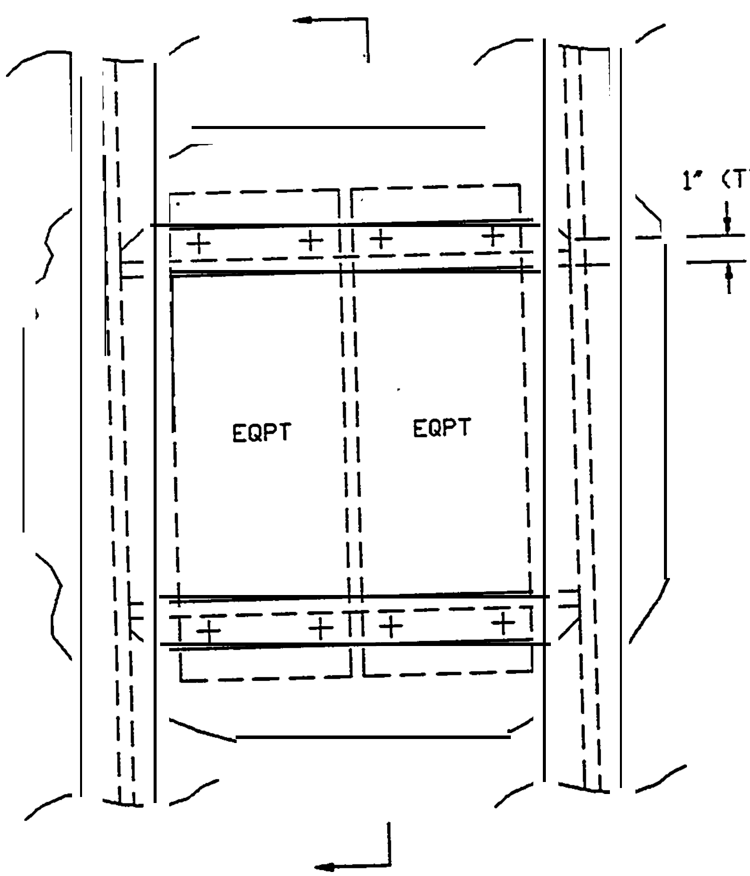


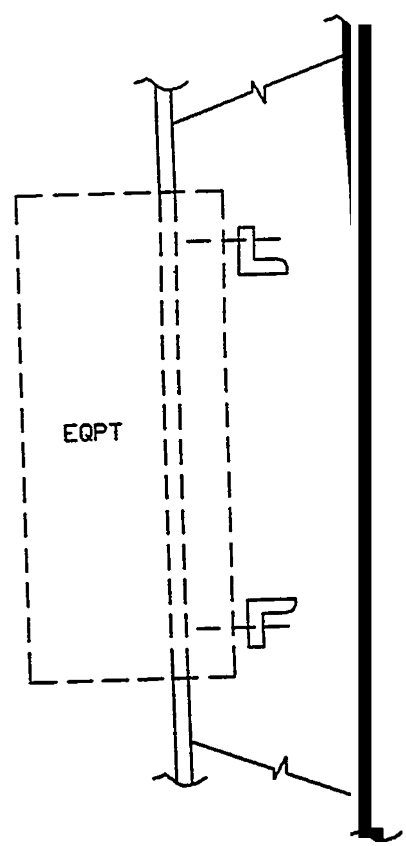


METHOD 11

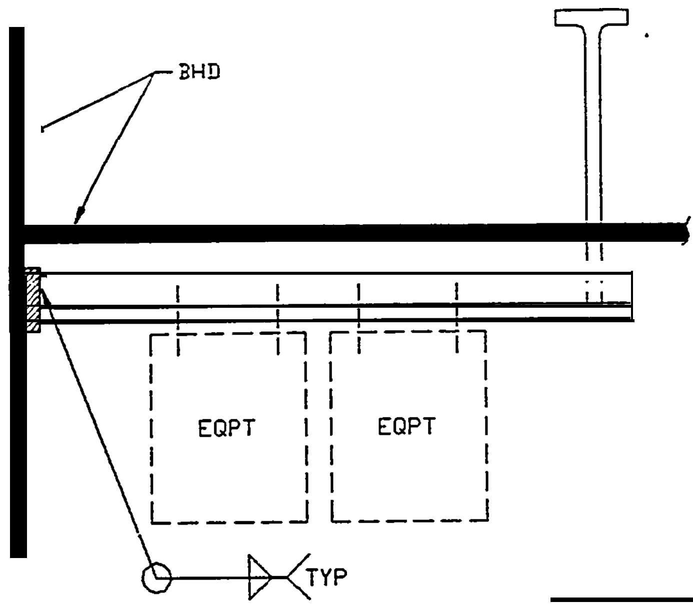
SCANTLING SIZES (in)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776



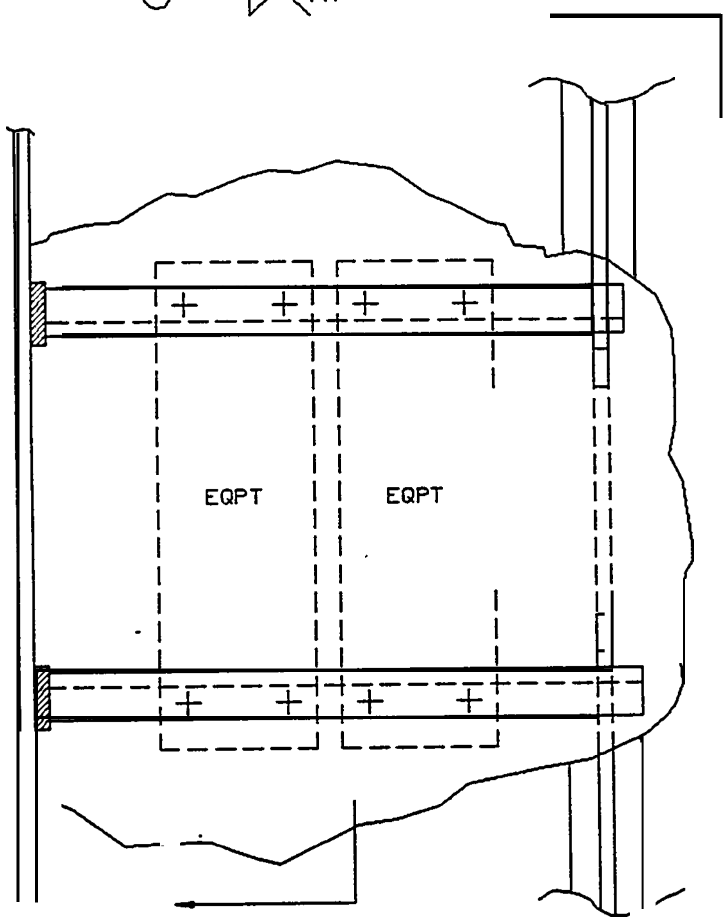


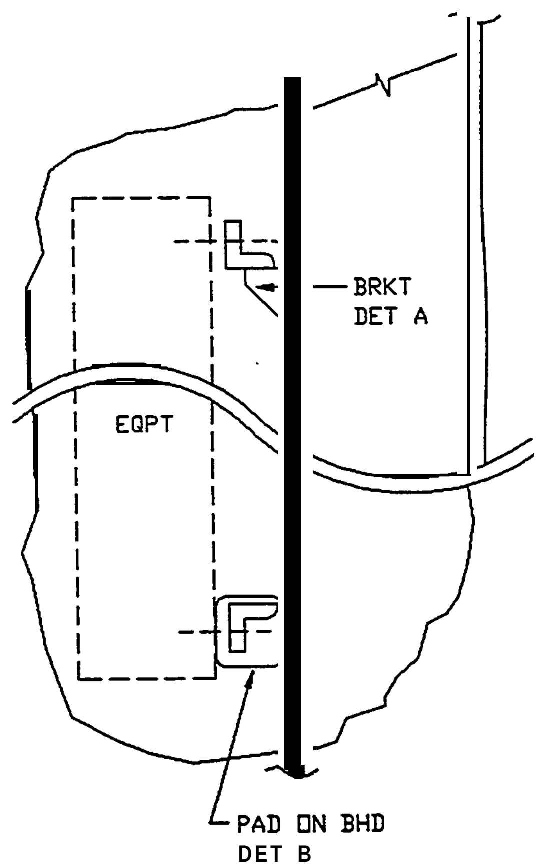


METHOD 12

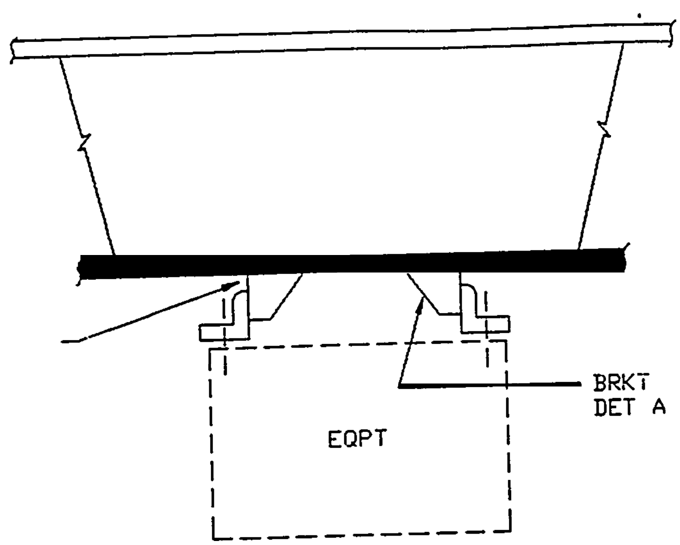


SCANTLING SIZES (in.)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776



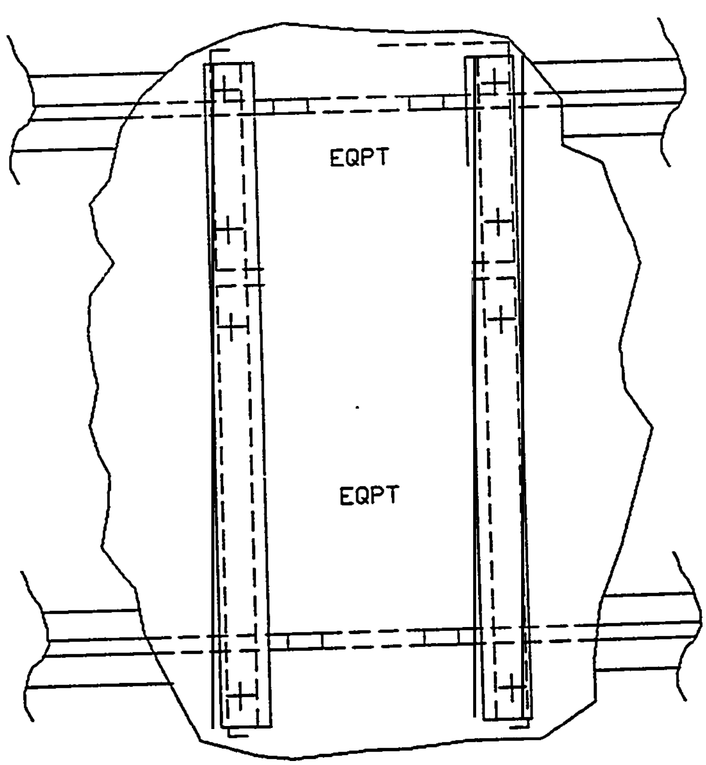


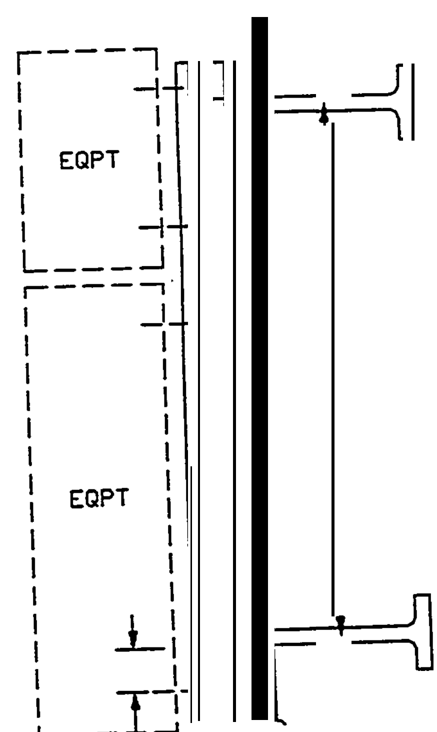
METHOD 13



SCANTLING SIZES (in.)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776

SCANTLING SIZES (in.)	e/h	GRILLAGE OVERHANG LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	160	80	53	26	13
	1	94	47	25	10	5
2.5x2.5x1/4	0.5	329	165	110	67	34
	1	195	98	63	27	14
3x3x1/4	0.5	449	243	162	118	61
	1	242	143	96	47	24
3x3x3/8	0.5	690	346	217	92	47
	1	409	205	87	37	19
3.5x3.5x3/8	0.5	957	481	321	241	140
	1	558	284	190	109	56
4x4x1/2	0.5	1630	820	548	411	271
	1	969	486	324	211	108

