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FEASIBILITY STUDY FOR AN INFLATABLE BOW RAMP

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13. ABSTRACT

A feasibility study for developing an inflatable bow ramp for the 1173 Class LST. The ramp must be 110 ft. long, 16 ft. wide, and carry the maximum loads imposed by an M103 tank.

Ten possible conceptual configurations were investigated with a more detailed design analysis effort being concentrated on two of the concepts.

The ramp will be constructed of a two ply neoprene fabric and inflated with an inflation system separate from ship air supply.

A scale model of one concept was built and tested which verified design calculations.

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FEASIBILITY STUDY

FOR AN

INFLATABLE BOW RAMP

BIRDAIR JOB NO. 7258

NAVY CONTRACT NO. N62399-73-C-0003

JUNE 21, 1973

TABLE OF CONTENTS

	PAGE
INTRODUCTION	1
DESIGN ASSUMPTIONS	5
DESIGN ANALYSIS	6
GENERAL COMMENTS ON FABRIC STRENGTH AND PRESSURIZATION SYSTEMS	8
CONCEPTUAL CONFIGURATIONS & PRELIMINARY FEASIBILITY EVALUATION	9
REFINED DESIGN ANALYSIS FOR CONCEPT NO. 2	21
REFINED DESIGN ANALYSIS FOR CONCEPT NO. 10	25
CONCLUDING REMARKS	33
GENERAL CONCLUSION	41
REFERENCES	
APPENDIX A: LOAD AND MOMENT CALCULATIONS	
APPENDIX B: DERIVATION OF EQUATIONS	
APPENDIX C: PRELIMINARY DESIGN CALCULATIONS	
APPENDIX D: REFINED DESIGN CALCULATIONS	
APPENDIX E: MODEL ANALYSIS FOR CONCEPT NO. 10	
APPENDIX F: DEFLECTION THEORY	
APPENDIX G: PRESSURIZATION CALCULATIONS	

INTRODUCTION

The purpose of this study is to perform a preliminary conceptual design investigation, and make recommendations as to the feasibility of an inflatable bow ramp for the 1179 Class LST (Landing Ship Tank). The new 1179 Class LST has an over-the-bow ramp for roll-on, roll-off assault vehicles and MCB (Mobile Construction Battalion) construction equipment. The present ramp is approximately 16 ft. wide, 6 ft. deep, 100 ft. long, and weighs 36.6 short tons. It is a welded aluminum structure, and is stowed on the main deck level. See Photos, on Page 4.

The following performance requirements for the inflatable bow ramp were authorized by the Navy, and were treated as design parameters. The refined design analysis will attempt to satisfy as many of the parameters as possible.

Performance Requirements

A. Concept. The inflatable ramp shall form a bridge for the transfer of military vehicles between the ship and a beach or pontoon causeway. The shipboard end of the ramp must be free to rotate horizontally through an arc of 15 degrees to port or starboard (30° excursion) of the ship's centerline. The causeway end of the ramp must be free to rotate through an arc of 12 degrees to port or starboard of the causeway centerline as well as move 20 feet longitudinally. The bearing surfaces of the ramp shall be designed to resist the forces generated by friction due to the ship's motion. The ramp shall be capable of accommodating ±10 degrees of ship roll when the outboard end of the ramp is supported on a causeway.

B. Ramp Size. The ramp shall have a minimum length of 110 feet and minimum width of 16 feet such that unrestricted passage of military vehicles up to the M-103 tank and construction equipment used by the MCB's is possible. MCB equipment includes such vehicles as scrapers, truck cranes and low-boy trailer/tractors. The vertical inclination of the ramp will vary from 10 to 20 degrees for the 110 foot ramp.

C. Design Loads. The ramp shall be capable of supporting the loads imposed by the M-103 tank (60 tons) and AASHO (American Association of State Highway Officials) H20 wheel loading in the fully extended position. Intermediate ramp supports may be incorporated into the inflatable ramp system. The ramp shall be capable of supporting the local loading of military vehicles with tracks and pneumatic tires.

D. Operational Requirements. Complete extension or retraction of the ramp shall be accomplished in no more than ten (10) minutes in winds up to 30 knots. In the beaching conditions, provisions shall be made to assure negative buoyancy when the outboard end is lowered into 4 feet of water with 5-foot breaking waves.

E. Special Requirements.

1. The ramp surface used for vehicle traffic shall be designed to assure positive traction for all vehicles at the maximum ramp inclination (20 degrees). Positive traction shall be maintained when vehicles move over the transition zones at both ends of the ramp.

2. The ramp shall be designed for Grade "A" shock loads according to Military Specification S-901C (Navy) in its stowed position.

3. The ramp shall withstand the forces imposed by green seas and ship motions in storm conditions while stowed.

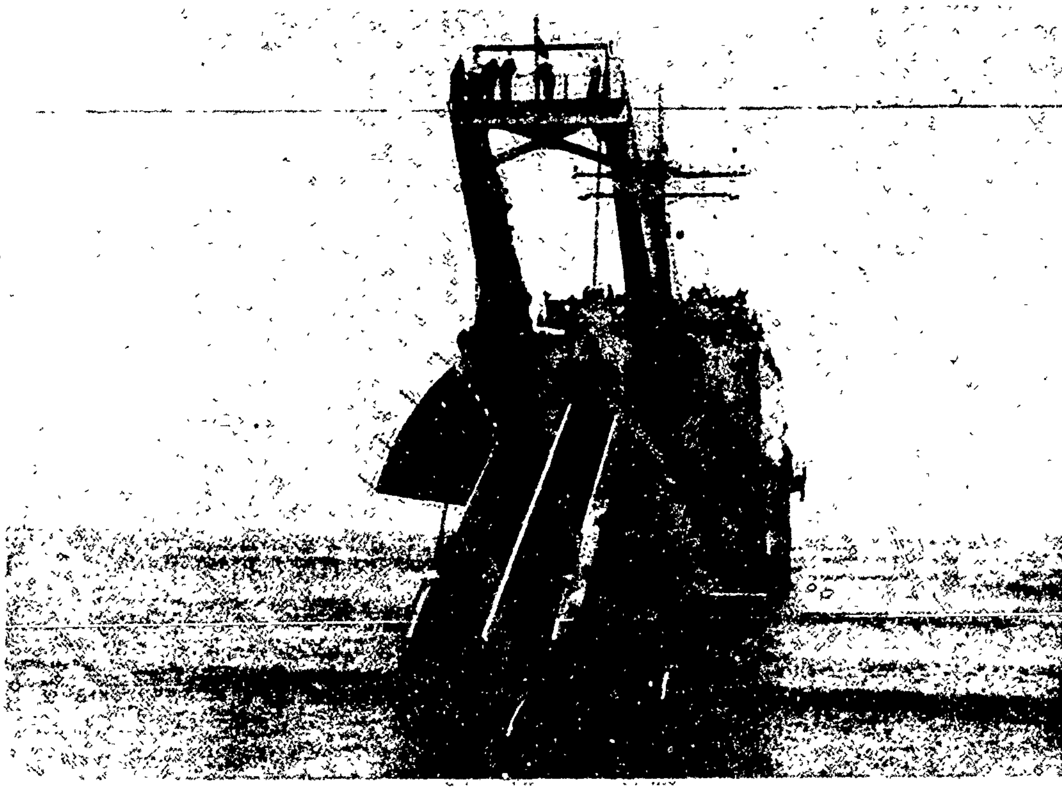
4. The ramp stowage configuration shall be as compact as practical to conserve deck space.

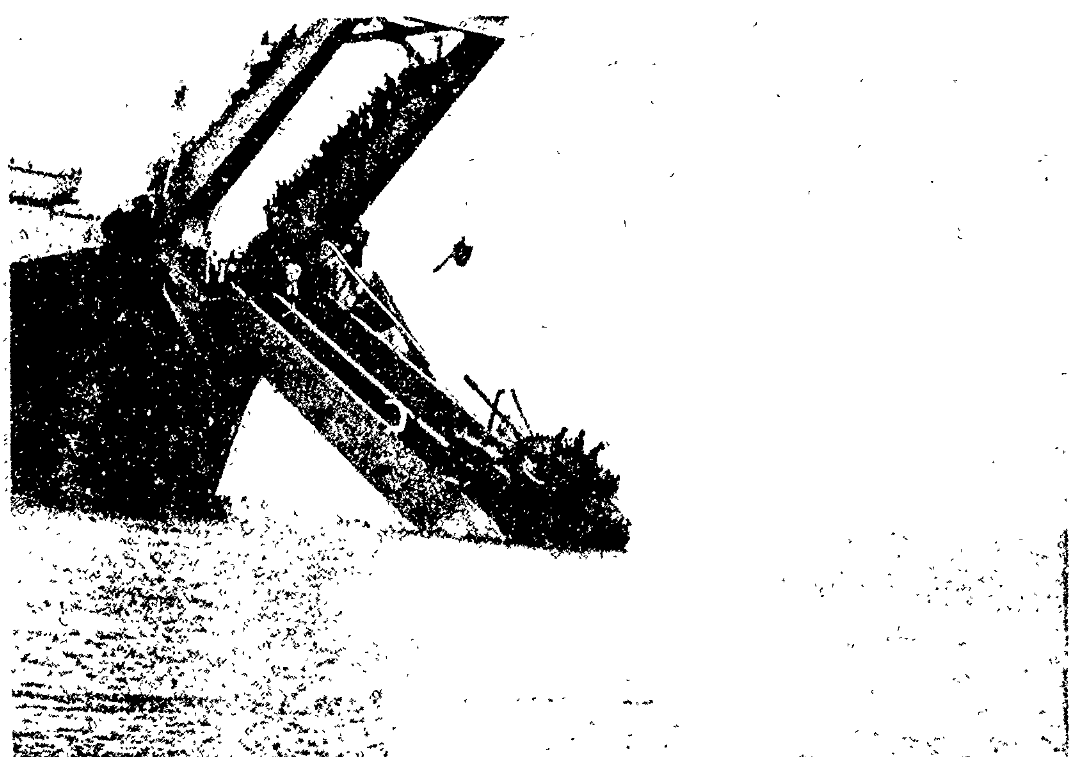
5. The ramp shall be designed to absorb damage by enemy action without compromising its structural integrity.