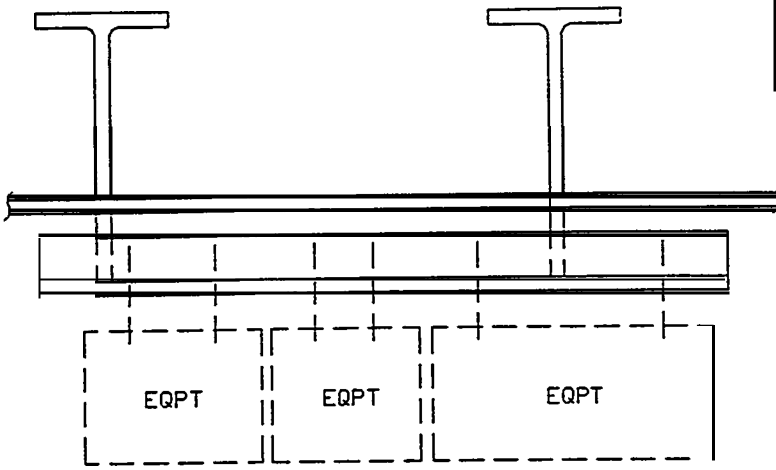




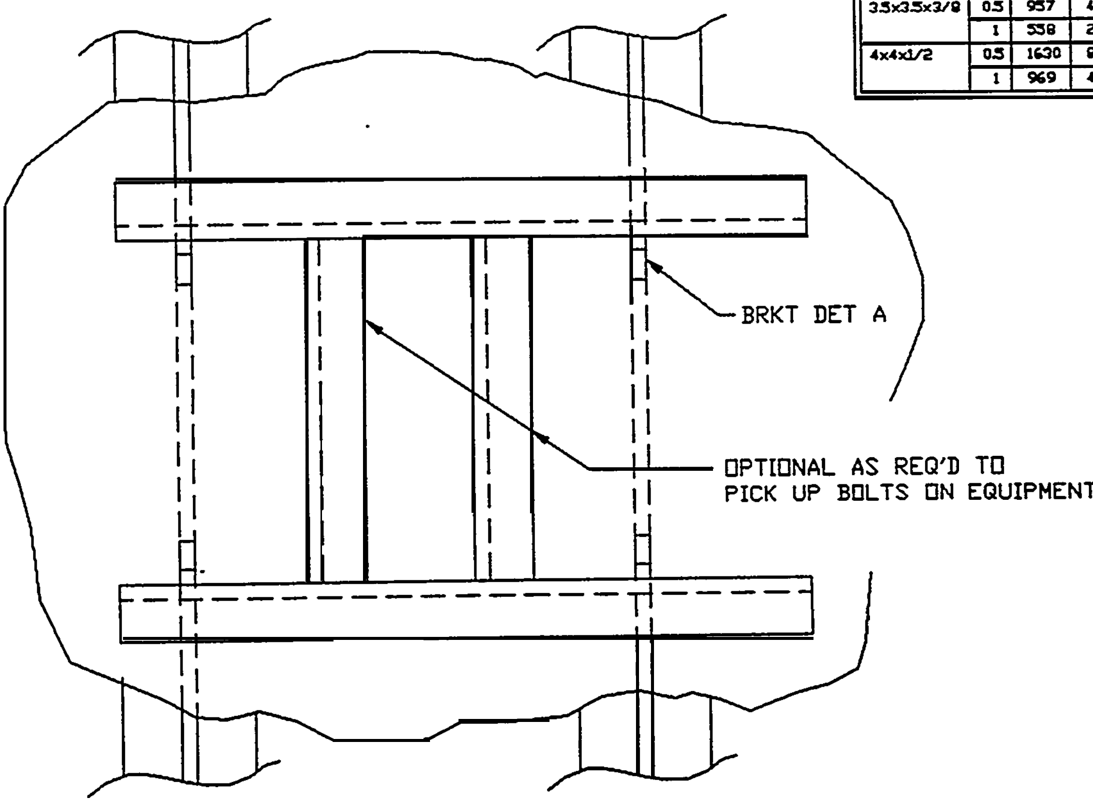
MAX l'/2 S

METHOD 14

SCANTLING SIZES (in)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776



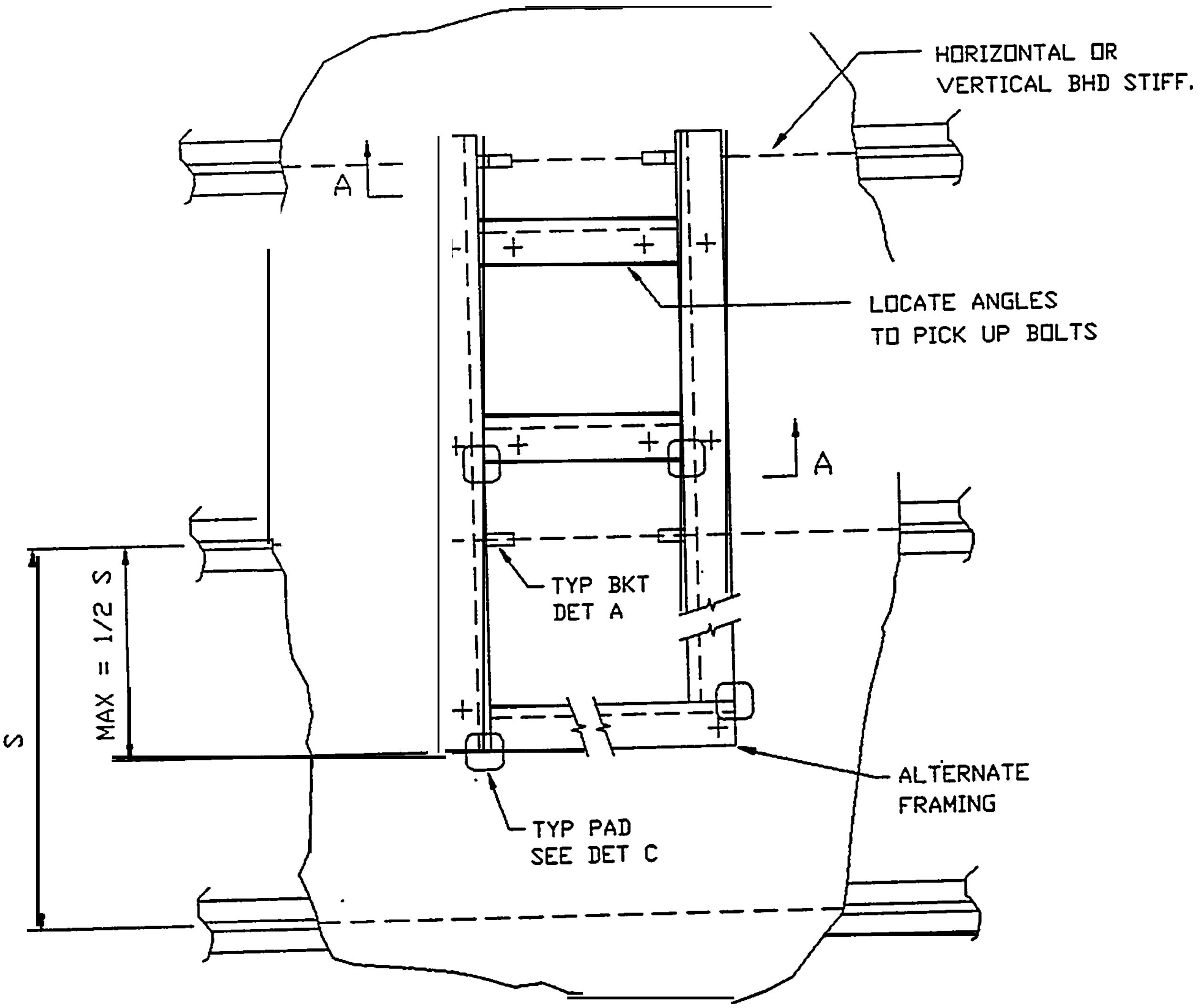
SCANTLING SIZES (in)	e/h	GRILLAGE OVERHANG LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	160	80	53	26	13
	1	94	47	25	10	5
2.5x2.5x1/4	0.5	329	165	110	67	34
	1	195	98	63	27	14
3x3x1/4	0.5	449	243	162	118	61
	1	242	143	96	47	24
3x3x3/8	0.5	690	346	217	92	47
	1	409	205	87	37	19
3.5x3.5x3/8	0.5	957	481	321	241	140
	1	558	284	190	109	56
4x4x1/2	0.5	1630	820	548	411	271
	1	969	486	324	211	108

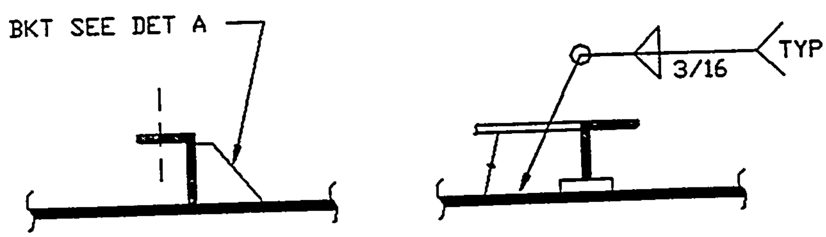


SCANTLING SIZES (in)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776

METHOD 15

SCANTLING SIZES (in.)	e/h	MOUNTING PLATE THICKNESS (in) 0.1875	0.25	0.375	0.5	0.625
2x2x3/16	0.5	112	261	831	1774	2976
	1	28	65	208	444	744
2.5x2.5x1/4	0.5	112	266	880	2012	3711
	1	28	66	220	503	928
3x3x1/4	0.5	112	262	843	1827	3127
	1	28	66	211	457	782
3x3x3/8	0.5	113	266	887	2047	3832
	1	28	67	222	512	958
3.5x3.5x3/8	0.5	113	266	866	1942	3479
	1	28	67	217	485	870
4x4x1/2	0.5	113	267	889	2058	3873
	1	28	67	222	515	968



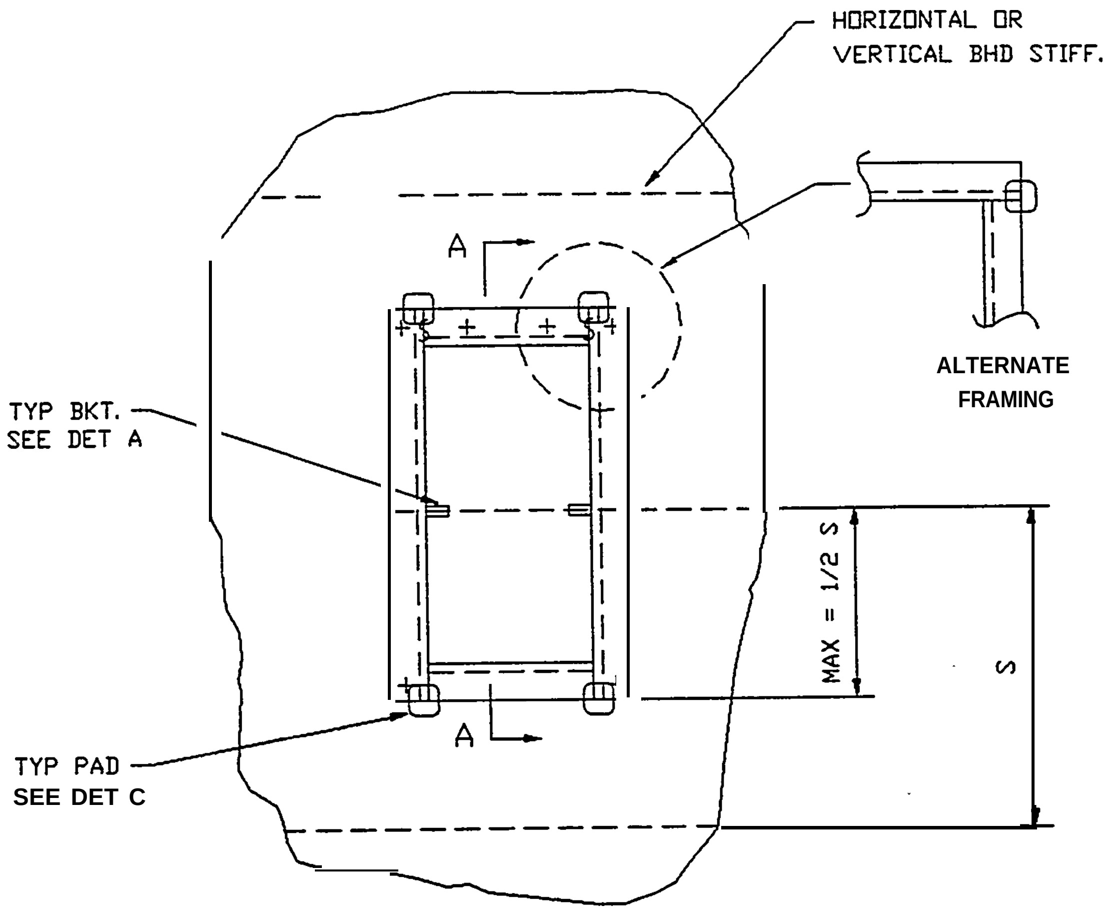


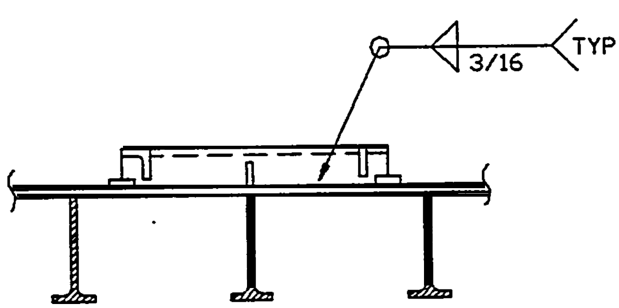
SECTION A-A

METHOD 16

SCANTLING SIZES (in)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776

SCANTLING SIZES (in.)	e/h	MOUNTING PLATE THICKNESS (in) 0.1875	0.25	0.375	0.5	0.625
2x2x3/16	0.5	112	261	831	1774	2976
	1	28	65	208	444	744
2.5x2.5x1/4	0.5	112	266	880	2012	3711
	1	28	66	220	503	928
3x3x1/4	0.5	112	262	843	1827	3127
	1	28	66	211	457	782
3x3x3/8	0.5	113	266	887	2047	3832
	1	28	67	222	512	958
3.5x3.5x3/8	0.5	113	266	866	1942	3479
	1	28	67	217	485	870
4x4x1/2	0.5	113	267	889	2058	3873
	1	28	67	222	515	968



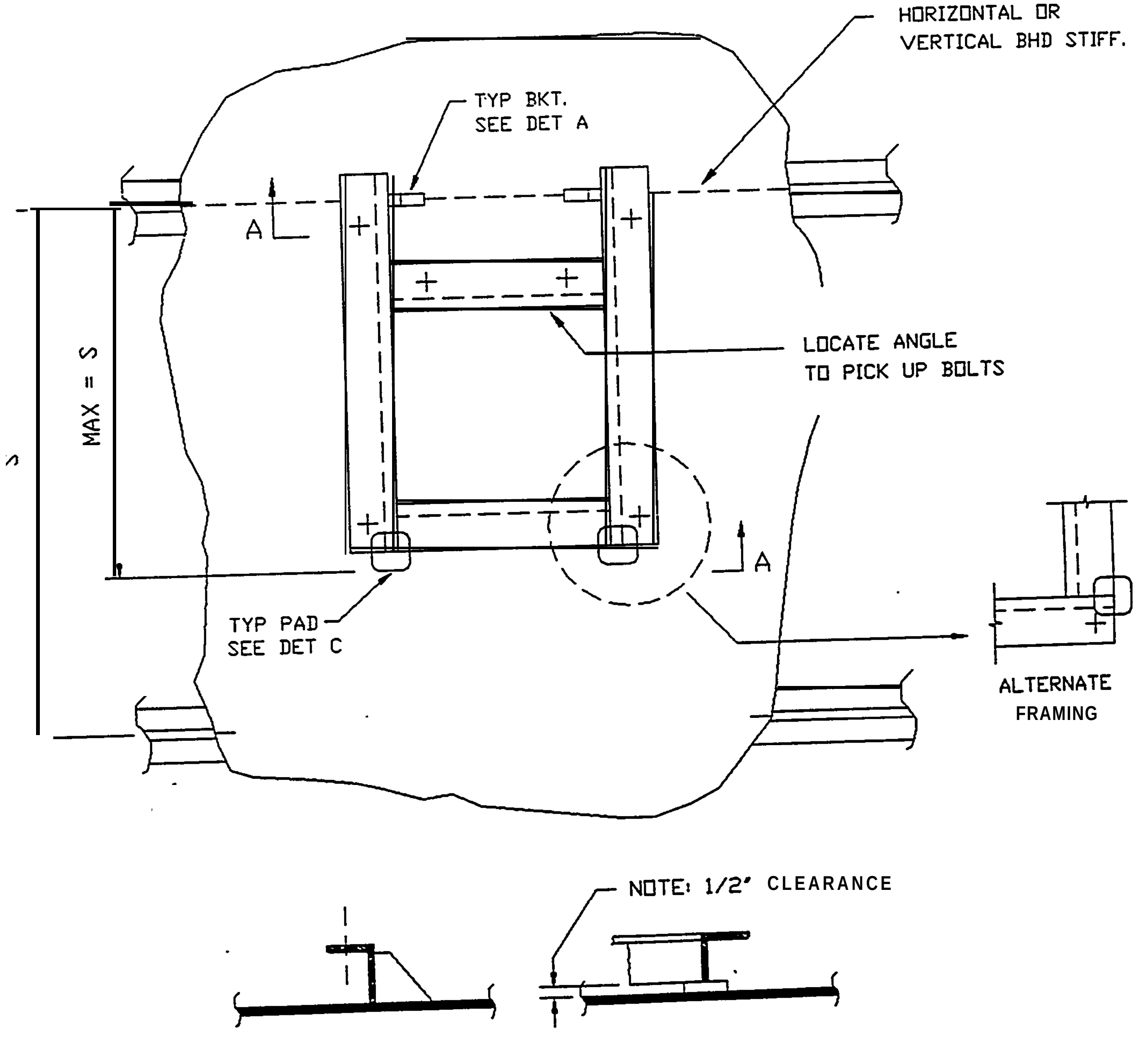


SECTION A-A

SCANTLING SIZES (in)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776

METHOD 17

SCANTLING SIZES (in)	e/h	MOUNTING PLATE THICKNESS (in) 0.1875	0.25	0.375	0.5	0.625
2x2x3/16	0.5	112	261	831	1774	2976
	1	28	65	208	444	744
2.5x2.5x1/4	0.5	112	266	880	2012	3711
	1	28	66	220	503	928
3x3x1/4	0.5	112	262	843	1827	3127
	1	28	66	211	457	782
3x3x3/8	0.5	113	266	887	2047	3932
	1	28	67	222	512	958
3.5x3.5x3/8	0.5	113	266	866	1942	3479
	1	28	67	217	485	870
4x4x1/2	0.5	113	267	889	2058	3873
	1	28	67	222	515	968

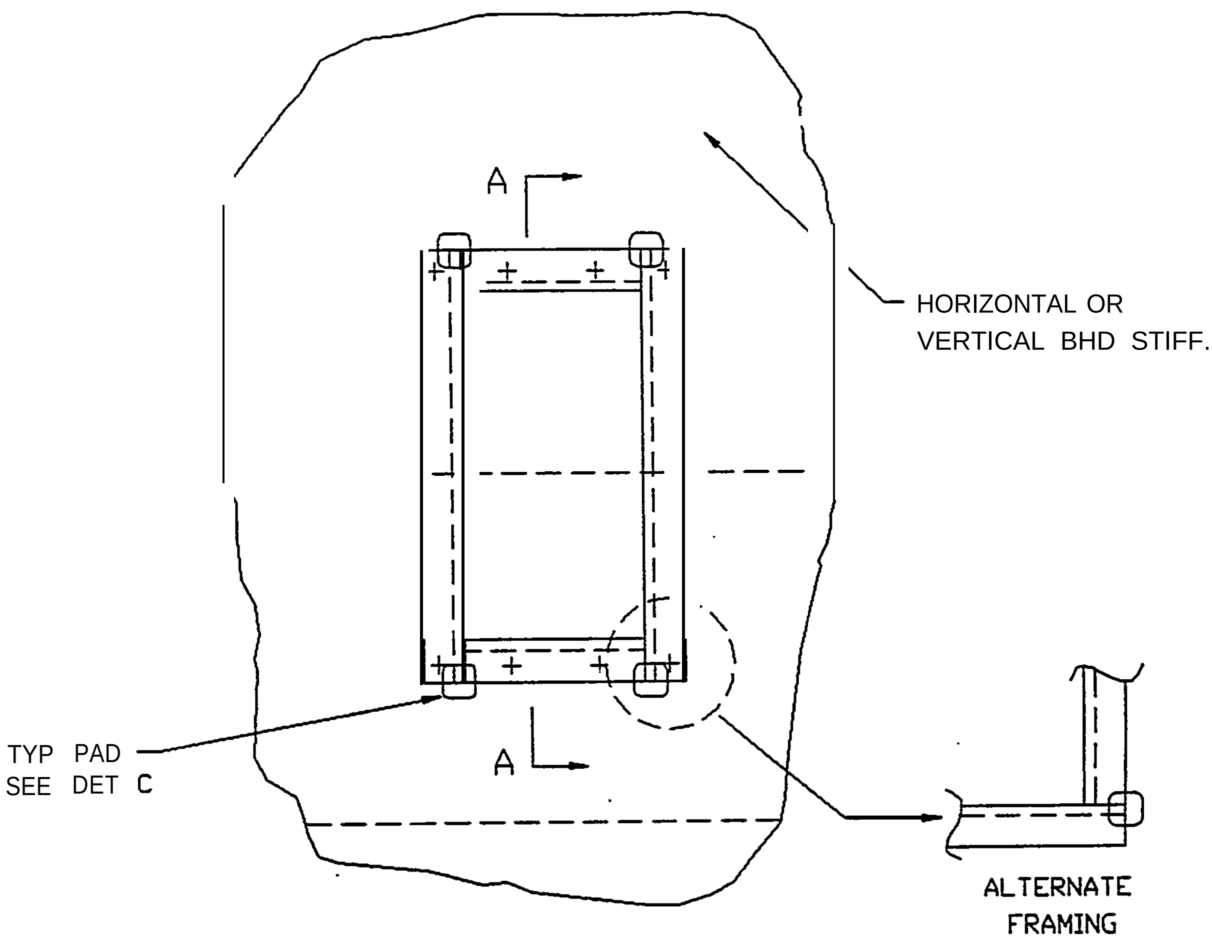


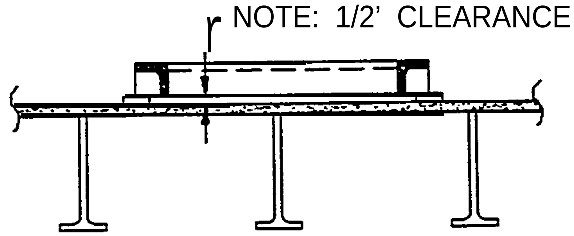
SECTION A-A

SCANTLING SIZES (in.)	e/h	GRILLAGE SPAN LENGTH (in) 10	20	30	40	50
2x2x3/16	0.5	258	258	213	160	128
	1	139	139	126	94	75
2.5x2.5x1/4	0.5	459	459	438	329	264
	1	247	247	247	195	156
3x3x1/4	0.5	449	449	449	449	388
	1	242	242	242	242	229
3x3x3/8	0.5	966	966	917	690	553
	1	520	520	520	409	295
3.5x3.5x3/8	0.5	1036	1036	1036	957	768
	1	558	558	558	558	454
4x4x1/2	0.5	1813	1813	1813	1630	1307
	1	1010	1010	1010	969	776