6. The ramp inflation system shall be self replenishing for multiple use.

7. Repair of the ramp shall be within the capability of shipboard personnel and equipment.

8. The life cycle cost of the inflatable ramp shall be comparable to the existing bow ramp.

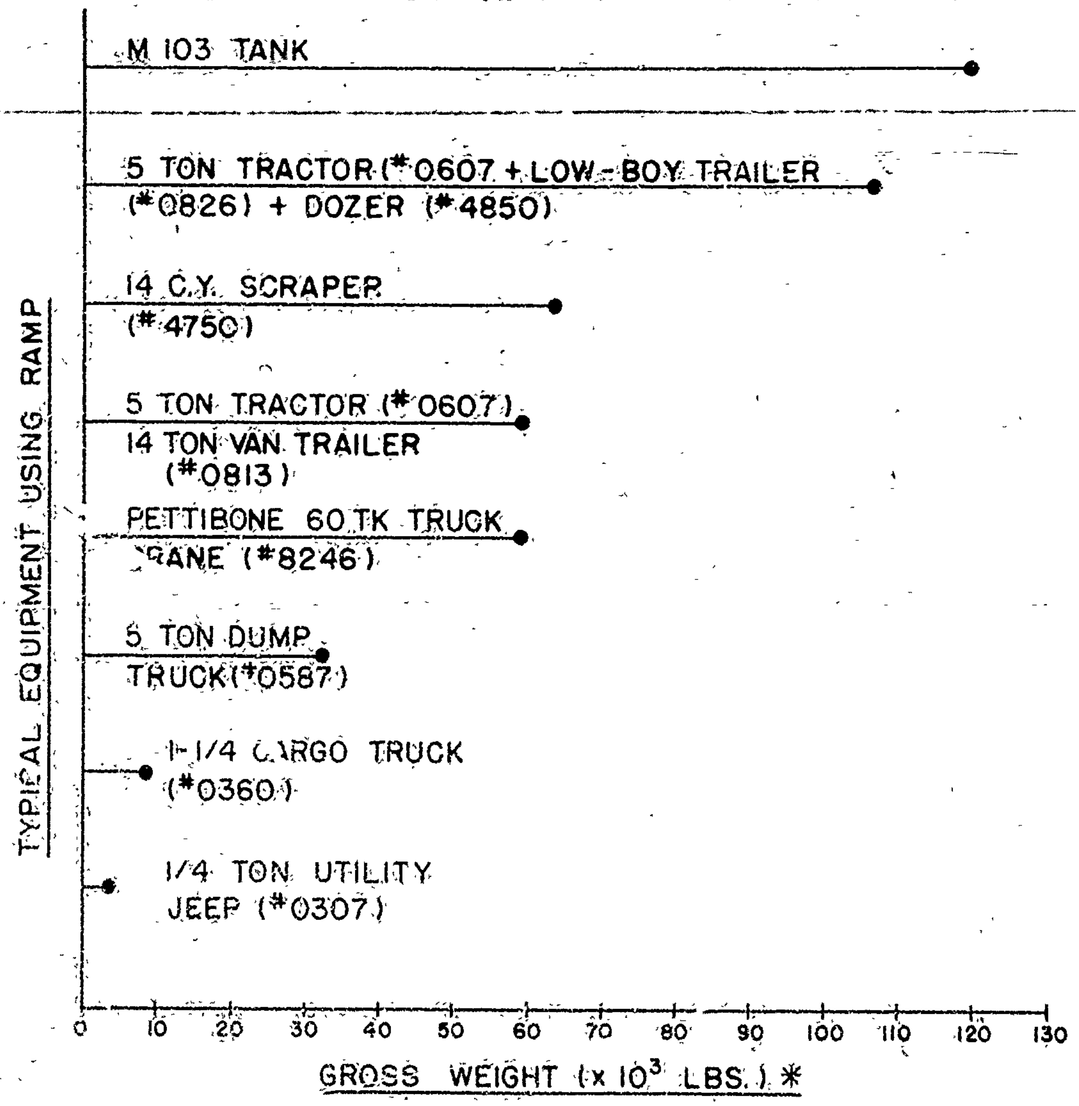




DESIGN ASSUMPTIONS

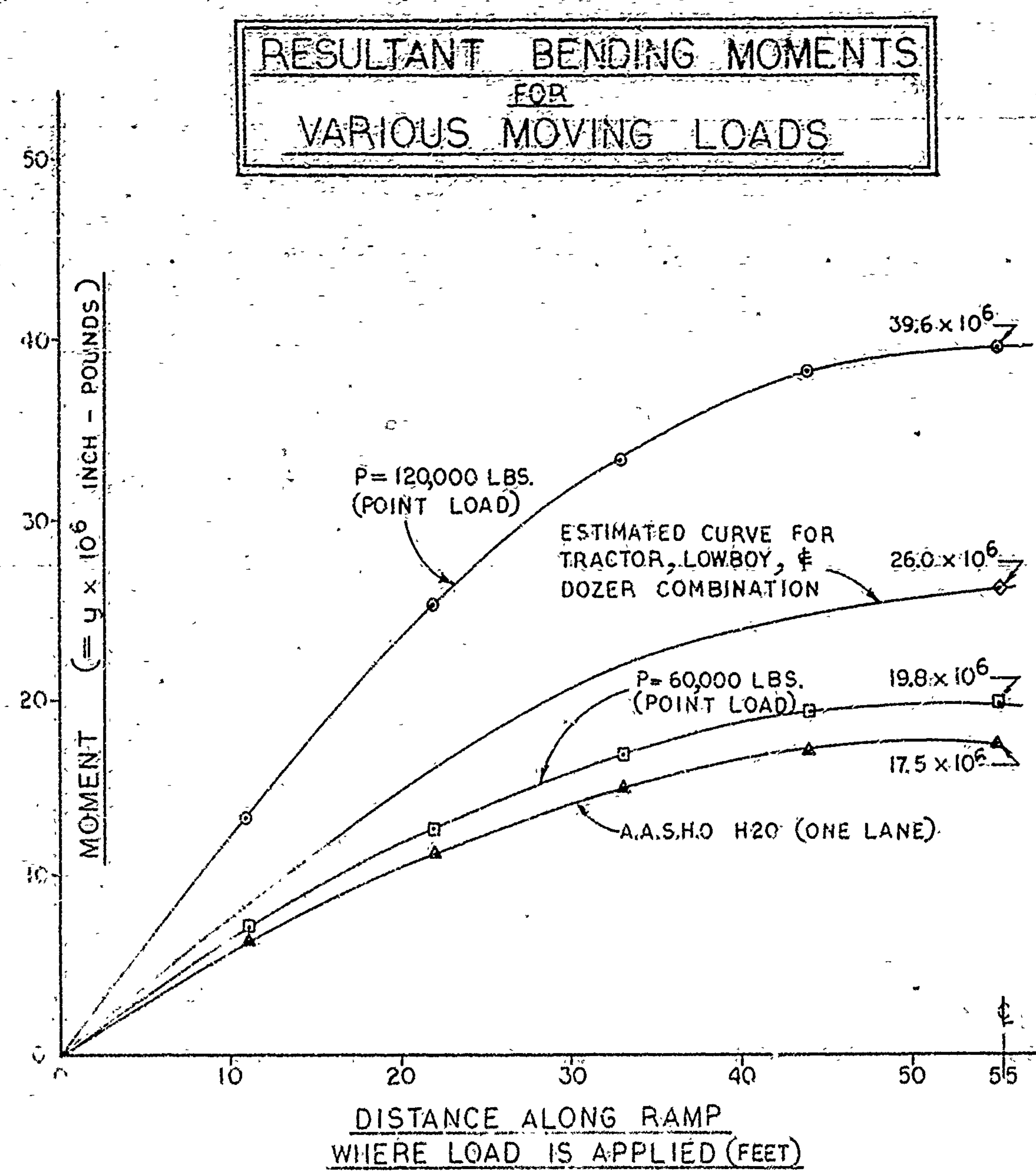
Since the inflatable bow ramp will be loaded with a variety of vehicles ranging from a 60 ton tank to a 1/4 ton jeep, a bar graph showing typical vehicles and gross weights of each was prepared in order that a graphical relationship of loads could be visualized (refer to Figure No. 1). These vehicles, with the exception of the M103 tank, fall under the P-25 allowance of automotive equipment. Conversely, the bending moments that are created for different load situations as vehicles move along the ramp were computed and are plotted in Figure No. 2. This is assuming that only one vehicle was on the ramp at a time. Refer to Appendix A for the calculations. The inclination of the ramp is also important in determining the vertical load component of the force normal to the roadway surface. For a conservative design, however, the ramp was considered to be in a horizontal position, therefore creating the maximum vertical component of the force equal to the weight of the vehicle. The effects of the horizontal force created along the ramp at maximum inclination (20°) will be discussed in the refined design portion of the report. Since the M103 tank is the heaviest of the vehicles normally using the bow ramp, the preliminary design for each of the conceptual configurations is based on a concentrated point load of 60 tons moving along the ramp, which has a clear span of 110 feet. This again is a slightly conservative design assumption, since the tank load is actually distributed over a length of tracks (1/4 in.). Also, the total length of the bow ramp is 110 feet, indicating that after supporting the ramp at each end, the actual clear span is something less than 110 feet.

WEIGHT COMPARISON OF TYPICAL VEHICLES USED ON BOW RAMP



* GROSS WEIGHTS LISTED ARE BASED ON PAYLOADS FOR CROSS-COUNTRY TRAVEL

BIRDAIR STRUCTURES, INC. BUFFALO, NEW YORK	VEHICLE LISTING	FIGURE I SHEET



BIRDAIR STRUCTURES, INC. BUFFALO, NEW YORK	BENDING MOMENT GRAPH	FIGURE 2
		SHEET

DESIGN ANALYSIS

Appendices B and F of this report explain the derivation of equations used to analyze the various fabric stresses, inflation pressures, and deflections that will be anticipated in the inflatable bow ramp. The derivations are rather self-explanatory if followed through in a systematic manner.

The basic theory applied to analyzing a structure of this type is commonly referred to as "initial wrinkle theory." That is, inflating a structure to a point where the tension in the fabric due to inflation pressure equals the compression force along the fabric due to bending moment. Theoretically, when these two forces are equal, the structure should just start to wrinkle. Tests have shown that the structure will not collapse at this point, however, but that only local wrinkling in the upper skin at the point of the load will be initiated. Actual collapse typically occurs when approximately twice this design load is applied to the structure.

The basic formulas used in analyzing an inflated beam with the initial wrinkle theory are:

INFLATION STRESSES

$$F = p\,A \qquad \text{(EQ. 1)}$$

where F = Force on Fabric

p = Inflation Pressure

A = Cross-Sectional Area

$$S_i = F/C \qquad \text{(EQ. 2)}$$

$$F = S_i C$$

where S_i = Fabric Stress per Unit (1") Width due to Inflation Pressure

C = Circumference of Section

Therefore,

$S_i C = pA$ (EQ. 3)

$S_i = \frac{pA}{C}$

BENDING STRESSES

Resistive Moment = (f_s) (A) (EQ. 4)

where f_s = Stress in Skin per Unit Width of Fabric (tension or compression)

Since the skin must be pretensioned by inflation pressure to resist compression loads produced by bending moment (inital wrinkle theory), then

$S_i = f_s$

$\frac{pA}{C} = \frac{M}{A}$ M = Bending Moment

Required inflation pressure to carry bending moment

$p = \frac{CM}{A^2}$ (EQ. 5)

The maximum longitudinal fabric stress is in the tension zone of the structure, and is equal to $S_i + f_s$. Since $S_i = f_s$, the maximum longitudinal fabric stress = 2 S_i.

The maximum transverse fabric stress = pR where R = radius (simple hoop stress).

It should be noted that initial wrinkle theory was used on all of the preliminary conceptual configurations, except Nos. 3, 6, 9, and 10 (see Figure 3). In concepts 3 and 6 the basic formulas for hoop tension governed since the inflated fabric portion was not required to resist bending moment. In concepts 9 and 10, special hybrid structures were investigated, which made use of aluminum structural components, along with fabric bladders. The theory used to evaluate these hybrid structures is discussed later in the report.

GENERAL COMMENTS ON FABRIC STRENGTH AND PRESSURIZATION SYSTEMS

Fabric

A study of various materials available on the market, excluding the exotic state-of-the-art types still being researched, indicate that a range of fabric strengths could go as high as 3000 to 4000 pounds per inch tensile strength. Fabrics with these high strengths are usually several plies and become difficult to handle. From past experience, however, considering toughness and workability, fabric strengths up to 1000 pounds per inch would be considered in a normal range.

A more detailed report on fabric typos and makeup, along with actual test reports, is included with the rafined design study at the end of the report.

Pressurization

Upon reviewing various types of inflation systems that are available, many were dropped from further consideration on the basis that they could not deliver the large volume and relatively high pressures that are required to quickly inflate the ramp for the specified 10 minute deployment time. It was also found that in the systems available, for pressures over 10 psi, there was a substantial jump in the horsepower required to drive the unit. For these reasons then, a normal range of inflation pressures of 0 to 10 psi were considered in the preliminary investigation.

A more detailed report on inflation systems is included with the refined design analysis at the end of the report.

CONCEPTUAL CONFIGURATIONS AND PRELIMINARY FEASIBILITY EVALUATION

Much research was conducted in order to review and summarize current state of the art and structural forms that might be applicable to the specific requirements for the inflatable bow ramp. Various agencies or organizations that were in any way connected with research that might apply to this study were contacted; the information gathered is tabulated in the list of references at the end of the report. It might be noted that the English at the Military Engineering Experimental Establishment at Christchurch, Hampshire, England seem to be the foreleaders in developing and testing various inflatable, single span bridges. These bridges ranged in spans from 20 to 30 feet; and carried loads in the neighborhood of 1 to 1 1/2 tons. As information on this work was the only data available that was directly related to inflatable bridges of the type that we are concerned with, and since our design requirements were of a nature that far exceeded those used by the English, it was imperative that a new and completely unique type of structural form or forms must be developed to carry the high loads (60 tons) over the relatively long clear span of 110 feet.

With this in mind, we were able to arrive at ten different preliminary conceptual configurations. These preliminary designs spanned a wide range of conceivable means of using the inflated structure principle. Refer to Figure 3 which shows a general elevation and section view of each configuration, along with a chart showing a comparison of various properties of each concept. The preliminary design calculations for each concept are shown in Appendix C, and a brief discussion of each, with specific reference to the calculations, will follow. The preliminary design information was tabulated and a review and evaluation of each concept was conducted at a meeting between Birdair and Navy personnel in order to arrive at one or more concepts to consider for refined design. The factors that were used in evaluating the feasibility of each concept are listed on Figure 3, along with additional comments that follow.

Refer to Figure 4 which lists possible operational methods for each concept, and Figure 5 which tabulates the required fabric strength that is required after the dead load of the structure is added to the fabric stress and then a factor of safety of three applied.

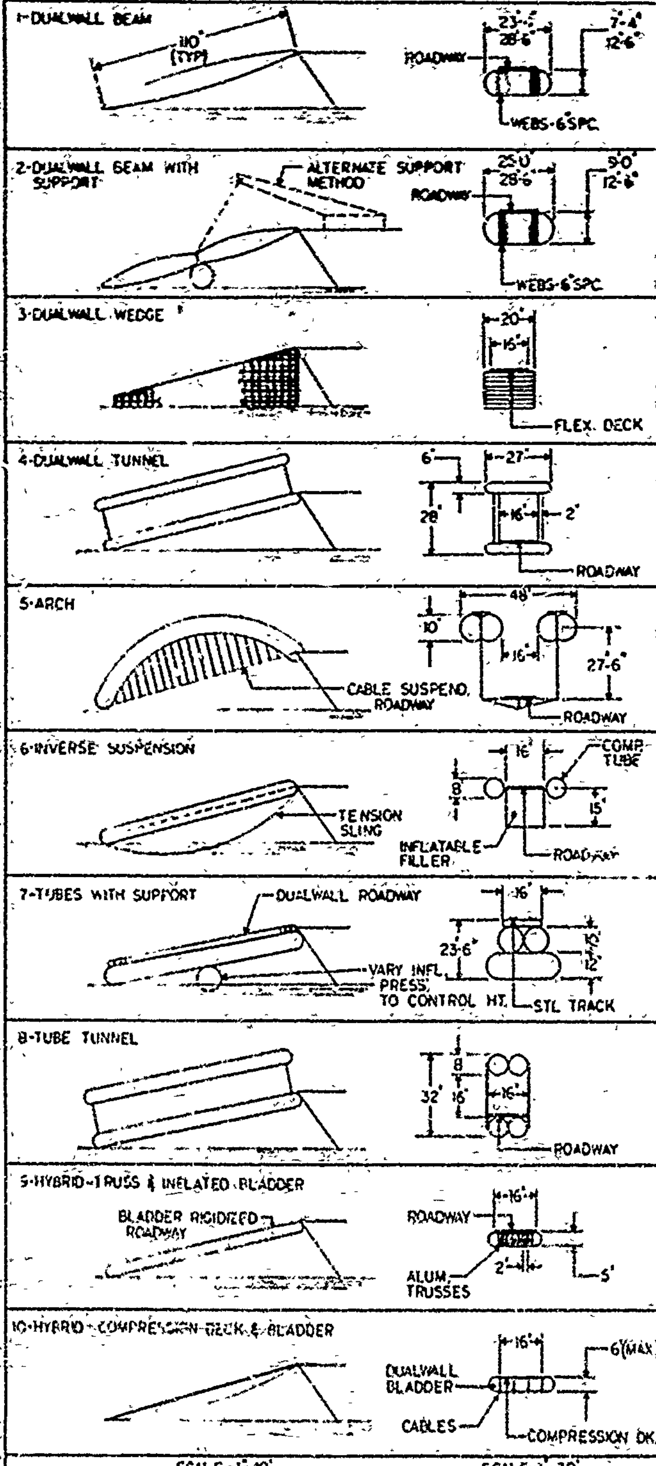
It should also be noted that in each concept, some type of roadway surface or decking is required to protect the fabric from abrasion under track vehicles, and also to maintain positive traction for vehicles using the ramp.

Some research was conducted in determining various materials which might be applicable for the roadway surface. Since the surface should probably be flexible and have the ability to be rolled or folded for storage, the following materials were under consideration:

(a) Non-skid conveyor belt fabric (photo No. 1). This material is light weight and flexible, and could easily be bonded to the fabric ramp. Lab tests conducted by Birdair indicate that the coefficient of friction between this material and neoprene is approximately .6, and when in contact with steel, approximately .5.

CONCEPTUAL CONFIGURATIONS

SPAN – 110 FT.
DESIGN LOAD – 60 TON



Configuration	① MAX. FABRIC STRESS (#/IN)	INFLAT PRESS (#/IN²)	APPROX VOL. (FT³)	APPROX FABRIC WGT. (TONS) ③	ATTACK [illegible] ABILITY	EFFECT OF WAVES	EASE OF OPER.	VARYING INCLINE ANGLE	COST
1-DUALWALL BEAM	1704	16	26400	23.9	1-2	1	1	1	2
2-DUALWALL BEAM WITH SUPPORT	692	6.4	29,150	11 ②	1-2	2	1-2	2	1-2
3-DUALWALL WEDGE	250	10	33,000	9.5	1	3	2	3	3
4-DUALWALL TUNNEL	624	8.7	40,980	24.4	2-3	1	2-3	1	3
5-ARCH	776	7.4	21,856	15.2	3	1	1-2	1	2
6-INVERSE SUSPENSION	674	14	28,658	12.8	3	2-3	1-2	1	2-3
7-TUBES WITH SUPPORT	1423	23.7	19,601	16.4 ②	3	2	2-3	2	2
8-TUBE TUNNEL	RANGE 456 - 2736	RANGE 10-57	22,117	25.5	3	1	2-3	1	2-3
9-HYBRID-TRUSS & INFLATED BLADDER	161	5	10,960	1.3	2	1	1	1	1-2
10-HYBRID-COMPRESSION DECK & BLADDER	108	3.6	7306	1.2	2	1	1	1	1-2

ON SCALE 1-3, 1 EQUALS BEST CHOICE

NOTES -
① DESIGN IS BASED ON MAX. BENDING MOMENT CREATED BY A 60 TON CONCENTRATED LOAD. WGT OF STRUCTURE WAS NEGLECTED FOR PRELIMINARY DESIGN.
② EXCLUDES WGT OF SUPPORT TUBE
③ WEIGHTS SHOWN DO NOT INCLUDE THE WGT OF STL. TRUSSES, DECKING OR CABLES.

FIGURE 3

BIRDAIR STRUCTURES, INC. BUFFALO, NEW YORK

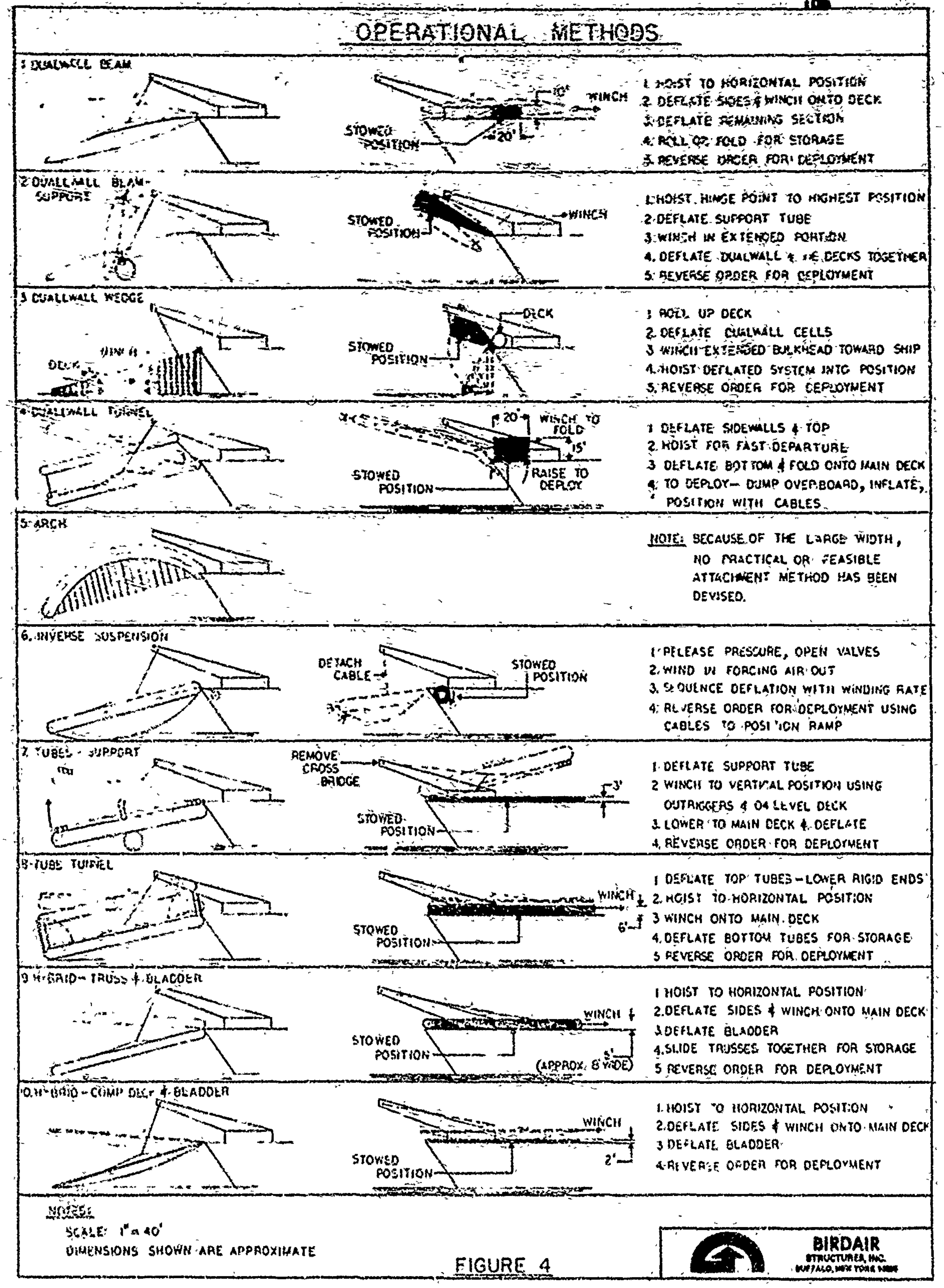
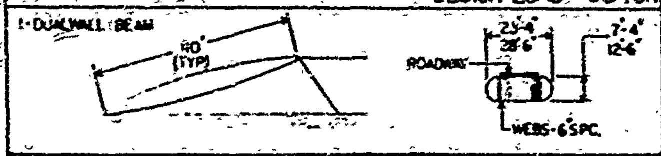
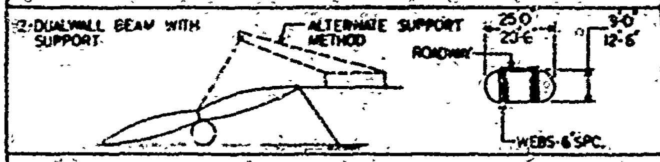
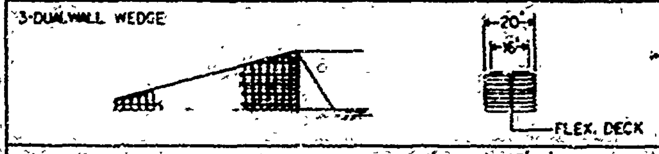
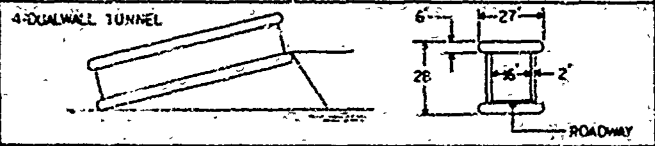
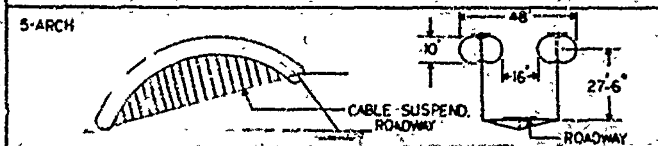
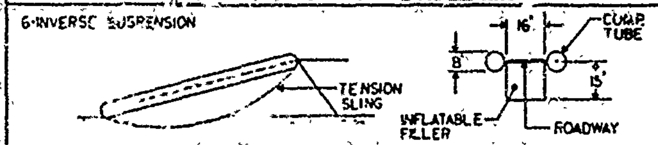
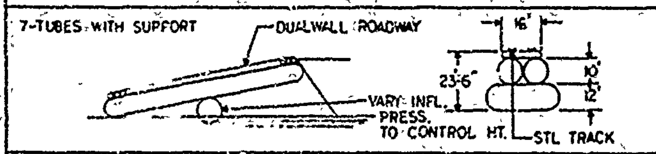
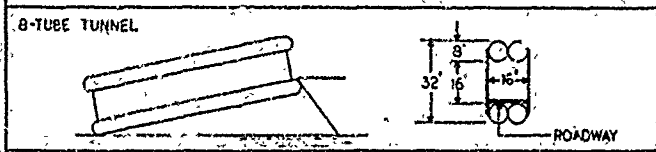
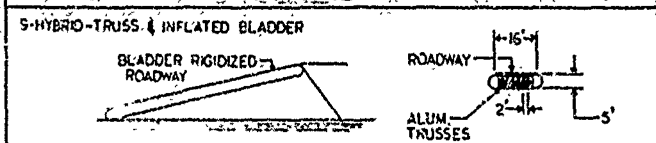
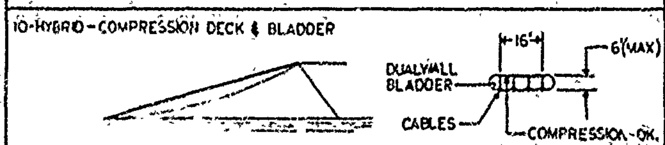

OPERATIONAL METHODS
1 DUALWALL BEAM
STOWED POSITION
WINCH
10'
20'
1. HOIST TO HORIZONTAL POSITION
2. DEFLATE SIDES & WINCH ONTO DECK
3. DEFLATE REMAINING SECTION
4. ROLL OR FOLD FOR STORAGE
5. REVERSE ORDER FOR DEPLOYMENT
2 DUALWALL BEAM-SUPPORT
STOWED POSITION
WINCH
1. HOIST HINGE POINT TO HIGHEST POSITION
2. DEFLATE SUPPORT TUBE
3. WINCH IN EXTENDED PORTION
4. DEFLATE DUALWALL & THE DECKS TOGETHER
5. REVERSE ORDER FOR DEPLOYMENT
3 DUALWALL WEDGE
DECK
WINCH
STOWED POSITION
1. ROLL UP DECK
2. DEFLATE DUALWALL CELLS
3. WINCH EXTENDED BULKHEAD TOWARD SHIP
4. HOIST DEFLATED SYSTEM INTO POSITION
5. REVERSE ORDER FOR DEPLOYMENT
4 DUALWALL TUNNEL
20'
WINCH TO FOLD
15'
RAISE TO DEPLOY
STOWED POSITION
1. DEFLATE SIDEWALLS & TOP
2. HOIST FOR FAST DEPARTURE
3. DEFLATE BOTTOM & FOLD ONTO MAIN DECK
4. TO DEPLOY— DUMP OVERBOARD, INFLATE, POSITION WITH CABLES
5 ARCH
NOTE: BECAUSE OF THE LARGE WIDTH, NO PRACTICAL OR FEASIBLE ATTACHMENT METHOD HAS BEEN DEVISED.
6 INVERSE SUSPENSION
DETACH CABLE
STOWED POSITION
1. RELEASE PRESSURE, OPEN VALVES
2. WIND IN FORCING AIR OUT
3. SEQUENCE DEFLATION WITH WINDING RATE
4. REVERSE ORDER FOR DEPLOYMENT USING CABLES TO POSITION RAMP
7 TUBE - SUPPORT
REMOVE CROSS BRIDGE
STOWED POSITION
3'
1. DEFLATE SUPPORT TUBE
2. WINCH TO VERTICAL POSITION USING OUTRIGGERS & 04 LEVEL DECK
3. LOWER TO MAIN DECK & DEFLATE
4. REVERSE ORDER FOR DEPLOYMENT
8 TUBE TUNNEL
WINCH
6'
STOWED POSITION
1. DEFLATE TOP TUBES—LOWER RIGID ENDS
2. HOIST TO HORIZONTAL POSITION
3. WINCH ONTO MAIN DECK
4. DEFLATE BOTTOM TUBES FOR STORAGE
5. REVERSE ORDER FOR DEPLOYMENT
9 HYBRID - TRUSS & BLADDER
WINCH
STOWED POSITION
5'
(APPROX. 8' WIDE)
1. HOIST TO HORIZONTAL POSITION
2. DEFLATE SIDES & WINCH ONTO MAIN DECK
3. DEFLATE BLADDER
4. SLIDE TRUSSES TOGETHER FOR STORAGE
5. REVERSE ORDER FOR DEPLOYMENT
10 HYBRID - COMP DECK & BLADDER
WINCH
2'
STOWED POSITION
1. HOIST TO HORIZONTAL POSITION
2. DEFLATE SIDES & WINCH ONTO MAIN DECK
3. DEFLATE BLADDER
4. REVERSE ORDER FOR DEPLOYMENT
NOTES:
SCALE: 1" = 40'
DIMENSIONS SHOWN ARE APPROXIMATE
BIRDAIR STRUCTURES, INC. BUFFALO, NEW YORK

FIGURE 4

CONCEPTUAL CONFIGURATIONS — SPAN – 110 FT., DESIGN LOAD – 60 TON	MAX. FABRIC STRESS (#/in)	INFLAT. PRESS (#/IN²)	APPROX. VOL. (FT³)	APPROX. FABRIC WGT. (TONS)	FABRIC TYPE: 45 BIAS	FABRIC TYPE: 2 ST. PLY
1-DUALWALL BEAM 	(6132) 2044 / 340 / 1704	16	26400	24/60 • 40% (20%) 23.9		
2-DUALWALL BEAM WITH SUPPORT 	(2262) 754 / .62 / 692	6.4	29150	11/60 • 18% (9%) =18 11	2FB15.5N70 2FB15.5H70	2FB9N56 2FB9H56
3-DUALWALL WEDGE 	(750) 250	10	33000	9.5	2N12N56 2N12H56 2D12.5N56 2D12.5H56	2N7N46 2N7H46 2D7.6N46 2D7.6H46
4-DUALWALL TUNNEL 	(2247) 749 / 125 / 624	8.7	40980	24.4/60 • 40% (20%) 24.4	2FB19N76 2FB19H76	2FB11N60 2FB11H60
5-ARCH 	(2619) 873 / 97 / 776	7.4	21856	15.2/60 • 25% (12.5%) 15.2	2FB19N76 2FB19H76	2FB11N60 2FB11H60
6-INVERSE SUSPENSION 	(2235) 745 / 71 / 674	14	28658	12.8/60 • 21% (10.5%) 12.8	2FB15.5N70 2FB15.5H70	2FB9N56 2FB9H56
7-TUBES WITH SUPPORT 	(5058) 1686 / 263 / 1423	23.7	19601	16.4/60 • 27% (13.5%) 16.4		2FB21N76 2FB21H76
8-TUBE TUNNEL 	(1668 TO 10,008 RANGE) 456 / 2736	RANGE 10–57	22117	25.5/60 • [illegible] (21.5%) 25.5		
9-HYBRID-TRUSS & INFLATED BLADDER 	(483) 161	5	10960	1.3	2N8.5N49 2N8.5H49 2D7.6N49 2D7.6H49	2N5N42 2N5H42 2D6N44 2D6H44
10-HYBRID-COMPRESSION DECK & BLADDER 	(324) 108	3.6	7306	1.2	2N5N42 2N5H42 2D6N42 2D6H42	2N5N42 2N5H42 2D4N40 2D4H40