METHOD 18

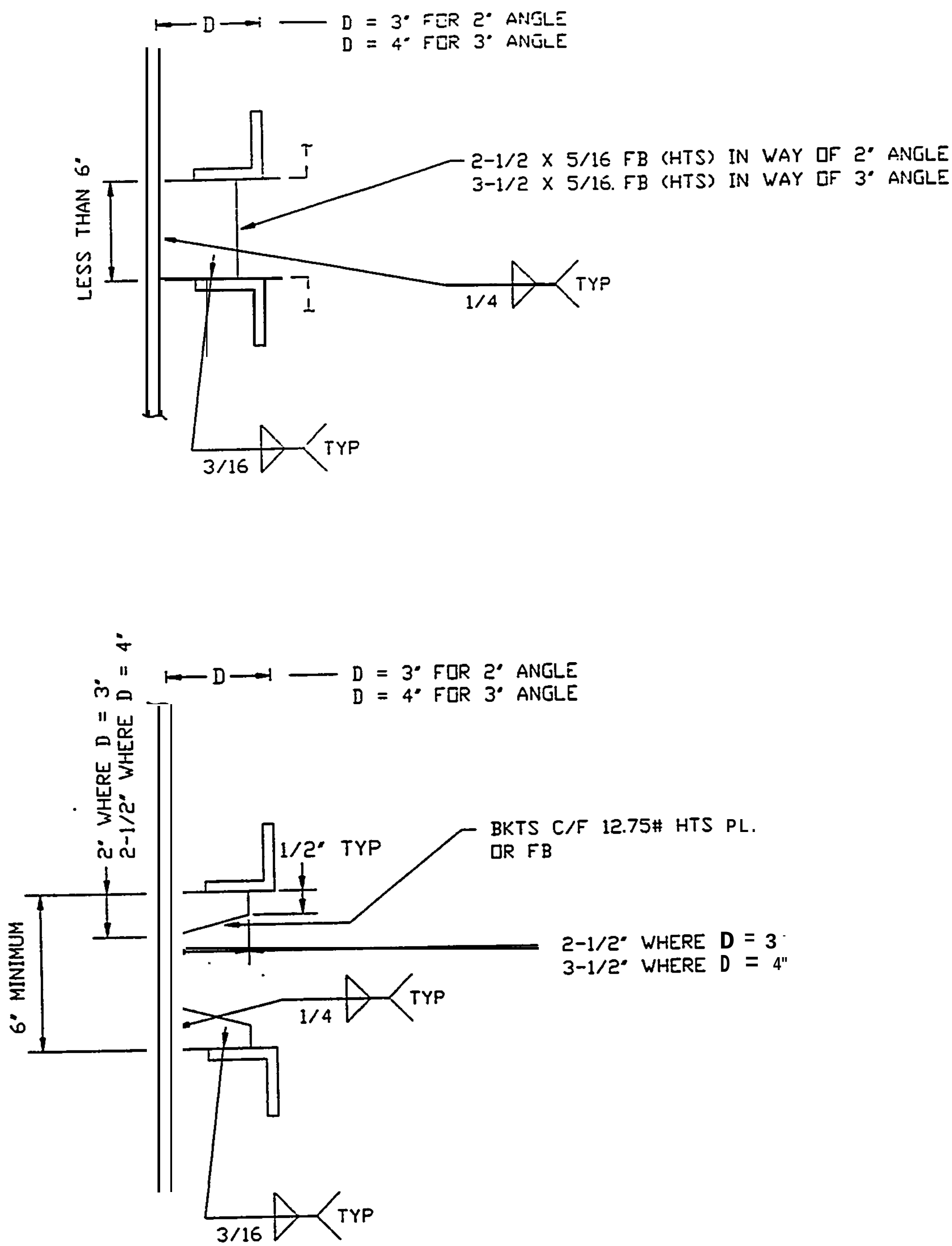
SCANTLING SIZES (in.)	e/h	MOUNTING PLATE THICKNESS (in) 0.1875	0.25	0.375	0.5	0.625
2x2x3/16	0.5	112	261	831	1774	2976
	1	28	65	208	444	744
2.5x2.5x1/4	0.5	112	266	880	2012	3711
	1	28	66	220	503	928
3x3x1/4	0.5	112	262	843	1827	3127
	1	28	66	211	457	782
3x3x3/8	0.5	113	266	887	2047	3832
	1	28	67	222	512	958
3.5x3.5x3/8	0.5	113	266	866	1942	3479
	1	28	67	217	485	870
4x4x1/2	0.5	113	267	889	2058	3873
	1	28	67	222	515	968