SCALE 1"= 40' SCALE 1"= 30'

NOTES
( ) = DESIGN FABRIC STRESS (FACTOR OF SAFETY = 3)

FIGURE 5

BIRDAIR STRUCTURES, INC. BUFFALO, NEW YORK

PHOTO #1

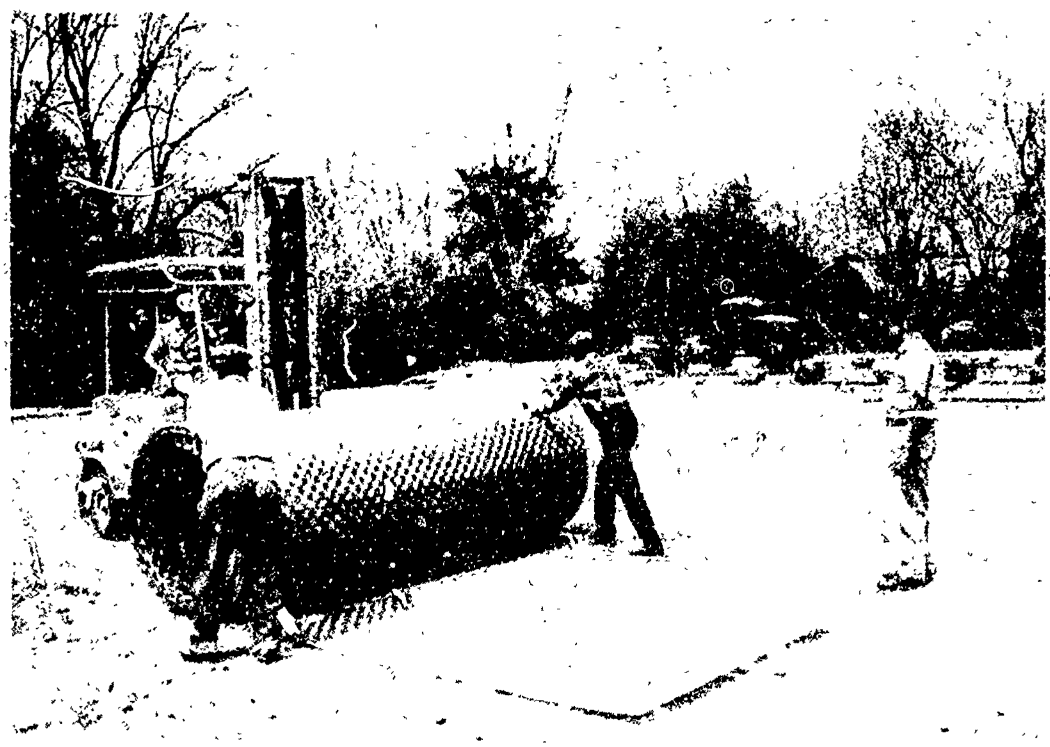


PHOTO #2

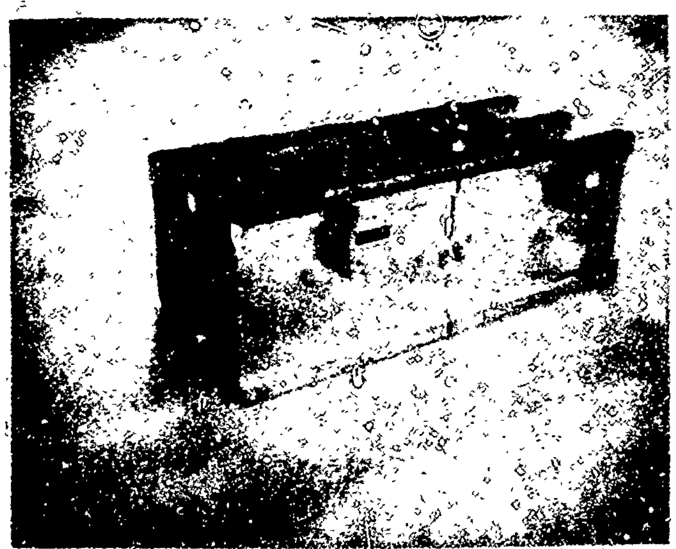


PHOTO # 3

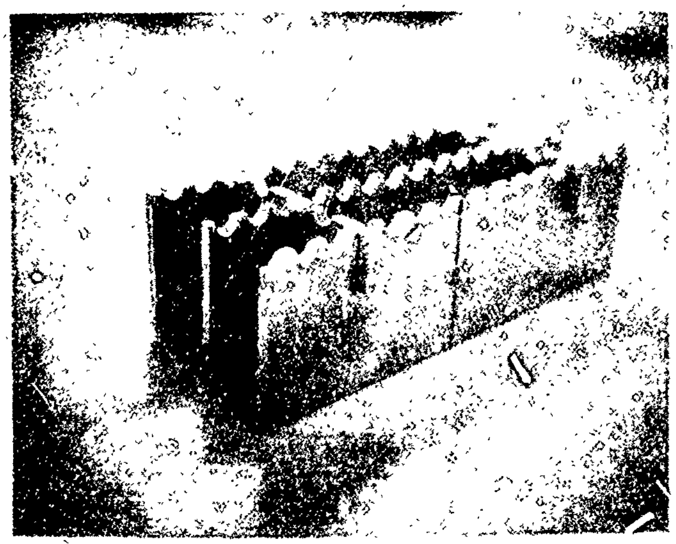


PHOTO # 4

(b) A type of landing mat (MO-MAT) that is used in the military was also under consideration because of its flexibility (Photo No. 2). No information was readily available that stated coefficients of friction. This type of material would have to be stiffened up structurally in the transverse direction in order to distribute wheel loads.

(c) A rigid type of aluminum grating that could possibly be folded is shown in Photos 3 and 4. Coefficients of friction vary according to the type of surface, and panels are available in various sizes.

Concept No. 1 - Dual-Wall Beam

The basic idea in this concept was to form a beam which would span the full 110 ft. It would consist of an upper and lower fabric skin, with a series of vertical fabric webs which would maintain the shape of the ramp and carry the shear loads along the ramp. Thus it is of the simplest air structure form: a dual-wall beam, or, if the webs are replaced with drop cords, airmat. In order for the top skin to carry the compressive force created by the bending moment, the structure must be inflated to a theoretical point at which the tension due to inflation pressure equals the compression due to bending moment (initial wrinkle theory). Likewise, the tension in the bottom skin is the summation of the tension due to inflation pressure, plus the tension due to bending moment.

On that basis then, the fabric stresses and inflation pressures required to resist the maximum bending moment for varying depth sections were computed. A graph of the results is shown on Page C 4 and, assuming a maximum depth of 150 inches at midspan is the optimum, an inflation pressure of 15.7 psi is required with the maximum fabric stress of 1704 lbs. per inch. After adjusting the fabric stress for dead load of the ramp, and then applying a factor of safety of three, the required fabric strength is 6132 lbs. per inch (refer to Figure 5).

After review, this concept was dropped from continuing study for the following reasons:

(a) In keeping with fabric types that are readily available on the market, there is no fabric that will meet the required strength of 6132 lbs. per inch, and still maintain the flexibility that is required for ease in constructing and handling a structure of this size.

(b) Also, the high inflation pressure of 15.7 psi presents some problems in selecting an inflator that will inflate the ramp in 10 minutes.

It should be noted, however, that if lighter loads and shorter spans were considered, this concept might prove to be very feasible.

Concept No. 2 - Dual-Wall Beam with Support

The idea here was the same as Concept No. 1, except that by using a support at midspan, the bending moment would decrease, therefore allowing the inflation pressure and fabric stress to decrease. Assuming again an optimum depth of 150 inches (refer to Page C 5), the inflation pressure required is 6.4 psi, and the fabric stress is 692 lbs. per inch. After adjusting the fabric stress for dead load, and then applying a factor of safety of three, the required fabric strength is 2262 lbs. per inch (refer to Figure 5).

After review, this concept was considered to have some possibilities for a more refined design. The fabric strength required is rather high, but not out of reach of some of the newer fabrics on the market. With the inflation pressure of 6.4 psi, there is no problem in finding an inflator that can deliver the volume of air required to get the structure up to pressure in 10 minutes.

The effects of more than one intermediate support should be considered in the refined design analysis.

Concept No. 3 - Dual-Wall Wedge

The principle here was to form an inflatable wedge that simply carries the load by floating on the water. The ramp would consist of a series of vertical dual-wall sections (see Page C 20) that, when inflated, would be bound together by a cable or web system. The inflation pressure required would be directly related to the local wheel or track loading, and in this case would be 10 psi. Fabric stress then is a function of cell diameter, and, for a 50-inch cell diameter, the resulting fabric stress is 250 lbs. per inch (see Page C 19). Applying a factor of safety of three, the required fabric strength is 750 lbs. per inch.

Although the fabric strength required is well within the limits of fabric types available, the inflation pressure is a little high for the inflation systems being considered.

Other, and probably more important, reasons for not pursuing this concept are the fact that this rigid type of wedge cannot accommodate varying degrees of inclination that are required for use on a causeway, or when landing on a beach. Also, since the wedge has a large surface area, the contact of 5 ft. breaking waves, along with the effects of 30-knot winds, make it possible to develop a moment of 39 million foot pounds at the shipboard end of the ramp. Therefore, guying or anchoring of this wedge concept is required when high winds and waves exist. A final point to be considered is the buoyancy effects of the ramp as a 60-ton tank moves across. As the tank first leaves the ship and debarks down the ramp, high shear stresses are developed at the shipboard end of the ramp. Provision must be made to handle these shear stresses until an appropriate volume of water is displaced to offset the weight of the tank. Also, as the tank approaches the extended end, approximately the last 20 feet will sink and rest on the bottom in 4 feet of water. Reference graph on Page C 28. This situation alone creates difficulty with transition areas between the extended end of the ramp and a floating causeway. For these reasons then, this concept was dropped from further investigation.

Concept No. 4 - Dual-Wall Tunnel

The idea here was to create the required depth of section to carry the bending moment, and in so doing make use of a box section in which the vehicles actually debark along the inside of the section. The design method is similar to Concept No. 1, that is, the fabric must be pretensioned with enough inflation pressure to resist the compressive force due to bending moment. Inflation pressure versus cell depth is plotted on Page C 31; for an optimum depth of 6 feet, an inflation pressure of 6.7 psi is required and the maximum fabric stress is 624 lbs. per inch. Adjusting this figure for dead load and applying a safety factor of three, the required fabric strength is 2247 lbs. per inch (reference Figure 5).

The fabric strength and the inflation pressure fall within the limits of materials available to handle the requirements; however, the size and vulnerability from enemy attack, along with an appropriate method for operating this concept, presented some questionable areas. For these reasons then, this concept was dropped from further consideration.

Concept No. 5 - Arch

The theory in this concept was to form two parabolic-shaped tubes which would in turn support a roadway system by a series of suspension cables. A computer program was written that analyzes the moment on the arch as the load moves along the roadway. It should be noted that the tank loading was distributed over three cables per side. The results are shown on Page C 54. Then, applying the initial wrinkle theory (as used in the preceding dual-wall concepts), it was found that for a 10 foot diameter tube, an inflation pressure of 7.4 psi and a fabric stress of 776 pounds per inch were required. (See graph on Page C 58.) After adjusting the fabric stress for dead load and applying a factor of safety of three, the required fabric strength is 2619 pounds per inch. Again, the fabric strength and inflation pressure fall within the limits of materials available to meet these requirements. However, the size of this concept left us with no feasible or practical method of attaching the arches to the ship. Also, the great vulnerability from enemy attack associated with quick collapse led us to the conclusion that this concept did not justify further investigation.

Concept No. 6 - Inverse Suspension Concept

The idea in this concept was to form an inflatable system in which tubes acting much like rams would carry the compression loads independent of the rest of the structure. The tension loads would be carried by a cable sling which would be attached at each end to a bulkhead. An inflatable filler resting on the cables would support the roadway. Any deflection of this cable sling would not deflect the compression tubes since they are only in contact at the ends. On this basis then, it was found that for a 10 foot diameter tube, the inflation pressure of 14 psi and the fabric stress of 674 pounds per inch are required (Reference graph on Page C 64).

Again adjusting the fabric stress for dead load and adding a factor of safety of three, the fabric strength of 2235 pounds per inch is required. Although the fabric strength falls within the limits of fabrics that are available, the inflation pressure is rather high and problems were encountered in selecting an inflator device that would deliver the volume in the required time to get the system up to pressure. Also, since the compression tubes are not laterally supported and might possibly buckle, some question was raised concerning the structural integrity of the system. Realizing that the compression tubes are very vulnerable under enemy attack, it was then decided to scratch this concept from further investigation.

Concept No. 7 - Tubes with Support at Midspan

The idea in this concept was to form an inflatable beam by using two tubes to carry the bending moment with a flat inflatable mat on top to form a surface for the roadway. In order to keep the fabric stresses down into a reasonable range, a support tube at midspan is required to reduce the bending moment.

For a design comparison, the shipboard end of the ramp was designed as being simply supported in one instance and fixed in the other. The reduction in bending moment, however, is not very significant, as shown on Page C 67. By applying initial wrinkle theory, it was determined that for an optimum tube diameter of 10 feet, the inflation pressure of 23.7 psi and a fabric stress of 1423 pounds per inch are required (refer to graph on Page C 69). After adjusting the fabric stress for dead load and applying a factor of safety of three, the required fabric strength is 5058 pounds per inch. With reference to Figure 5, it should be noted that two straight plies of the Fiber B fabric would carry the load. However, the inflation pressure is very high, and selecting a system to deliver this pressure and volume in the required time proved infeasible. Some questions were also raised concerning the torsional stability of this concept if the load should get off center, along with the catastrophic results if one of the tubes is punctured. The operational method of deploying the support tube, along with the effect of waves on the support tube, was also of some concern. Therefore, because of the above mentioned considerations, this concept was also dropped from further investigation.

Concept No. 8 - Tube Tunnel

The idea in this concept is similar to the approach taken in Concept No. 4, except the dual-wall beams are replaced with tubes, and the sides are constructed of two ply bias fabric. The exact method of analysis for this concept is difficult to arrive at, since it is not known if the bias sides will transmit the full or a portion of the shear load. Therefore, two design approaches were taken. A conservative approach would be to consider that each of the tubes will carry one fourth of the bending moment. On this basis, the inflation pressure of 57 psi is required and the fabric stress of 2736 pounds per inch is developed. A less conservative approach would be to assume that the side webs carry the full shear load and the four tubes act as one beam. On this basis, the inflation pressure of 9.5 psi is required with the fabric stress of 456 pounds per inch being developed. Refining each of the fabric stresses for dead load and then adding a factor of safety of three, the required fabric strength would fall somewhere in the range of 1668 to 10,008 pounds per inch, while the inflation pressure would be between 9.5 to 57 psi. Because of the uncertainty of the exact design approach, the mean value of the fabric strength and inflation pressure fall well above the normal ranges under consideration. Therefore, this concept was discontinued from further study.

Concept No. 9 - Truss and Inflated Bladder

The idea in this concept was to develop a hybrid structure which would use an air-supported bladder in conjunction with some type of aluminum truss work. The aluminum trusses would actually carry the bending moment, while the inflated bladder would simply stiffen and hold the trusses in the correct position. To do this, an inflation pressure of 5 psi is required which creates a fabric stress of 161 pounds per inch. Applying a factor of safety of three, the required fabric strength is 483 pounds per inch. These factors are well within the limits of fabric types and pressurization systems available. Typical truss systems and details that might be incorporated in this concept are shown on Pages C 79 to C 82. After reviewing this concept with Navy personnel, however, it was decided that this concept was basically the some type of system that is presently being used, and that the inflatable portion did very little to actually carry the load. For this reason then, this concept was dropped from further investigation.

Concept No. 10 - Compression Deck and Inflated Bladder

Since high fabric stresses and inflation pressures are required to resist the compressive force due to bending moment, a system which could use a rigid aluminium-type deck to carry the compression load, and a cable system underneath to carry the tensile loads, will allow the main components of force to be carried by the structural members, rather than the fabric. The fabric bladder would serve as a means of tensioning out the cables and maintaining their shape.

A preliminary investigation of this concept revealed that an inflation pressure of 3.6 psi would be required and a fabric stress in the outer skin of 108 pounds per inch would be developed. Applying a factor of safety of three, the required fabric strength would be 324 pounds per inch.

Both the inflation pressure and fabric stress required fall within the normal range of materials available to meet these requirements. Upon evaluation, it was decided to continue with a more refined design analysis of this concept.

In summary then, after evaluating each of the ten preliminary conceptual configurations, it was decided to continue with a refined design analysis of the dual-wall beam with intermediate supports (Concept No. 2) and the compression deck with inflated bladder (Concept No. 10). It was also decided at this time in the study that the types of deck materials that were under consideration as being suitable for the roadway surface would not meet the toughness and durability that are required for conditions imposed by the M103 Tank.

Navy personnel then directed us to evaluate each of the two remaining concepts to undergo refined design analysis on the basis that the roadway surface would consist of a material similar to that presently being used on the existing bow ramp. That is, the deck will consist of an aluminum grating approximately 3 1/2 inches deep, with rectangular openings approximately 3" x 6" on centers, with the individual bars 1/2" thick. Details of this grating are shown on Page D.23 in the refined design analysis.

It should also be noted that when evaluating each of the 10 concepts against the performance requirements outlined earlier, no mention was made concerning Grade "A" shock loads in the stowed condition and repairability by shipboard personnel. In each of the concepts the ramp was stowed in a manner which we felt would pose no problem in withstanding Grade "A" shock loads. Also, since all of the concepts were constructed of fabric, the repairability of the structure is well within the capabilities of shipboard personnel. The method of repair simply involves cleaning and patching of the affected area.

The effects of winds and waves had great importance only in Concept No. 3, since this concept had the most contact with the seawater. The remaining concepts, however, had little contact with the sea and therefore posed no serious problem concerning the effects of wind and waves. When speaking of vulnerability, it should be noted that any air-inflated fabric structure is vulnerable to some degree. The concepts which we felt are the most vulnerable and would lead to quick collapse were pointed out.

REFINED DESIGN ANALYSIS FOR CONCEPT NO. 2

Dual-Wall Beam with Intermediate Supports

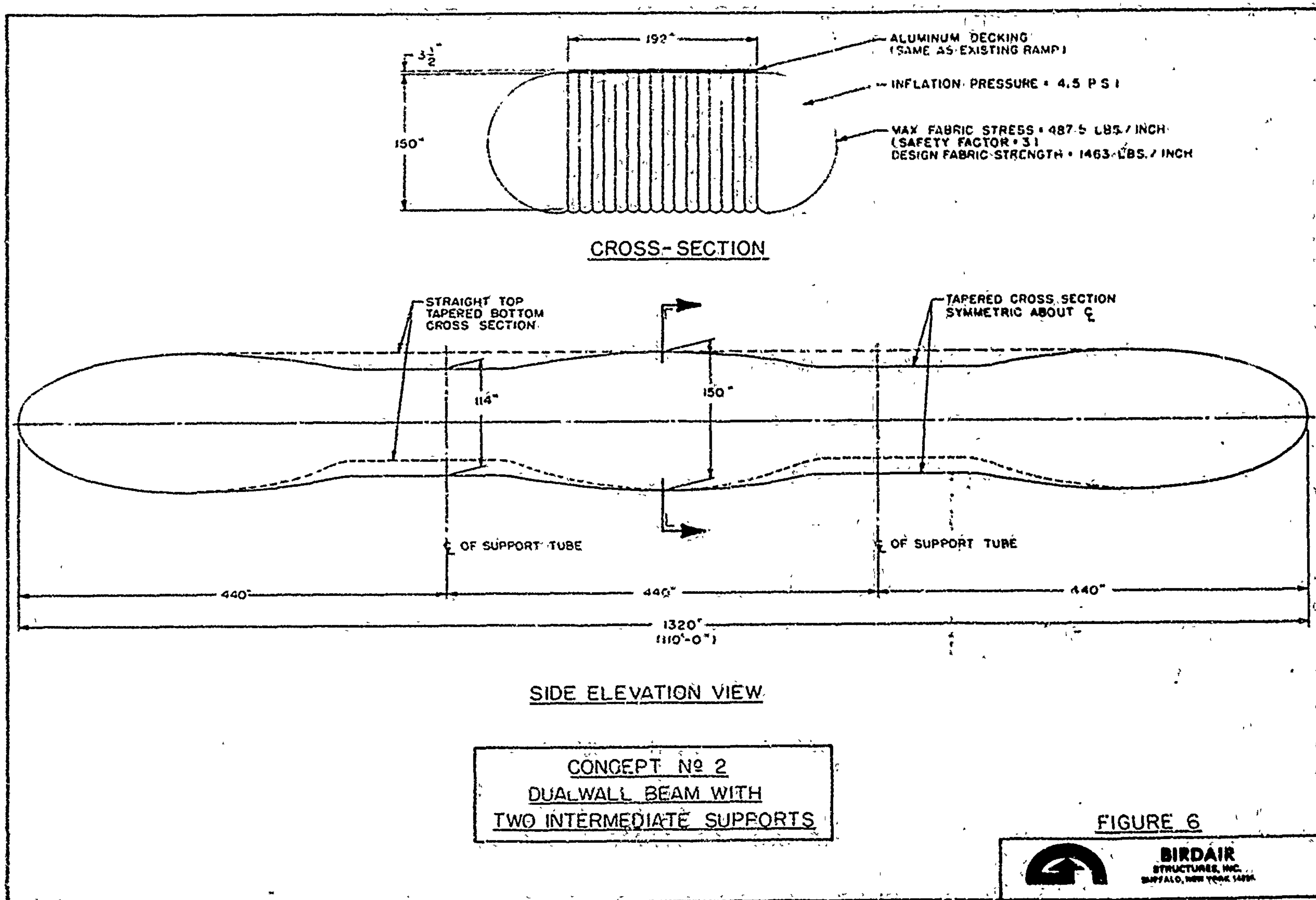
The refined design calculations for this concept are shown in Appendix D, and a drawing conveying the final shape is shown in Figure 6. Reference will be made to these items.

With the refined design analysis, two new parameters entered into the design. First, since the roadway surface to be used must be similar to the existing bow ramp, this adds an additional dead load of approximately 11 tons to the structure. Secondly, with this increased load, consideration should be given to the effects of more than one intermediate support mechanism.

Therefore, applying a concentrated live load of 120,000 pounds and a dead load of 33.8 pounds per inch (Reference Page D 2), the maximum bending moments were computed for a two and three span continuous inflatable dual-wall beam. Computer printouts of the bending moment are shown on Pages D 6 thru D 9.

Applying the initial wrinkle theory as used in the preliminary design, the resulting fabric stresses and inflation pressures for varying depth sections are plotted on Page D 12. Again, an optimum depth of 150 in. seems to occur at the knee of the curve, and a three span continuous inflatable dual-wall beam requires the least inflation pressure and fabric stress to carry the load.

A graph on Page D 17 shows the relationship between bending moment, fabric stress, and inflation pressure for 0, 1, or 2 intermediate support tubes. By extrapolating the curves, it can be seen that the use of three support tubes will probably have little effect in reducing the bending moment.



192"
3½"
150"
ALUMINUM DECKING (SAME AS EXISTING RAMP)
INFLATION PRESSURE = 4.5 P S I
MAX FABRIC STRESS = 487.5 LBS./INCH
(SAFETY FACTOR = 3)
DESIGN FABRIC STRENGTH = 1463 LBS./INCH
CROSS-SECTION
STRAIGHT TOP TAPERED BOTTOM CROSS SECTION
TAPERED CROSS SECTION SYMMETRIC ABOUT ℄
114"
150"
℄ OF SUPPORT TUBE
℄ OF SUPPORT TUBE
440"
440"
440"
1320"
(110'-0")
SIDE ELEVATION VIEW
CONCEPT № 2
DUALWALL BEAM WITH
TWO INTERMEDIATE SUPPORTS
BIRDAIR
STRUCTURES, INC.
BUFFALO, NEW YORK

FIGURE 6

since the curve is flattening out. Therefore, for a three span continuous inflated dual-wall beam, the inflation pressure of 4.5 psi is required which creates a maximum longitudinal fabric stress of 487.5 pounds per inch in the outer skin. Applying a factor of safety of three, the required fabric strength in the outer skin is 1463 pounds per inch.

Up to this time, little has been said concerning how the inflatable dual-wall will transmit the shear loads as the load moves along the ramp. On Figure 6, the cross section view shows a series of 17 vertical webs. These webs, in addition to defining the shape of the structure, will carry the shear loads from the upper to lower skin along a 45° line. On Page D 20 and D 21, the calculations are shown for determining the shear load in the webs. After applying a factor of safety of three, the required fabric strength is 150 pounds per inch in the bias ply and 162 pounds per inch in the straight ply.

One other important design consideration is the deflection of the dual-wall beam. With reference to Appendix C under deflection, it was concluded that an exact method for determining the deflection of an inflated dual-wall beam is very complex, if not impossible. The English, however, in their studies have arrived at an equation which in all cases seems to give very conservative results. Simply, the equation expresses deflection as a function of inflation pressure, cross sectional area, and the shear load at the point in question.

Upon applying this equation, reference Pages D 18 to D 19, it was found that a maximum 61 inch deflection would occur under a

120,000 pound point load. (It should be noted that if this equation were applied to the dual-wall beam with any number of interior supports, the deflection equation yields the same results. This is due to the fact that the inflation pressure, bending moment, and shear are a function of each other.) Since this 61 inch deflection is very conservative, in actual practice the deflection would probably be something less. However, an exact answer in this regard would involve actual field testing of a prototype.

The exact method of developing support tubes is of some concern also. Preliminary ideas were to actually float a cylindrical bag on the water's surface and, by varying the inflation pressure, regulate the height for accommodating the ramp to varying inclination angles. However, when investigating the idea further, it was found that such a large volume of water must be displaced to hold the load and that the diameter of the support bag became so large it was totally infeasible. Other methods of rigid vertical support mechanisms were considered, but with little success.

In conclusion then for Concept No. 2, the best way to evaluate its overall feasibility is to actually list the advantages and disadvantages:

<u>Advantages</u>

1. The inflation pressure is well within the limits of inflation devices available that will deliver the volume and maintain the pressure in the time requirement specified (10 minutes).
2. The fabric strengths required for the webs are well within the limits of easily workable fabrics available, while the fabric

strength required for the outer skin is within the limits of some of the newer fabrics.

3. The fact that each of the individual cells between the webs can be sealed off separately, and inflated with a manifold system, allows the ramp to withstand a puncture of a few cells and still remain intact.

<u>Disadvantages</u>

1. Size is the main problem. With reference to Figure 6, it can be seen that the structure is basically 150 inches deep for its entire length. This makes transition areas from the ship to ramp, and ramp to causeway difficult. A secondary type of inflatable would be required in these areas.

2. Operational methods also present problems (see Figure 4). Because of its width, clearance in winching the ramp back onto the deck between the derricks require that the side closures be deflated. Conversely, for deployment, the sides must be inflated after the ramp is extended.

3. Method of attachment to the ship is a problem because of its size. It does not fit into the existing area.

4. The negative buoyancy requirement when the extended end is lowered into [illegible] feet of water is a problem. The large volume of water that must be displaced makes it difficult to sink the extended end when not loaded.

5. The difficulty in finding a suitable support mechanism that is easy to deploy or retract, and still be versatile enough to accommodate the various heights required for varying ramp inclination, also exists.

6. Since the roadway must be similar to the present aluminum grating used on the existing bow ramp, it is difficult to handle or fold this structure into a compact unit.
7. Although not known for certain, it appears that the deflection under the tank loading will be significant and severely affect the maximum gradient the vehicles can encounter.

It is our opinion then, when weighing the advantages against the disadvantages, that this concept is infeasible with respect to its present application. Other similar applications might exist, however, where the span and load conditions are reduced, and the rigid deck requirement is removed. This would then allow the structure to be much more flexible and easier to handle, along with being able to store the unit in a more compact area.