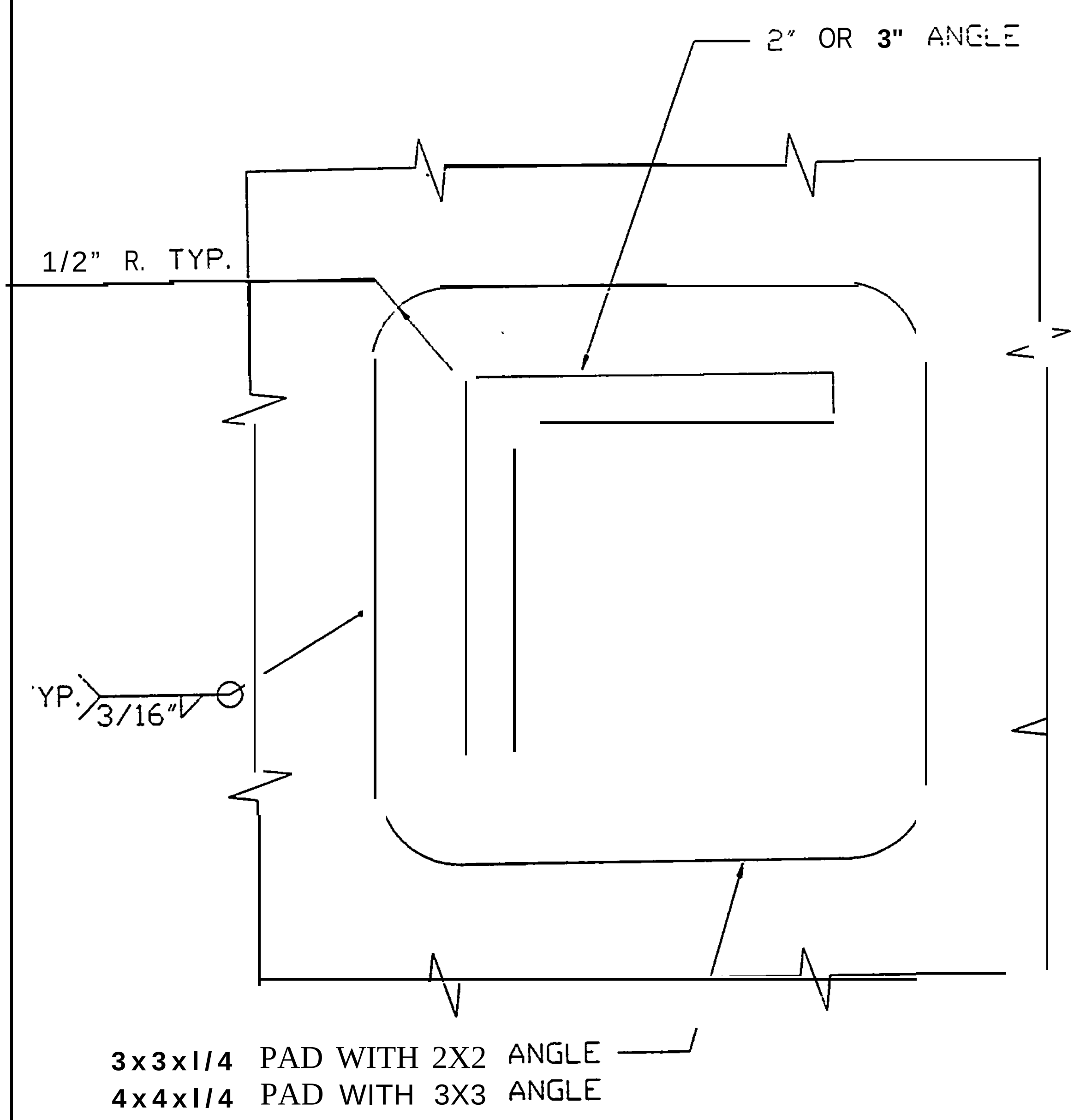
SECTION A-A

DET A



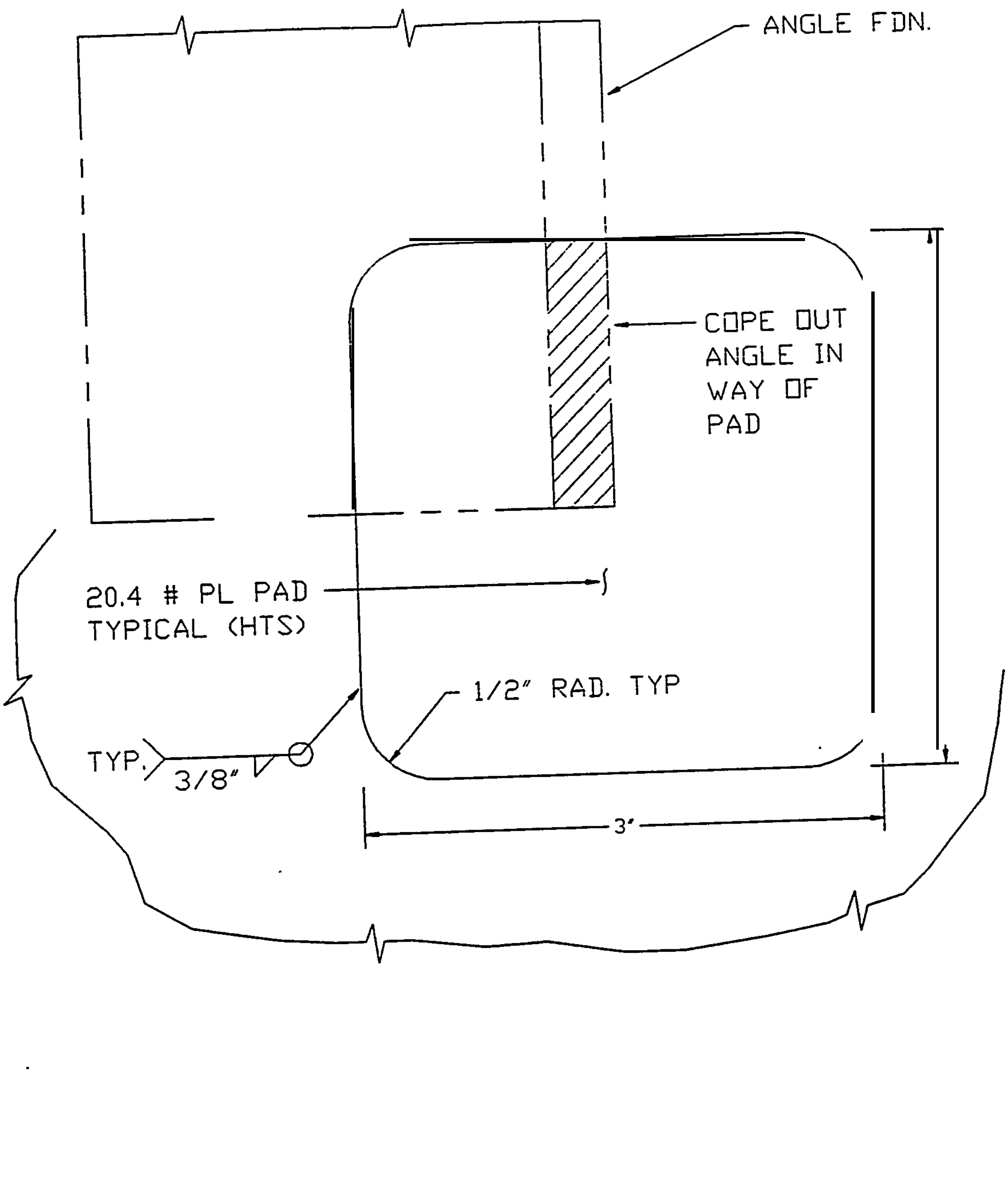
D
D = 3" FOR 2" ANGLE
D = 4" FOR 3" ANGLE
LESS THAN 6"
2-1/2 X 5/16 FB (HTS) IN WAY OF 2" ANGLE
3-1/2 X 5/16. FB (HTS) IN WAY OF 3" ANGLE
1/4
TYP
3/16
TYP
D
D = 3" FOR 2" ANGLE
D = 4" FOR 3" ANGLE
2" WHERE D = 3"
2-1/2" WHERE D = 4"
1/2" TYP
BKTS C/F 12.75# HTS PL.
OR FB
6" MINIMUM
2-1/2" WHERE D = 3
3-1/2" WHERE D = 4"
1/4
TYP
3/16
TYP

DET B



2" OR 3" ANGLE
1/2" R. TYP.
TYP.
3/16"
3x3x1/4 PAD WITH 2X2 ANGLE
4x4x1/4 PAD WITH 3X3 ANGLE

DET C


ANGLE FDN.
COPE OUT ANGLE IN WAY OF PAD
20.4 # PL PAD TYPICAL (HTS)
1/2" RAD. TYP
TYP.
3/8"
3'

9.4 **Typical Foundations Using Stud Equipment Mounting**

Stud mounting of equipment can be used as another standard installation method, especially for light-weight equipments. As demonstrated in cost/labor saving illustrations in section 7.0, stud mounted installation can to a great extent eliminate certain types of fabrication intensive foundations.

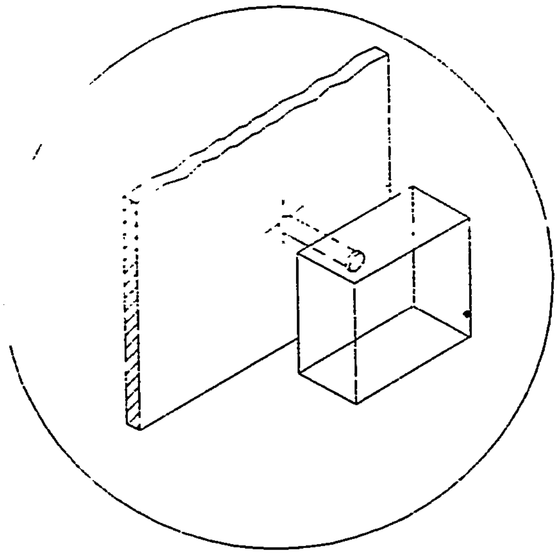
Enclosed design data tables were computed using certain limiting criteria for the studs and mounting plates. The view-graphs are based on Low-Carbon Corrosion-resistant Steel Studs with a design allowable of 30 KSI (60% of Yield Strength). Designer can scale the limit loads as obtained from the view-graphs according to their design specifications. The worst combination of sea-loads along with the worst orientation of stud installation were adopted during design data view-graph computation. Described below is a generic procedure to use these view-graphs for foundation design

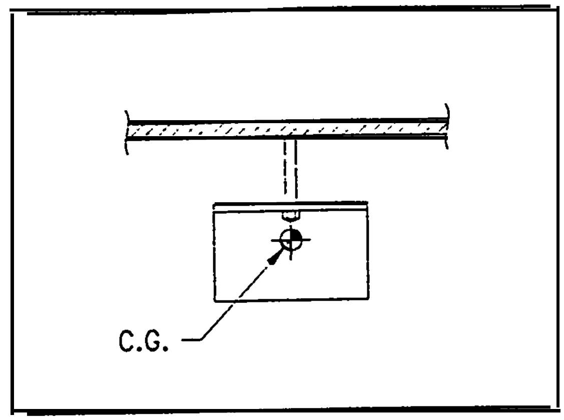
- Categorize the installation as either Single stud or Multi stud installation. For single stud the entire weight of the equipment has to be borne by it, while for multi-studs the weight bearing capacity of each stud is computed by dividing the weight of the equipment by the number of studs.

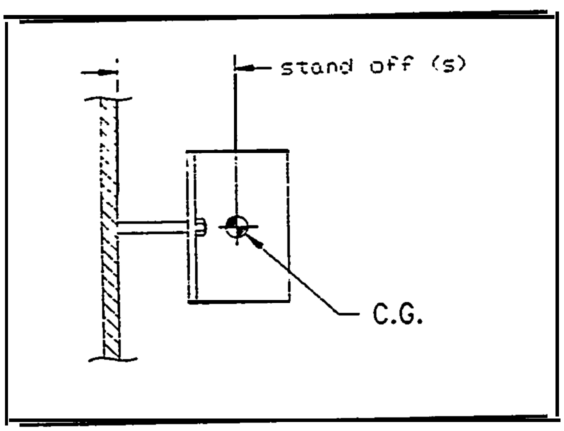
- Estimate the Stud Stand-off length according to the measuring method described in view-graphs.

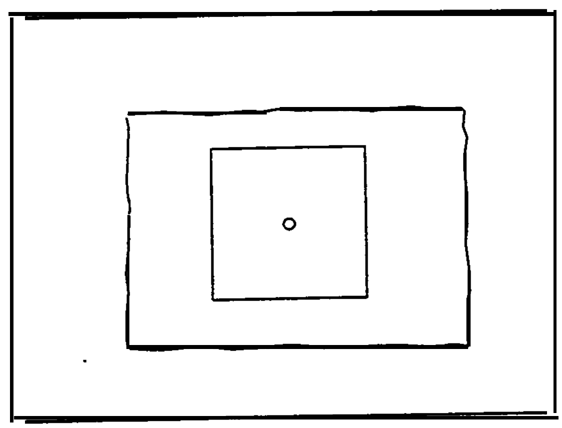
- The load bearing capacity per stud is checked off on the design data table corresponding to the Mounting Plate thickness and Stud stand-off length, and the minimum stud size which gives the allowable load higher than the required load bearing capacity, is selected for the equipment installation.

SINGLE STUD









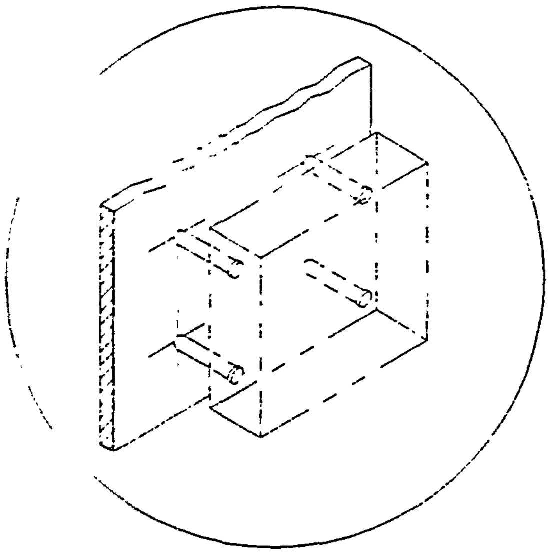
Design Data of Limit Load in Lbs.

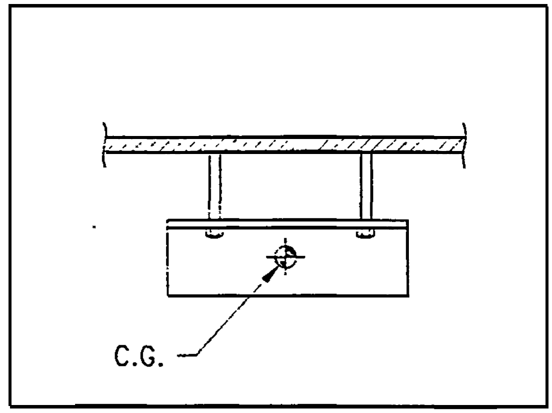
STUD (IN) STAND OFF	STUD DIA. 3/8in		STUD DIA. 1/2in		STUD DIA. 5/8in		STUD DIA. 3/4in	
	MOUNTING PLATE THICKNESS (IN)							
	0.1875	>=0.25	0.1875	>=0.25	0.25	>=0.375	0.25	>=0.375
1	59	59	120	147	272	303	321	552
2	28	28	54	67	120	134	138	237
3	18	18	35	43	77	86	88	151
4	13	13	26	32	57	63	64	110
5	11	11	21	25	45	50	51	87
6	9	9	17	21	37	41	42	72
7	8	8	15	18	32	35	36	61
8	6	7	13	16	28	31	31	53
9	4	5	11	14	24	27	28	47
10	3	4	8	10	21	24	25	42
11	3	3	7	8	16	20	22	38
12	2	2	5	6	13	15	20	31

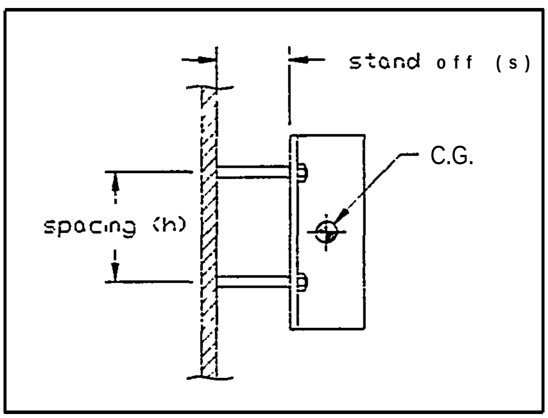
VIBTECH, INC.
P.O. BOX 435
NORTH KINGSTOWN, RI 02852
TEL: 401/294-1590
FAX: 401/295-2592

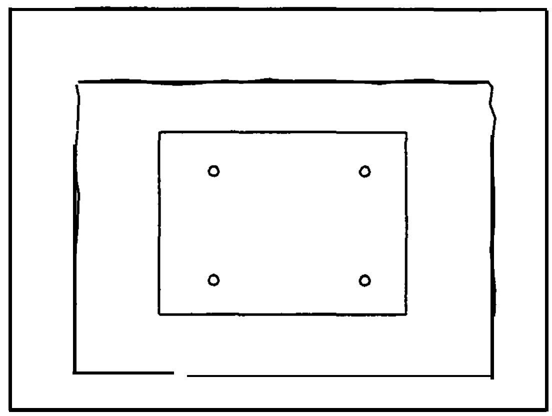
DRWN BY:	S. Ducharme		REV
CHCK BY:	M. Gupta		A
APPR BY:	JJH		
SCALE: NONE	DATE: 18 AUG 95		

MUTIPLE STUDS









Design Data of Limit Load in Lbs.