REFINED DESIGN ANALYSIS FOR CONCEPT NO. 10

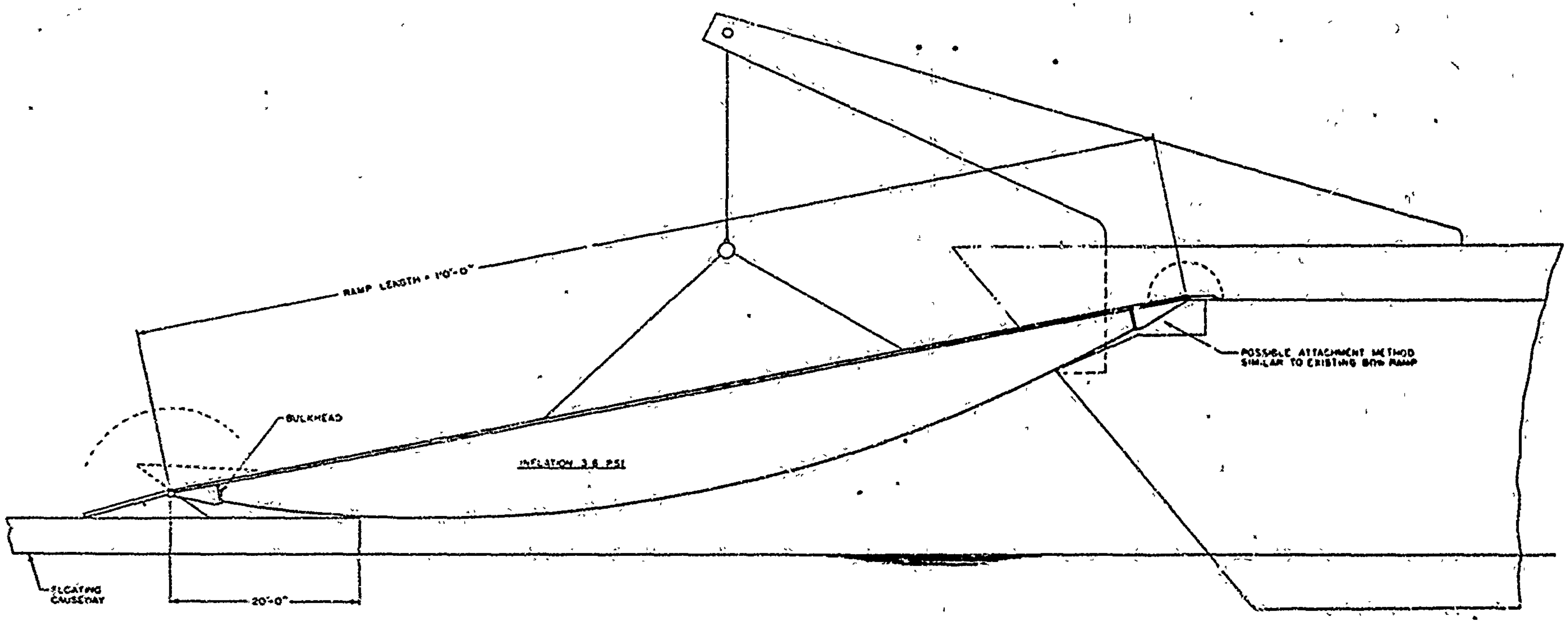
Compression Deck with Inflated Bladder

Since it is mandatory to use the type of deck that exists on the present bow ramp, we investigated the possibility of using this aluminum grating as the structural member to carry the compression force due to bending moment. In turn, as noted in the preliminary design, a series of cables forming a sling will carry the tension loads created by the bending moment and inflation pressure. The inflated bladder will tension out and hold the cables in position, while the fabric webs will transmit the shear loads along the ramp.

Figures 7, 8, 9, and 10 show general conceptual views and details, and will be referred to in later text. The method of operation proposed for this concept is similar to that being used for the existing ramp. The ramp will be attached to the ship with a kingpin connection which will allow for the rotational requirements, while the derrick and winch system will be used to deploy and retract the inflatable ramp. The ramp itself will be inflated and deflated on the main deck level. The design calculations start on Page D 23, and a brief summary of the design procedure and theory follows.

Investigating the structural properties of the existing deck, and assuming that the deck is fully supported in the longitudinal direction to the fabric bladder, and that the compressive force is distributed over the width (16 feet) of the grating, it was discovered that the deck is capable of supporting an allowable compressive load of 1,592,500 pounds. Further evaluation also indicated that under the tank loading, the deck is capable of distributing the track pressure equally across the width of the ramp. The effects of wheel loadings on the deck were also investigated, and the deck again was found satisfactory to distribute the wheel loads over an area equally equivalent to or better than the area of contact created by track loading. Upon this basis, it was concluded that an inflation pressure of 3.6 psi

26a

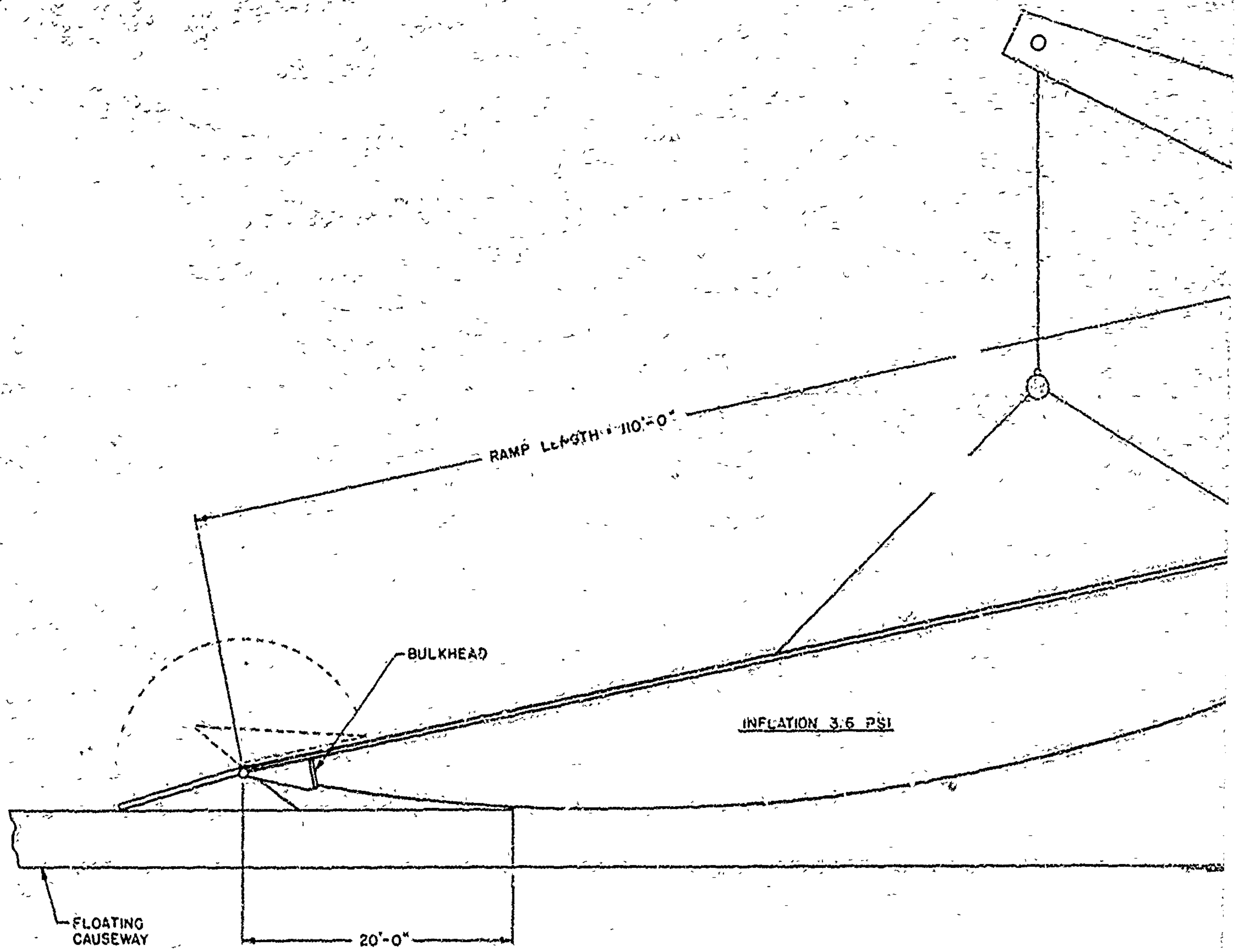


ELEVATION

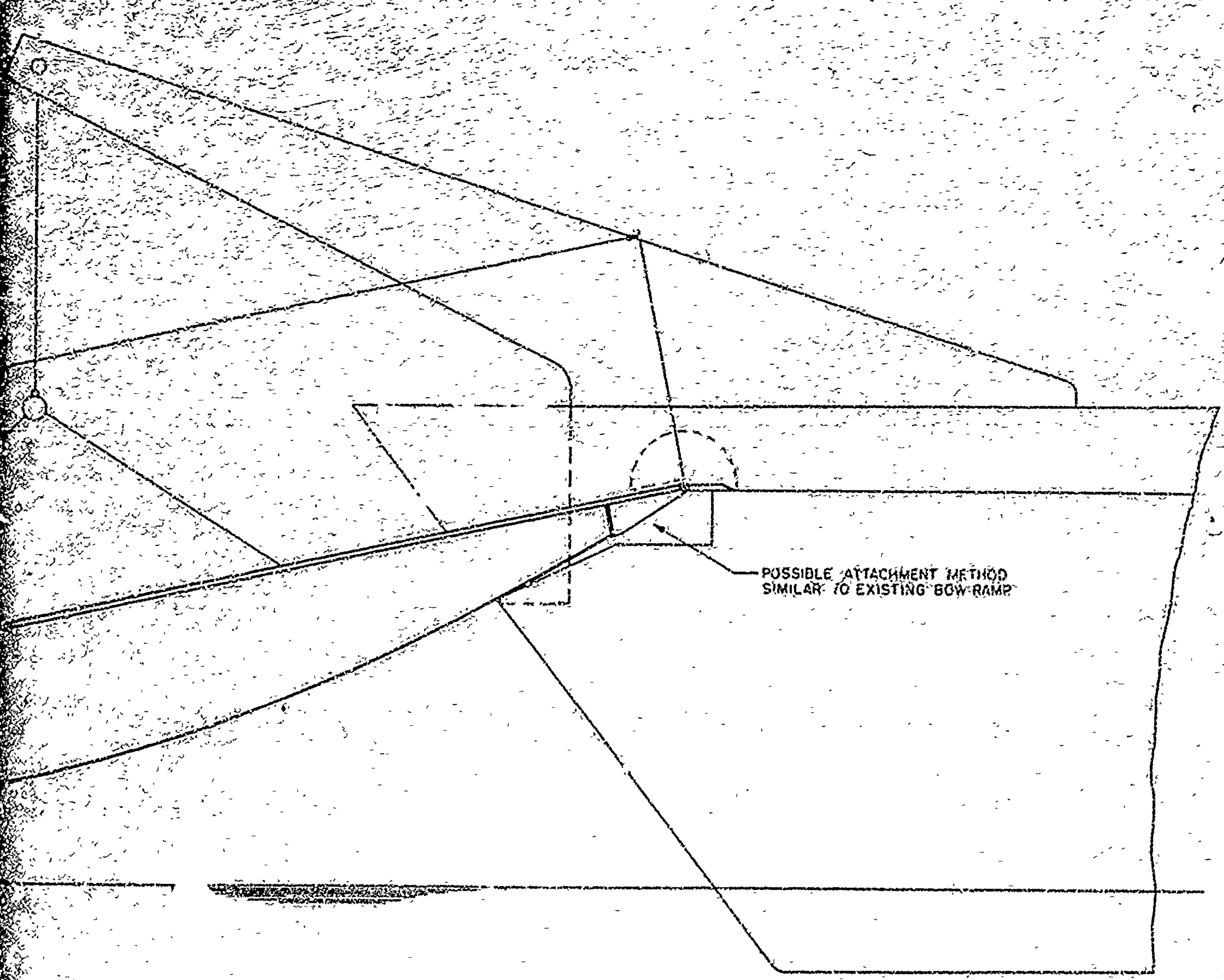
See the following page for greater detail.

FIGURE 7

BIRDAIR

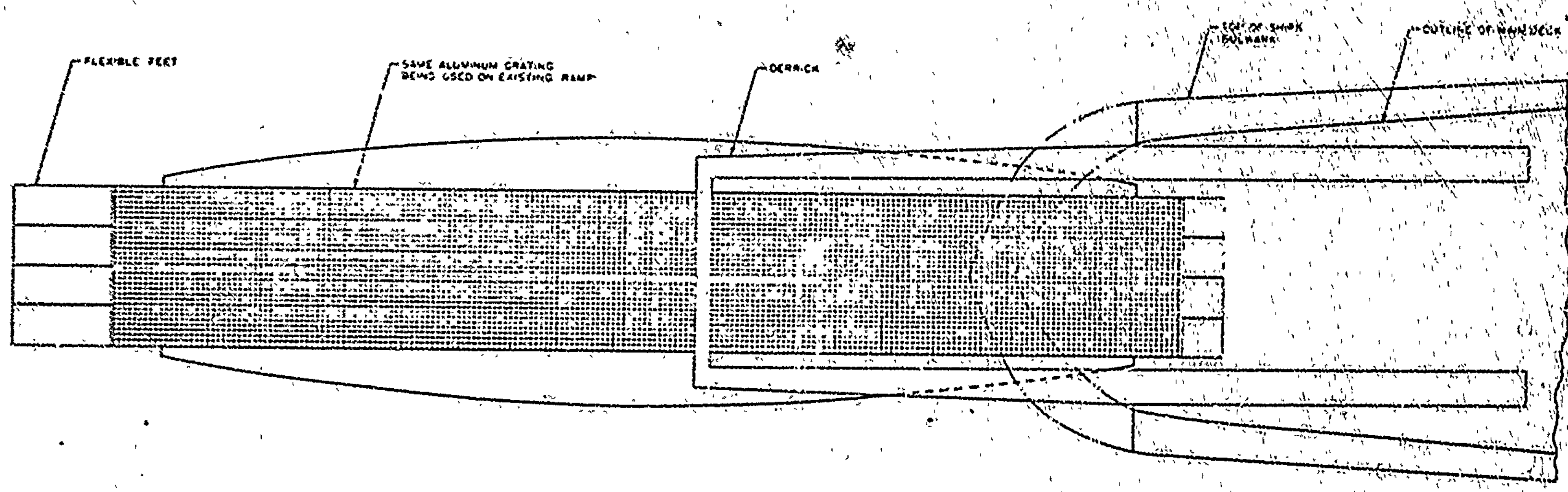

RAMP LENGTH 110'-0"
BULKHEAD
INFLATION 3.6 PSI
FLOATING CAUSEWAY
20'-0"