STUD (IN) STAND OFF	STUD DIA. 3/8in		STUD DIA. 1/2in		STUD DIA. 5/8in		STUD DIA. 3/4in	
	MOUNTING PLATE THICKNESS (IN)							
	0.1875	>=0.25	0.1875	>=0.25	0.25	>=0.375	0.25	>=0.375
1	59	59	120	147	272	303	321	552
2	28	28	54	67	120	134	138	237
3	18	18	35	43	77	86	88	151
4	13	13	26	32	57	63	64	110
5	11	11	21	25	45	50	51	87
6	9	9	17	21	37	41	42	72
7	8	8	15	18	32	35	36	61
8	6	7	13	16	28	31	31	53
9	4	5	11	14	24	27	28	47
10	3	4	8	10	21	24	25	42
11	3	3	7	8	16	20	22	38
12	2	2	5	6	13	15	20	31

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TEL: 401/294-1590
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DRWN BY: S. Ducharme
CHCK BY: M. Gupta
APPR BY: JJH
SCALE: NONE
DATE: 18 AUG 95
REV A

APPENDIX A

Design Data Table Calculation Methodology

The purpose of this appendix is to describe the calculation methodology used to obtain the allowable weights shown in the design data tables in Section 9.0. The calculations were done under three (3) primary categories of foundation/stallation, namely

a) Grillages -- Grillage welded to mounting plate
-- Grillage lifted off mounting plate
-- Overhanging Grillage
-- Method Mountings

b) Frames & Trusses

c) Stud Mountings -- Single Stud
-- Multiple Stud

This section will also elaborate the loading criteria, failure criteria and allowable limits used in the design data table calculations, so that the designer can extrapolate the design data table values to suit their applicable criteria and specifications.

METHOD OF ANALYSIS

Allowable weight for a given foundation type was determined based on a number of different failure criteria, all of which fall into two categories, strength criteria and frequency criteria. Finite Element Models and Spreadsheets were created to calculate the weight limits based on each criteria for a large envelope of foundation configurations. For each configuration, the lowest allowable weight from the most limiting criteria was used for that specific foundation. The allowables for each of these criteria is calculated using conservative methods, loads and assumptions as described further.

LOADING

Loads are induced into foundation scantlings through the equipment attachments. Ship's motion loads on the equipment, measured in terms of equivalent static G's, are applied to the equipment and the resultant forces are resolved at the attachments. Acceleration values, based on relatively worse case scenario, of 3 G's vertical, 1.5 G's transverse and 0.75 G's longitudinal are applied to the equipment simultaneously. Combined with the equipment weight, these accelerations produce forces on the equipment acting in all three directions.

In calculating resultant forces at the foundation attachments the number of attachments/ bolts on the scantling span was not considered, instead a worst case assumption was made that each scantling span had only two effective bolts. For example, axial and shear forces were computed as if there was only one bolt on either scantling of a foundation span. Overturning forces were computed based on the e/h of the equipment and distributed on the foundation spans as if they were supported by only one bolt. Since forces are acting in three directions, there were two directions which produce overturning forces and in reality two different equipment e/h's to consider, but to be conservative the minimum of the two values, producing the higher resultant force for a given load, was used for both directions of overturning. Additionally, the worst conceivable load at the bolt was calculated by orientating the foundation so that the ship's motion loads produce the highest bolt loads. Figure A-1 shows the resolved forces for a particular grillage configuration.

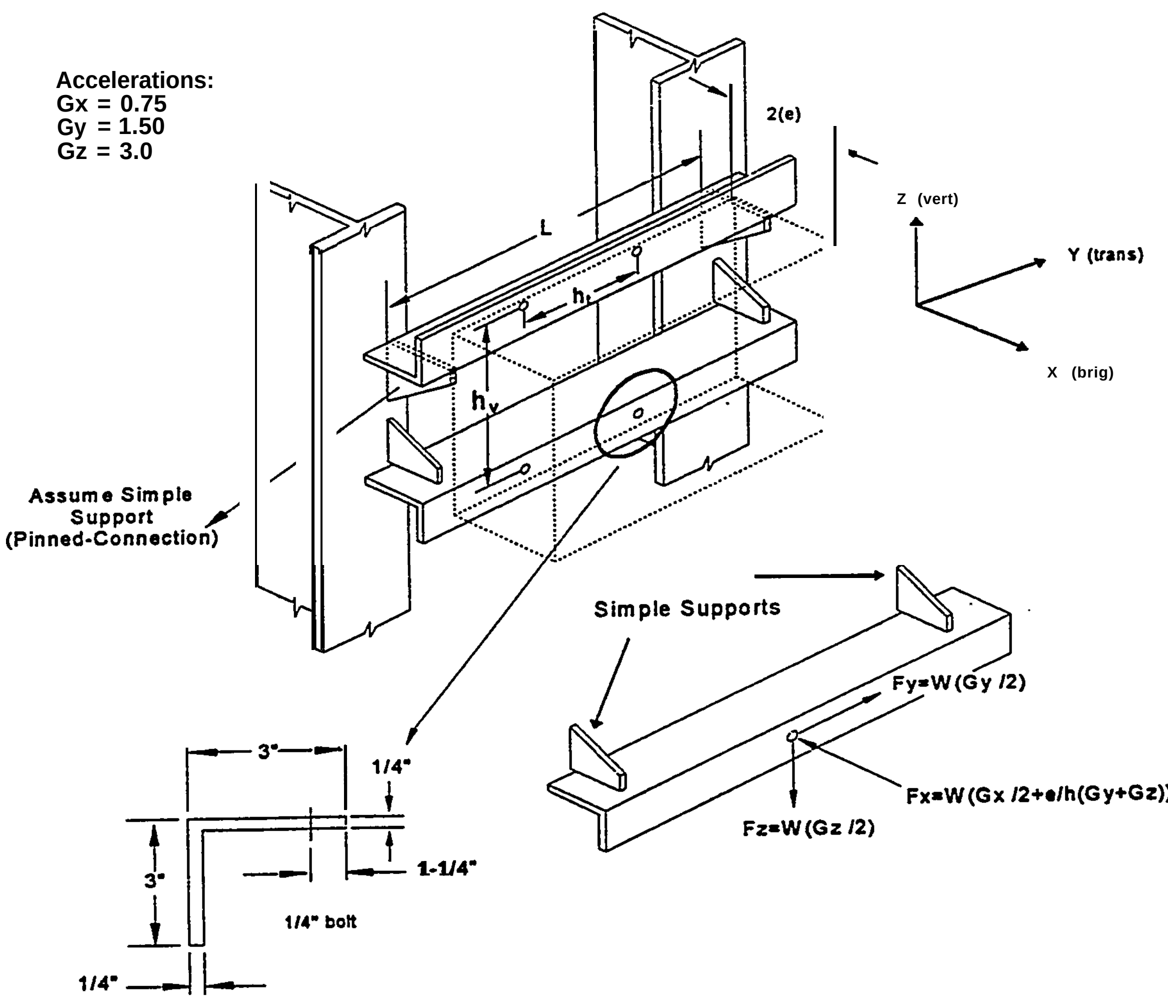


Figure A-1 : Resolving of Grillage Forces

FAILURE CRITERIA

Srength-- Based on the worst foundation configurations and loads, stresses were computed for all possible failure modes. Failure is assumed to occur through yield failure in one or all of the scantlings, or by local yield failure in way of one or more bolts. All stresses are computed at their worst location, the spot on the foundation where the biggest force or moment occurs.

Angle stresses were calculated using beam formulae. Critical stress occurs in a scantling as a result of both bending and axial loads in the beam. Bending stresses were combined for hi-axial bending, where the stress at the toe of the angle from one direction of bending was added to the stress at the heel from the other direction of bending and vice-versa. This worst bending stress was then combined with the nominal axial stress calculated from the highest axial load in the foundation scantling/angle and the corresponding cross-sectional area.

Figure A-2, shows graphically the various local attachment failure criteria. Bolt attachment was checked for all modes of shear, bearing and bending. All calculations were performed assuming 1/4” bolts, because this is the smallest bolt size any equipment would generally need and smaller bolts produce higher stresses for all failure modes. Shear failure can

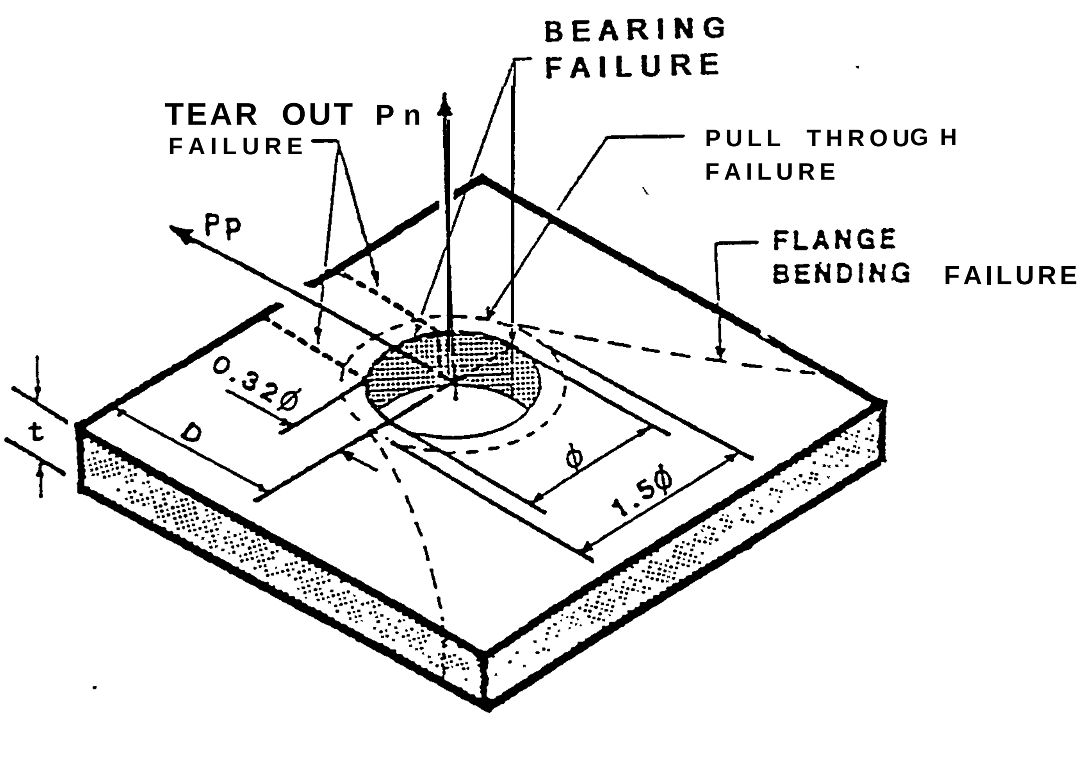


Figure A-2: Foundation Bolting Plate

where,	Pn	= Bolt load normal to the plate
	Pp	= Bolt load parallel to the plate
	t	= plate thickness
	ϕ	= Bolt diameter
	D	= Edge distance

either occur perpendicular to the angle flange due to axial bolt loads or parallel to the flange from shear loads in the bolt. Bearing stress is a nominal stress computed from the cross-sectional area of the bolt hole.

Flange bending is the result of the moment created between the centerline of a bolt and the heel of the angle. The greater the bolt distance from the heel, the greater the flange bending moment. So to be conservative, the bolt was assumed to land at its furthest possible location from the heel,i.e. approximately 35 to 40% of the flange width from the toe of the angle. The moment produced is resisted partially at the bolt and partially at the angle heel depending on the condition of fixity at those locations. The most conservative assumption for moment distribution was assumed, which is when the equipment is always clamped to the flange at the bolt and the heel is partially free, putting 80% of the moment at the bolt and 20% at the heel.

Frequency -- For all foundations, it is important to insure that the lowest natural frequency of vibration of the foundation is greater than the excitation frequency of the propeller. The natural frequency was checked for several modes of vibration, and the lowest natural frequency of the foundation was compared to the allowable frequency. Springs included in the natural frequency calculation for a foundation are the bending of the scantling, in two directions, and the flexibility of the flange. Torsional flexibility of the mounting scantlings were disregarded because of the assumption that the flange was clamped to the equipment. Three different vibration modes were calculated for foundations, i.e. parallel to the mounting plane, perpendicular to the mounting plane, and due to over-turning motion of the equipment.

When a foundation does not fully land on rigid ship structure, it is necessary to check the natural frequency of the foundation coupled with the vibration of the mounting plate. It is no longer necessary to include the angle as a spring in the vibration calculation, thus the springs for this natural frequency calculation were the flange flexibility and the out-of-plane bending of the mounting plate. The natural frequency was calculated for the perpendicular and over-turning modes of vibration.

ALLOWABLES

Stress -- The stress allowables were based on the assumptions that scantlings are of mild steel and studs are of high strength steel, having yield strength and tensile strength of 34 Ksi and 50 Ksi, respectively.

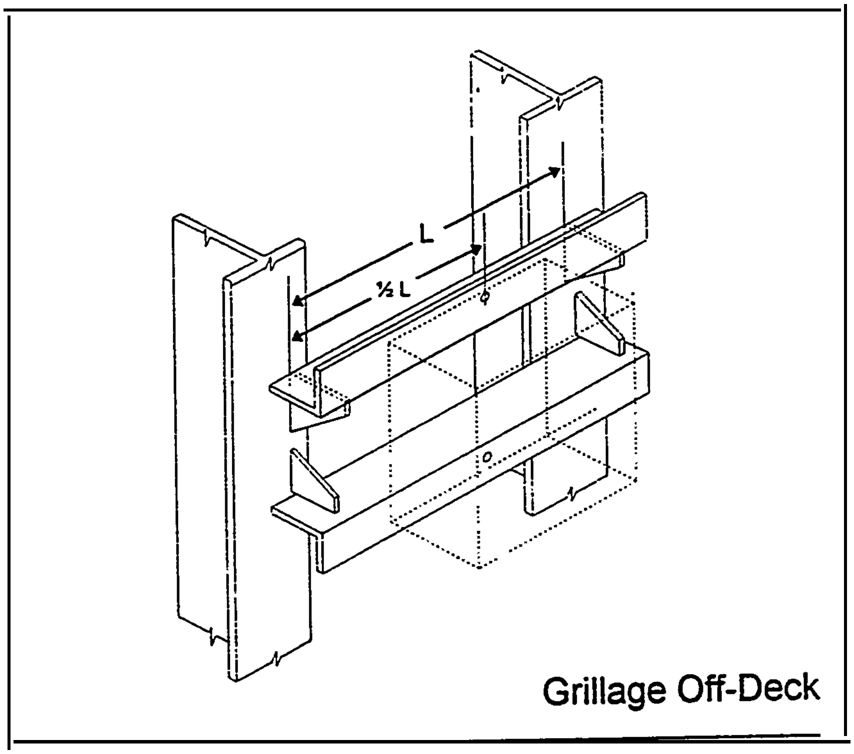
Nominal Tensile Stress Allowable is 80% of Yield Strength	27.2 Ksi
Shear Stress Allowable is 60% of Tensile Allowable	16.3 Ksi
Bearing Stress Allowable is 80% of Tensile Allowable	21.8 Ksi
Stress Allowable for Studs is 60% of Tensile Strength	30.0 Ksi

Frequency -- Based on the propeller excitation frequency of 12 Hz, which is found mostly in vessels of higher speeds, the allowable natural frequency for the foundations was kept 25% higher than the propeller excitation frequency. Thus, the allowable frequency used to obtain the values in design data tables was 15 Hz.

FOUNDATION CONFIGURATION

Grillages -- Three different types of grillage configurations were considered for the calculations, namely: Grillage welded to mounting plate Grillage lifted off mounting plate; Overhanging Grillage. Method Mountings are extensions or combinations of these three primary configurations. The allowable weights in the design data tables were obtained using a spreadsheet approach to check for the various failure criteria for 6 different angle sizes, for 2 cases of 4 ratios. Figure A-3 shows the Grillage Off-deck and Overhanging Grillage configurations.

Frames/Trusses -- Various configurations of Frames and Trusses were analyzed using finite element models (FEM) for 5 different angle sizes, for 2 cases of e/h ratios. The FEMs were run for the worst combination of G loadings, and effect of overturning of equipment was also included. All the models were of 4 equal size legs and the mounting attachments(bolt locations) were assumed to be at the four comers of the mounting plane. The results of FEMs were used to obtain the allowable weight capacity for the legs of the frames and trusses. Grillage spreadsheet approach was used to obtain the allowable weights for mounting scantlings.



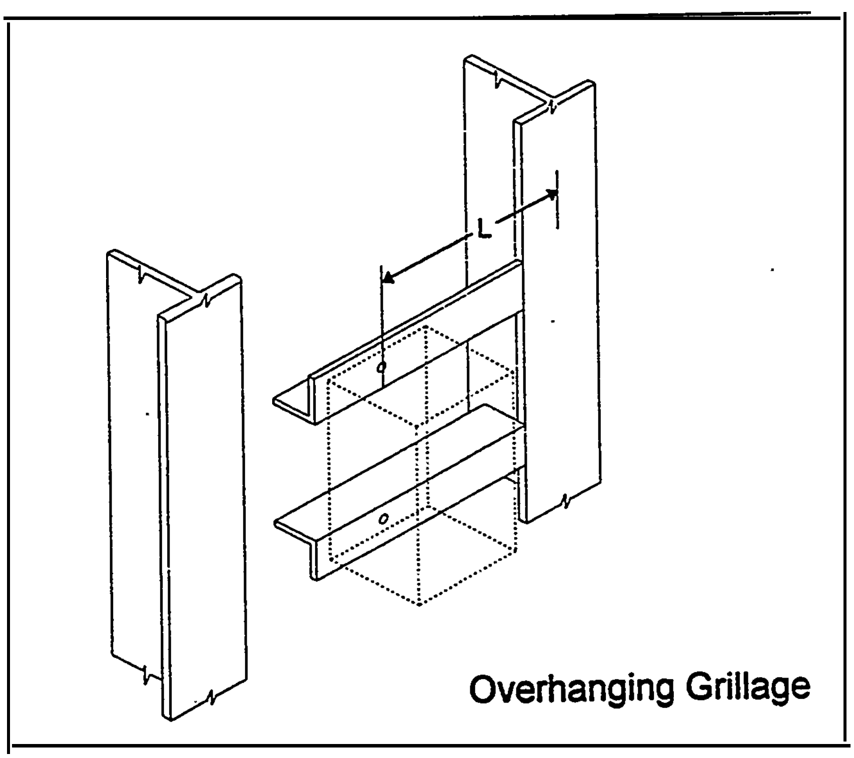


Figure A-3: Grillage Off-deck and Overhanging Grillage confirmations

Studs -- Studs of various lengths for four sizes, 3/8”, 1/2”, 5/8” and 3/4”, were analyzed using a spreadsheet approach, to obtain the allowable weight capacities. The worst combination of G loading on two configurations were analyzed, namely: single stud, and multiple stud (4 studs). In case of single stud configuration, the varying stand off length was considered from the base of the stud to the C.G. of the equipment, thus taking equipment overturning into consideration. Whereas, for the multiple stud configuration the varying stand off length was the actual stud length, and the equipment overturning was assumed to be restrained.

Both vibration and strength limiting criteria were checked. Under vibration, frequency due to out-of-plane mounting plate bending, and frequency due to stud and stud/plate connection bending were checked for. Under strength limitation, studs by themselves were checked for axial plus bending stresses. Further, the stud/plate connection was analyzed using Roark’s equation (“Roark’s Formula for Stress and Strain”, Warren C. Young, 6th edition, pg. 435, 1989), using plate thicknesses of 3/16”, 1/4” and 3/8”, because beyond these sizes the stud/plate connection was not the limiting criteria.

APPENDIX B

Recommendations

(Based on this project and foundations for double hull combatant papers -- Bibliography items 8 and 9)

Based on the development work performed in this one year project, the following tasks should be performed:

- Expand the data base of equipment and foundations for existing classes of commercial ships and naval combatants.
- Develop standard configurations based on the 27 representative foundation types for use on commercial ships and naval combatants.
- Appraise the foundation data base to determine which foundations occur most frequently so that producibility improvements can be implemented on as many foundations as possible.
- Complete additional investigations to better quantify the magnitudes and relationships between slamming, whipping and vertical accelerations.
- Develop a more comprehensive definition of foundation loading.
- Investigate the machinery space structural system for combined loading to ensure machinery performance.
- Investigate the effects of hull flexibility on loads induced in foundations and machinery system performance.
- Develop standard foundation designs based on parametrically developed configurations.
- Produce engineering validation of the standard foundation types by expanding on the parametric analysis. This would entail extending the approach used in this study to include a wider range of foundation types, scantlings, geometry's and other important variables.

- Investigate shock induced distortions on foundation attachments to soft plate in way of alignment sensitive equipment installations by FEA and appropriate shock testing.

- Study the effects of heavier scantlings, placing an emphasis on the fatigue effects.

- Determine the impact of various steel strengths on the parametric foundation process.

- The hot-spot stress range method should be applicable to a broad range of details in conventional as well as double hulls. To evaluate this applicability, the full scale test data base should be broadened by testing a greater variety of details. For example, the following should be evaluated through further testing 1) the effect of plate thickness, 2) the advantage of pad details, and 3) the range of eccentricities between one and six thickness' where the transition from weld root cracking to weld toe cracking occurs.

- The **effect** of multi-axial loading should be further evaluated through additional full-scale testing, including: 1) loads in two or more axes that are almost equal in magnitude, and 2) loads that are out-of-phase or at different frequencies.

- Investigate the validity of the root-mean-cube effective stress range concept through long life variable-amplitude loading, particularly in light of recent evidence that Miner's rule can be unconservative for loading with wideband frequency content like seaway loading.

- Investigate the apparent crack arrest that often occurs in bending loading and (for very large eccentricity) in fully reversed axial loading.

- Perform tests on mock-ups of attachments in way of light structure, decks, and bulkheads.

- The modeling of configurations with bending loads should be refined, with special attention paid to accurate modeling to actual as well as nominal dimensions. If additional effort is needed in order to obtain good correlation, the use of a non-linear finite element analysis should be supported by FEA to provide a basis for evaluating alternative configurations.

- Clarification and revise traditional specifications with respect to the eccentric attachment detail.

- Develop quantitative requirements to clarify, enhance or replace the qualitative requirements for NAVSEA 0908-LP-OOO-3010 and specifications sections 072,073 and 180 as they apply to the advanced double hull structures and conventional combatant structures.

- Design and producibility guidelines and requirements should be developed and mandated by the specifications to achieve cost and weight savings.

APPENDIX C

Q & A Review of Various Shipyard Responses

- **Please describe the procedures used by your shipyard to develop foundation drawings.**

System engineer determines what equipment is required, arranges group then completes compartment(s) arrangement(s) for that system. VFI and arrangement info is sent to foundations group to develop drawings. VFI should have equipment size, weight, CG location, bolt pattern, size of bolt holes, torque requirements(if any), maintenance envelope(if required), stability requirements(sway bracing or upper support), locating dimensions of any hook-ups(electrical, fluid or air), shock test info, equipment material(steel or aluminum) and thickness of mounting surface of equipment.

-INGALLS

1) Determine static loads
2) Determine dynamic loads
3) Analysis
4) Drafting
5] Engineering check

-McDERMOTT

After information is channeled to the designers, then 3D foundation design is transferred to a 2D drafting system for annotation and dimensioning.