ELEVATIO



EVATION

FIGURE 7

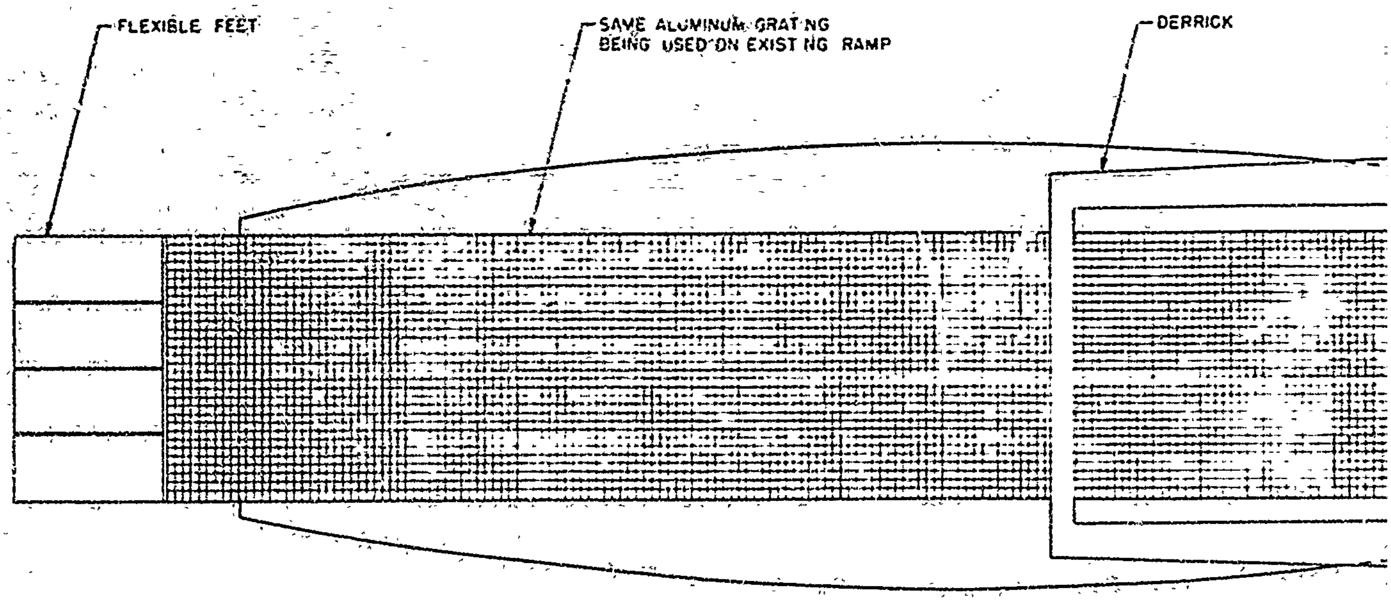


PLAN

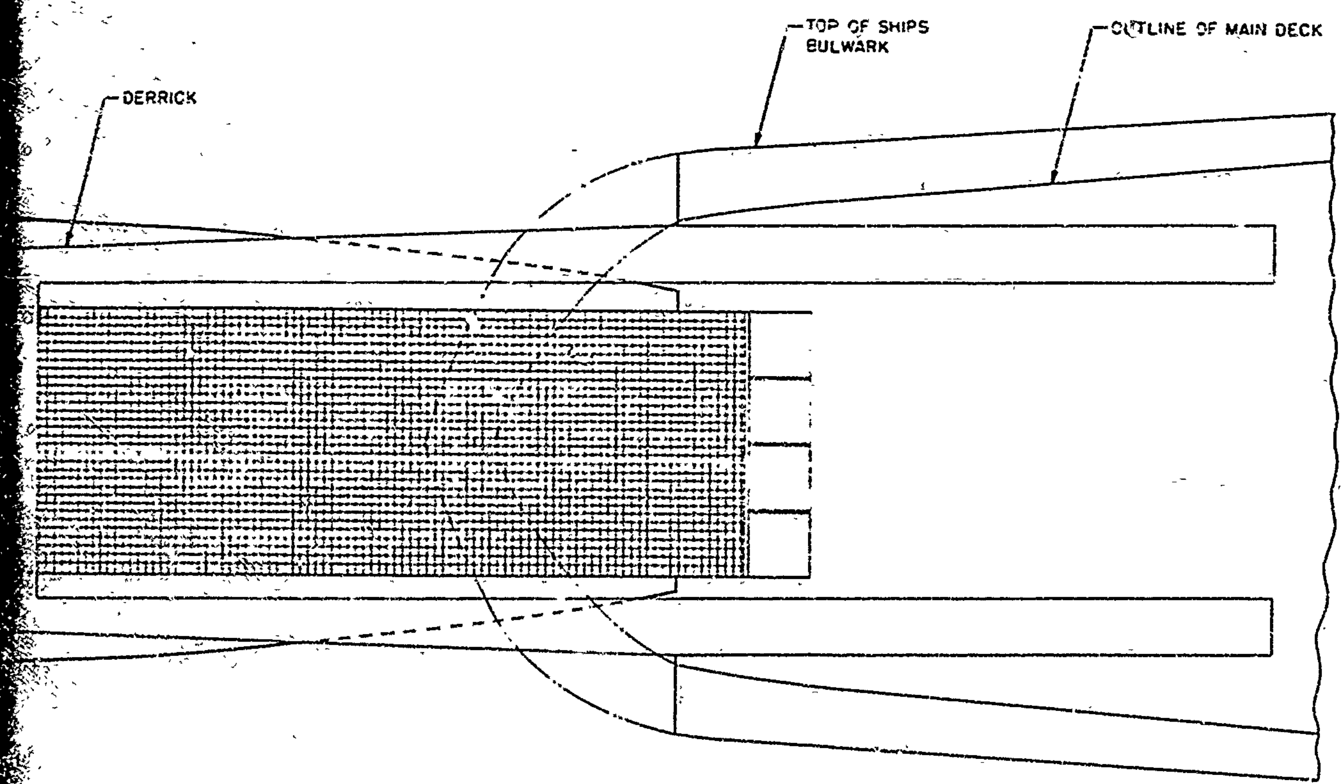
See the following page for greater detail.

FIGURE 9

BIRDAIR STRUCTURES INC.


FLEXIBLE FEET
SAME ALUMINUM GRATING BEING USED ON EXISTING RAMP
DERRICK

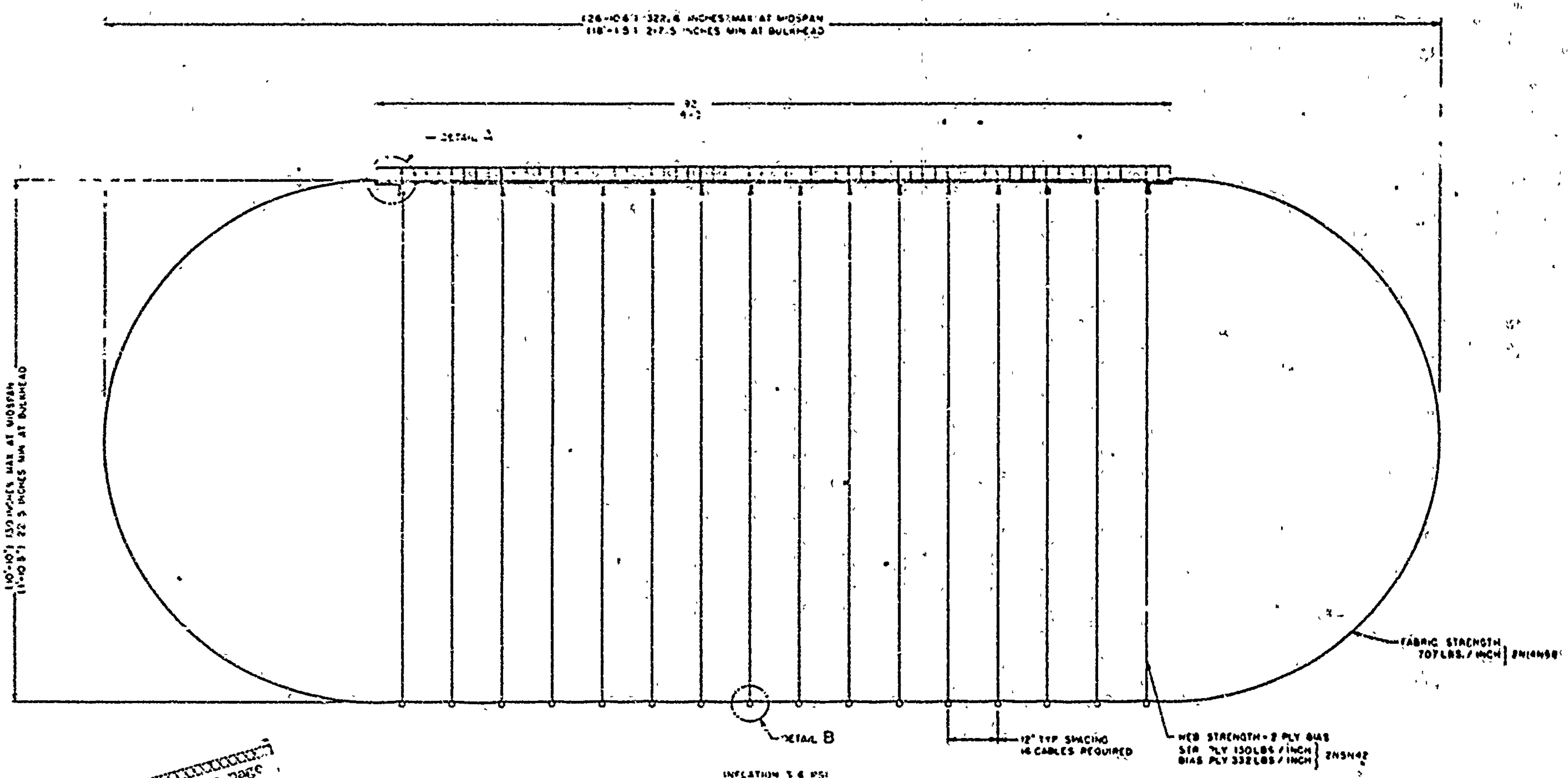
PLAN



PLAN

FIGURE 8

BIRDAIR
STRUCTURES, INC.
BUFFALO NEW YORK 14225

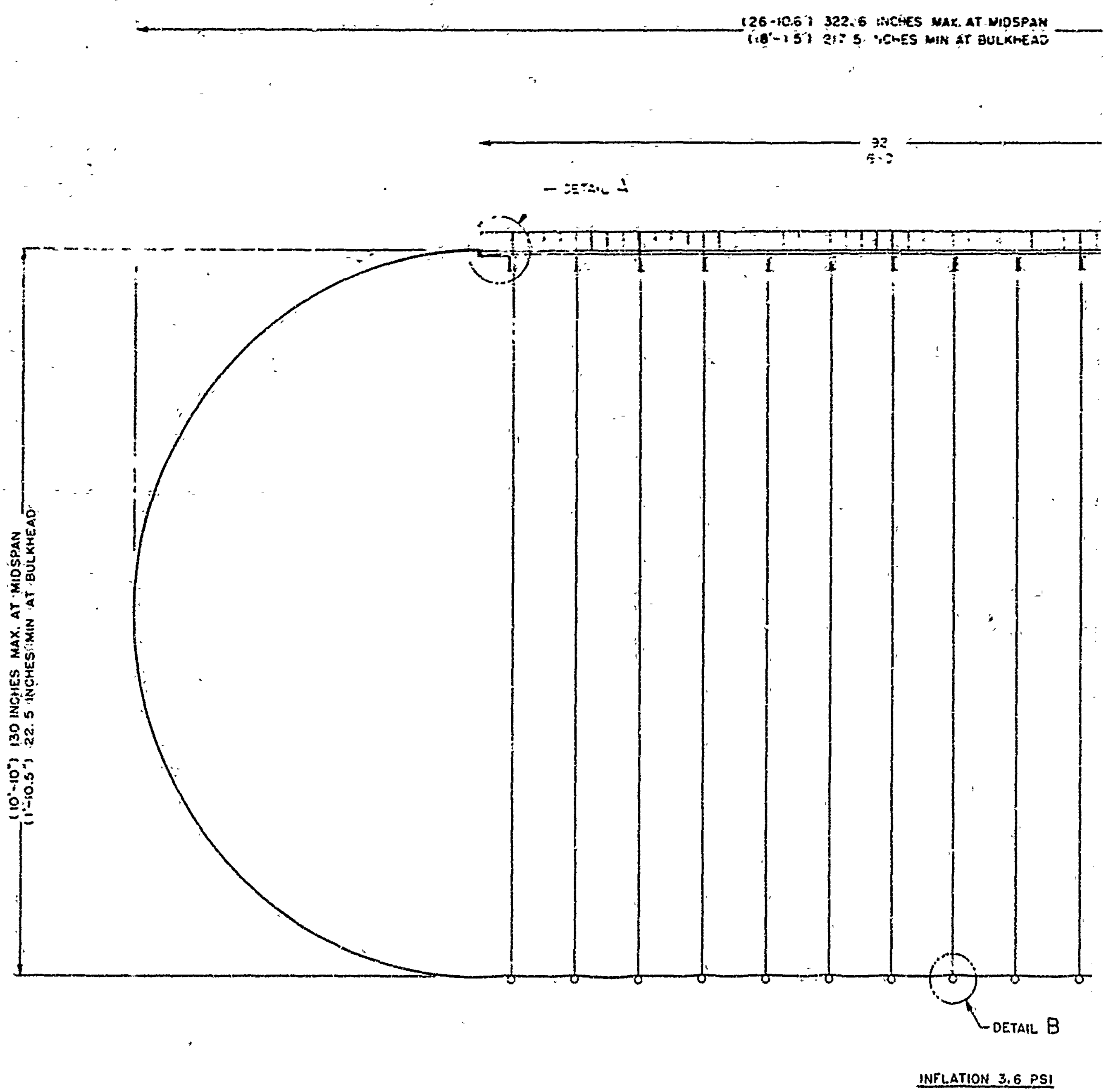


See the following page for greater detail.