-NNS

Foundation drawings are developed using data provided to the structural department by other interdepartmental engineering groups such as electrical, machinery, ventilation. Data provided includes request form, unit location, vendor info, weight of unit(wet/dry), mounting hole dimensions, zone or block# and special instructions if needed. After data is received, it is then reviewed on a foundation status list and given to the designer. Foundations are developed using standard shapes, design guidelines, and technical support when required, shock, bolts and nuts and foundations are kept similar for similar types of equipment, lapped end connections are being considered as well as this concern to raised foundations off the deck or bulkheads to save welding time. Input from production is incorporated where necessary to save time and material. (448) was a peculiar situation because of the late to start schedule.

-NASSCO

1) Process vendor drawings - for various equipment to be mounted.
2) Arrangement drawings define locations.
3) Hull design department uses vendor drawing/outfit arrangement for location and design foundations.
4) Not clear on how interface works in today's world regarding hull foundation design, outfit departments. Also not clear on responsibilities for interference checks i.e. envelope for foundation/equipment.
5) No central point or focus in entire process from procurement through all design phases i.e. comprehensive list of equipment needing foundation up front.

-NASSCO

Foundation drawings are developed using information provided by other engineering departments who are installing equipment that require foundations. Designers use standard shapes, design guidelines and technical support when required. Ship's specifications direct any special requirements such as shock and any special fastening requirements. Designs are kept similar for similar types of equipment. Input from production is incorporated where feasible to save time and material.

-NASSCO

a) Vendor submits equipment drawings which are forwarded to composite and foundation groups.
b) Composite group locates equipment and forwards to foundation group.
c) Foundation group develops foundation design and submits to structural engineer for checking.
d) Engineer checks foundation and submits back to foundation group.
e) Foundation group forwards foundation sketch or drawing to composite

group who clears it on the composite drawing and advises foundation group.
f) Cognizant Engineer is advised of any comments by composite and/or foundation group.
g) Cognizant Engineer advises the vendor of any drawing approval comments
h) Foundation group back fits drawings as required and issues files and records for distribution.

-AVONDALE

- Please give a description of the interdepartmental relationships involved, i.e. how is equipment and systems information channeled to the designers?

1) Vendor to Purchasing
2) Purchasing to Engineering
3) Engineering to Composite
4) Engineering to Designers

-McDERMOTT

1) Equipment/system owner identifies equipment
2) Compositor locates equipment in product model
3) Once equipment located in model, equipment owner passes detail info to foundation designer
4) Foundation designer uses detail data plus equipment model to develop foundation in model
5) Compositor checks completed foundation in model for fouls

-NNS

The department installing the equipment provides the foundation group with the equipment location, any special requirements and the vendor information. This info is sent using a foundation request form.

-NASSCO

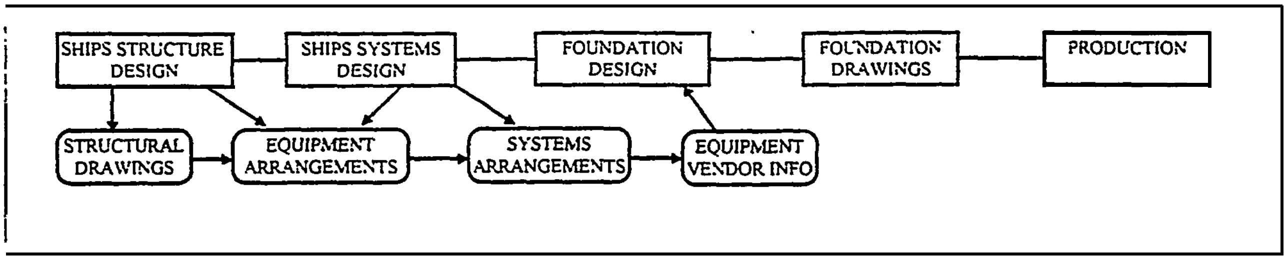
Drawings are forwarded by files and records department via use of standard memos. Approvals and releases are transmitted via memos.

-AVONDALE

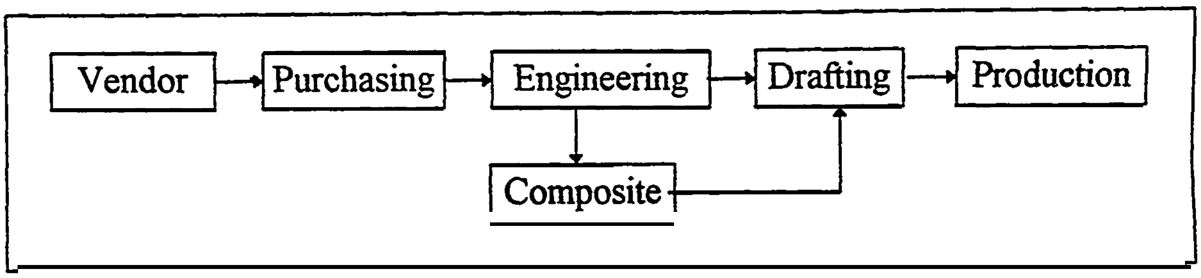
- **Please include a foundation design process flow-chart or process description.**

Designer utilizes equipment model and bounding primary structure to define foundation envelope and details foundation supports using typical standards and guidance documents from the technical section.

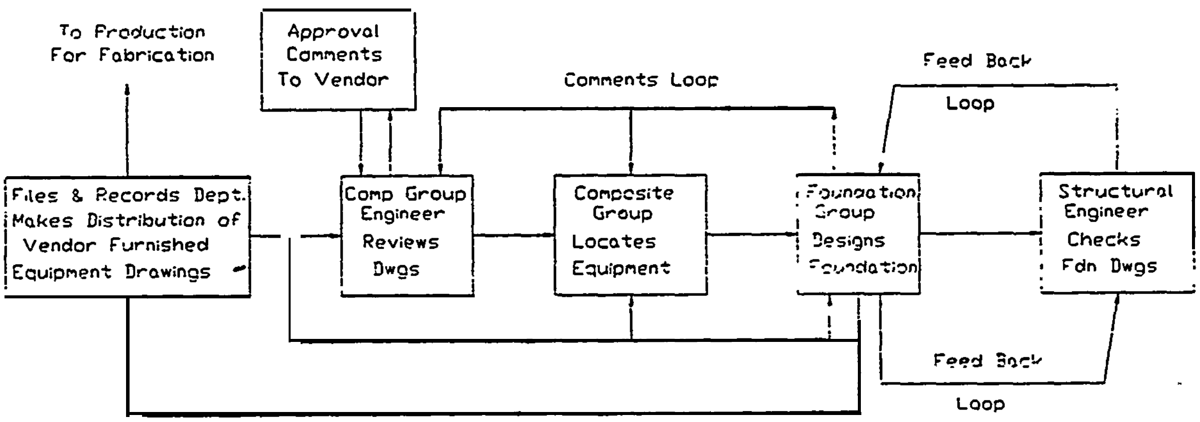
-NNS



-NASSCO



-McDERMOTT



-AVONDALE

- Do your designers use a foundation design manual that includes graphs and tables to speed up the design process, or guidelines which illustrate the needs of production?

  An Ingalls Designers' Handbook
  -INGALLS

  No
  -McDermott

  Structural Details, Welding Design Details, Specifications and Design Rules
  -NNS

  Yes, Standards presently working
  -NASSCO

  A manual is used and is presently being revised to include more up to date reference material
  -NASSCO

  AII has used some standard design info in the past on our LSD contract and does use a production (fabrication) schedule to plan and sequence work to meet production needs
  -AVONDALE

- What are your pet peeves about foundation design and construction?

  Lack of standards.
  -McDERMOTT

  Detail design data for equipment is late and changes as different vendors are selected. This usually places the foundation designer in a continuous redesign loop.
  -NNS

Incomplete work packages - missing information required to design and build the foundation.

-NASSCO

Lack of standards. Excessive reinforcements. Welding details are an afterthought.

-NASSCO

Our main problem is getting the required information on time to meet our schedule. Much too often, the vendor furnished information is missing.

-NASSCO

Lack of timely vendor information.

-AVONDALE

- **What are the most frequently encountered obstacles in your foundation design program (engineering)?**

Time doesn't permit economizing of foundations.

-INGALLS

Lack of standard for dynamic loads. Lack of vendor data in a timely manner.

-McDERMOTT

Lack of timely vendor information. Baseline design is lacking sufficient detail. Spaces end up being too crowded; which leads to poor arrangement which compromise foundation design, leading to costly designs.

-NASSCO

- **What are the most frequently encountered obstacles in your foundation design program (design)?**

Inadequate VFI. Delayed receipt of VFI holds up the entire foundation design process.

-INGALLS

Incomplete equipment information. Limited space for designs.

-McDERMOTT

Relocation of equipment after design is completed.

-NASSCO

Non-standard designs.

-AVONDALE

- **What are the most frequently encountered obstacles in your foundation design program (drafting)?**

Short time in drafting of foundation drawings due to late info or VFI that is changed while designing foundation drawing.

-INGALLS

Lack of qualified designers.

-McDERMOTT

. Each foundation is drawn separately, even if some foundations are similar.

-AVONDALE

- **What are the most frequently encountered obstacles in your foundation design program planning)?**

Lack of up-front planning for staging.

-McDERMOTT

Foundation and foundation backing structure are typically not added/built/installed at the same time. Tolerances must be established to ensure that all will fit together after installation.

-NNS

Late info from other groups.

-NASSCO

Difficult to meet schedules due to late info from other groups.

-NASSCO

Shop workloads are difficult to properly anticipate when drawings are issued so close to fabrication start dates. Standardization and up front identification of foundation type would help.

-AVONDALE

- **What are the most frequently encountered obstacles in your foundation design program (construction)?**

Poor weld access; too many piece parts have to add temporary structure (e.g. lift lugs) to handle foundation during construction. These could have been designed in. Backup is obviously excessive. Obvious mismatch between foundation and equipment (e.g. 100# structural foundation with backup to hold a sheet metal magazine rack). Machining used when liners would be adequate.

-INGALLS

Many non-standard small parts to fabricate, fit weld prepare. Foundation geometry not formed by straight lines and right angles.
Loose parts such as braces lost in transit from shop to structural unit.
Headers difficult to fit, trimming must be carried out.
Interference of foundation structure, i.e. legs, diagonals, braces, with adjacent piping systems.
Interface of foundations with ships structure, too much fitting and trimming, light decks tending to warp.
Minimum welding clearances.

-NASSCO

Back-up structure not put in panel line stages.

-McDERMOTT

Adding backing structure to a painted area due to late foundations.

-NNS

Need more "system" view so dimensions are compatible and interferences are reduced.

-NASSCO

The shops sometimes do not build the foundation in accordance with the drawing. Crafts sometimes install the foundation in the incorrect location.

-AVONDALE

- What are the most common problem you are forced to deal within fabricating hull foundations?

Existing back-up structure.

-McDERMOTT

Tracking material - configuration changes.

-NNS

High mix of material. Insufficient bolting clearances. Mismatch with components. Poor interface with associated duct or other equipment.

-NASSCO

Late release of engineering drawings to shops because drawings cannot be prepared because of late vendor info.

-AVONDALE

- **Do you have any suggestions on how the common foundation fabrication problems could be most easily solved?**

Timely vendor info.

-McDERMOTT

Produce design guidance manual-for standard material configuration. Improve interface between design groups, particularly ventilation design and foundation design. Improve knowledge of production processes within engineering - weak area concerning “Design for Manufacturing”.

-NASSCO

Earlier equipment /vendor selection.

-AVONDALE

- **Are there any fabrication methods used by your shipyard that you believe to be especially efficient?**

Farming out the manufacture of commercial ship foundations to outside vendors.

-NNS

Sheet metal shop use of CNC plasma/punch machine for cutting foundations out of plate. Vent penetration spools from thicknesses 1/8” to 1“ thick. All ventilation duct work.

-NASSCO

APPENDIX D

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