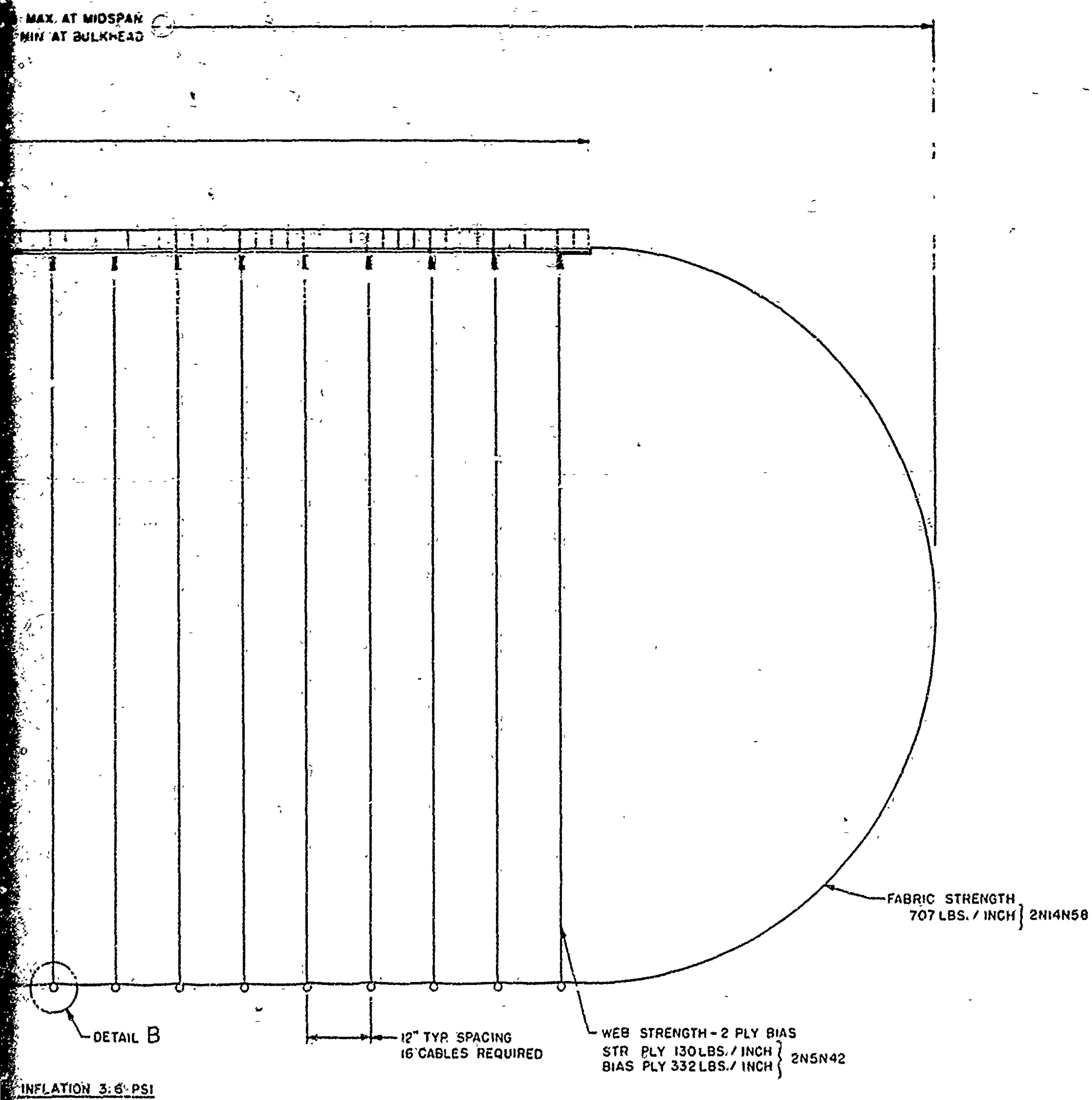
TYPICAL CROSS SECTION AT MIDSPAN

FIGURE 9

BIRDAIR



TYPICAL CROSS SECTIO



SECTION AT MIDSPAN

FIGURE 9

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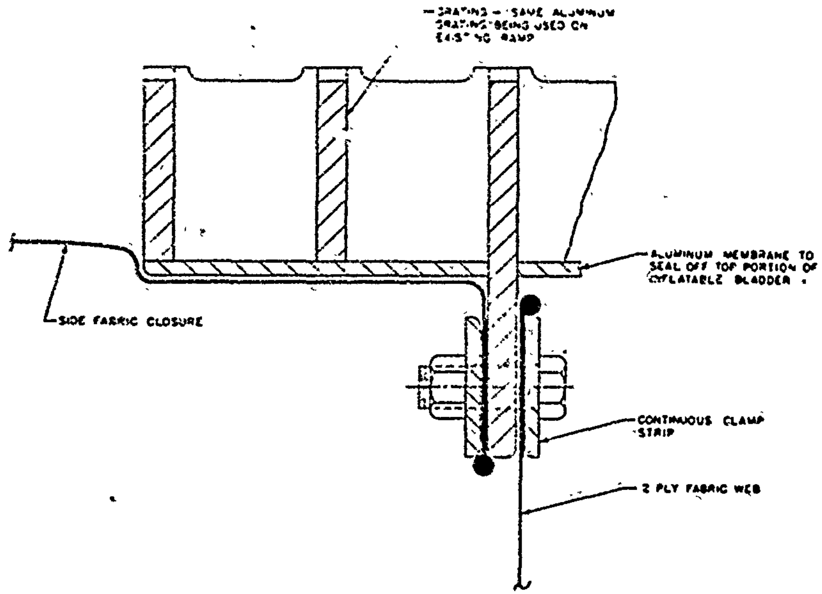
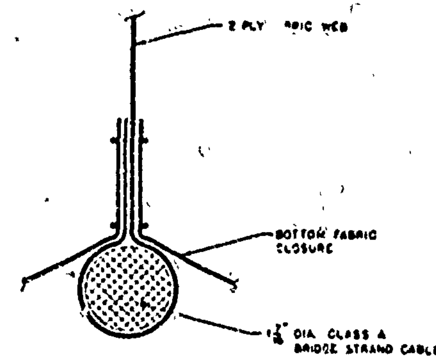
BUFFALO, NEW YORK 14225



DETAIL A



DETAIL B

See the following page for greater detail.

FIGURE 10

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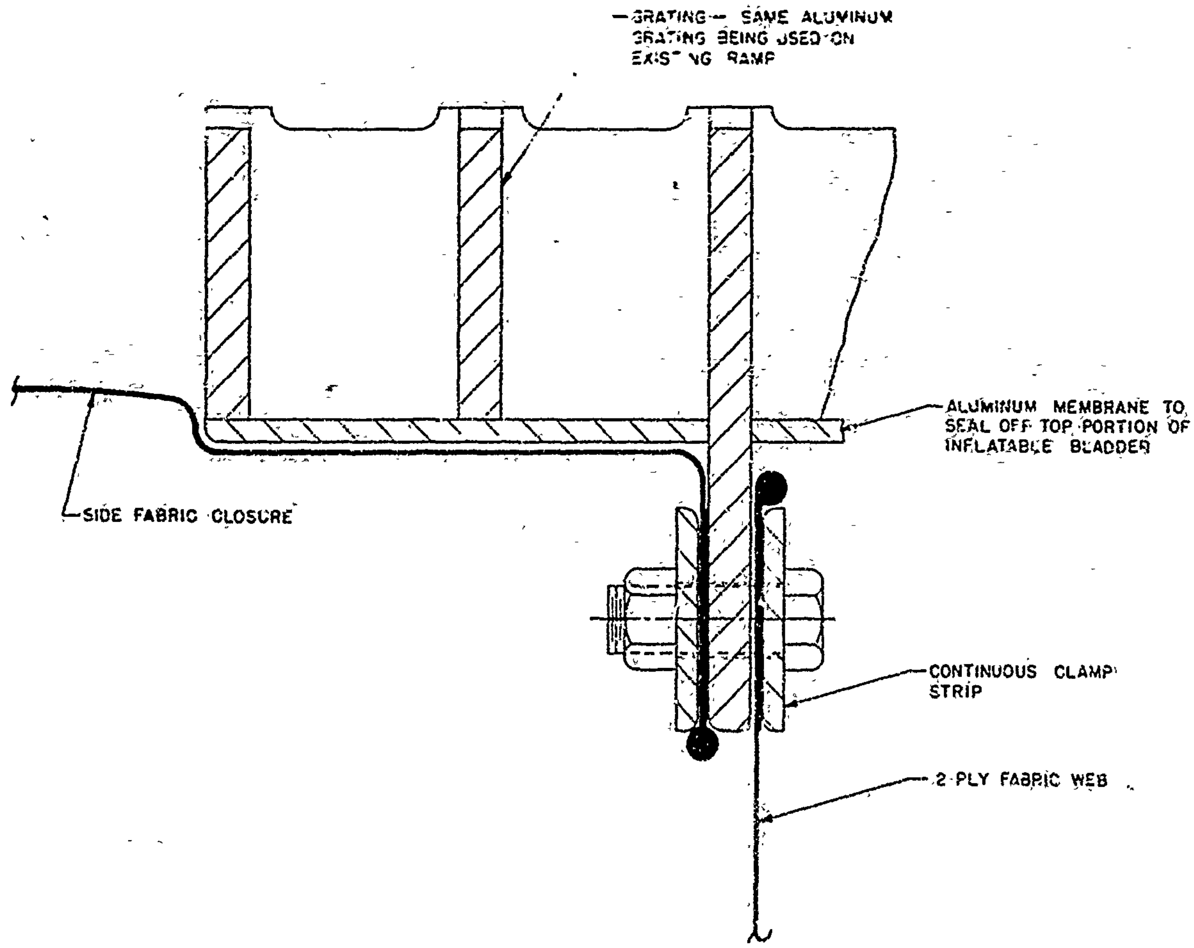
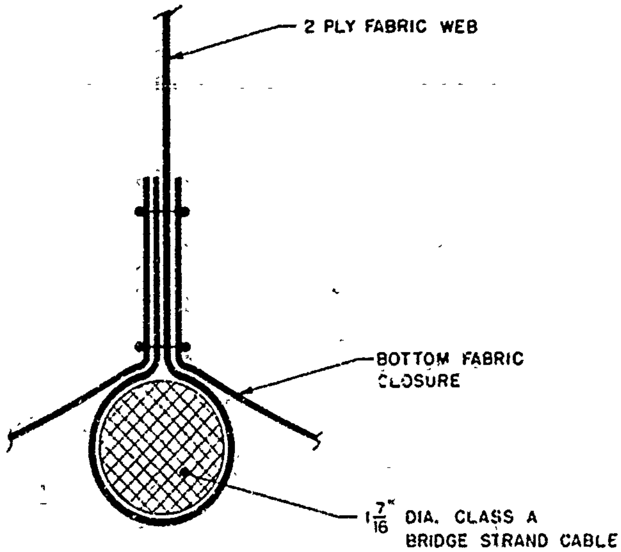

GRATING — SAME ALUMINUM GRATING BEING USED ON EXISTING RAMP
ALUMINUM MEMBRANE TO SEAL OFF TOP PORTION OF INFLATABLE BLADDER
SIDE FABRIC CLOSURE
CONTINUOUS CLAMP STRIP
2 PLY FABRIC WEB

DETAIL A



DETAIL B

FIGURE 10

BIRDAIR STRUCTURES, INC. BUFFALO, NEW YORK

(required to support tank loading) would be required to resist local buckling or severe deflection under the tracks. It should be noted this design pressure is a little conservative, since the area of contact was considered to be the width of the deck by the length of the track. Actually, the deck will distribute the load in the longitudinal direction something greater than the track length, as well as across the ramp.

The actual theory of how the stresses are distributed in the structure is outlined on Pages D 27 and D 28. Basically, because of the parabolic shape of the cable band, the inflation pressure creates a tensile load along the cables, which in turn transmit a compressive load to the deck. The stresses due to bending moment then are simply determined by computing the moment at any point as the load moves along the ramp and dividing by the depth of the section at that point. The summation of these stresses due to inflation pressure and bending moment then dictate the maximum compressive and tensile loads in the structure. Knowing the allowable compressive stress that the deck is capable of supporting, along with the inflation pressure of 3.6 psi, it was found that a minimum depth of 124 inches at mid-span is required. For a slight cushion, the design depth at mid-span was considered to be 130 inches.

Based on this depth (130 inches), and a span of 110 feet, a computer print out on Page D 31 shows the total compressive and tensile loads on the structure as a 60 ton tank moves along. A brief summary of stresses is shown on Page D 32 and, with 16 cables spaced at 12-inch centers, 1 7/16 inch diameter, Class A, Bridge Strand Stainless Steel

Cables are required. These cables in turn are attached to a bulkhead at each end of the ramp which transfers the load into the deck (see Figures 7 thru 10).

The fabric stresses in the outer skin of the inflatable bladder are simply a function of inflation pressure, and the theory of hoop tension applies. That is, the fabric stress is a function of inflation pressure and radius of curvature. On this basis then (reference Page D 37), it was found that the maximum fabric stress in the side and bottom closures is 235.7 pounds per inch and, with a factor of safety of three, the required fabric strength is 707 pounds per inch.

The analysis of the shear distribution along the ramp is similar to that in the dual-wall beam. The webs transfer the shear force between the cables which are in tension, and the deck that is in compression. It is assumed that by using a two-ply bias web fabric, the stresses will be transferred along a 45° line. Using this concept, and assuming that the minimum depth of section that is required to transmit the full shear load is 52 inches deep (see Page D 38), it was found that the actual stress in the straight ply due to inflation pressure was 43.3 pounds per inch, and that the stress in the bias ply due to shear was 110.5 pounds per inch. Applying a factor of safety of three, the required strength in the straight ply is 130 pounds per inch and 332 pounds per inch in the bias ply.

Further discussion on fabric types most suitable to meet these requirements will be outlined later in this section.

Deflection under load is another important design considered, and again it is difficult to arrive at an exact theoretical solution (see Appendix F). Based on the assumption that the fabric portion of the ramp does very little to influence deflection, basic elastic beam theory was applied, and it was determined that approximately a 1 1/2 inch deflection could be expected under the 60 ton tank loading. Exactly how realistic these values are is difficult to assess at this time.

Because of areas of uncertainty in the design, specifically, the actual distribution of the shear forces and the deflection, a 1/10th scale model of the concept was constructed and tested. Design notes on scaling down the various parameters are shown in Appendix E.

An optimum load for the model will consist of a 1200-pound load distributed over an area 19 1/4 by 17 1/2 inches. The inflation pressure required to resist this load is 3.6 psi. These conditions then, would simulate the actual full size bow ramp under a 60-ton tank loading.

The test model, see photos 5 and 6, was constructed of two ply, light-weight fabric with sixteen 1/8 inch diameter coated cables, which were bonded to the webs (see detail B, Figure 10). These cables were in turn attached behind the bulkhead to the deck. The deck in the model was constructed of 6061-T6 aluminum, 1/16" thick, which again simulated the allowable compressive stress of the full scale deck. The deck in the model did not have the transverse rigidity that the bars create in the actual full size decking, however; therefore, a frame was constructed to distribute the load across the width of the ramp when under test.

PHOTO 5

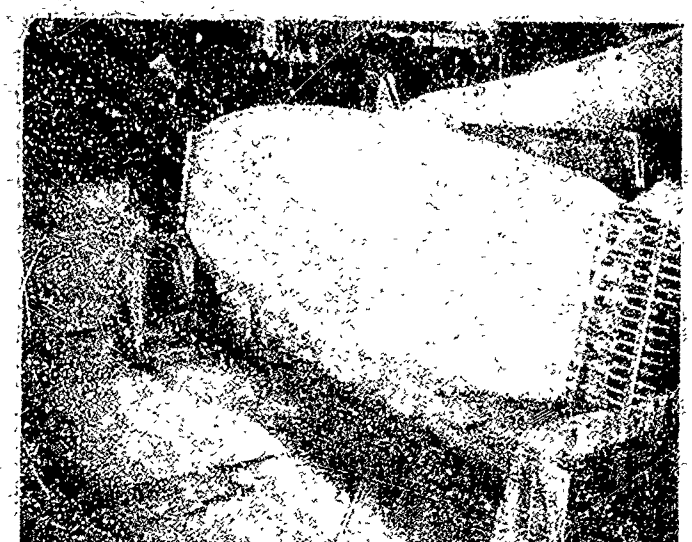
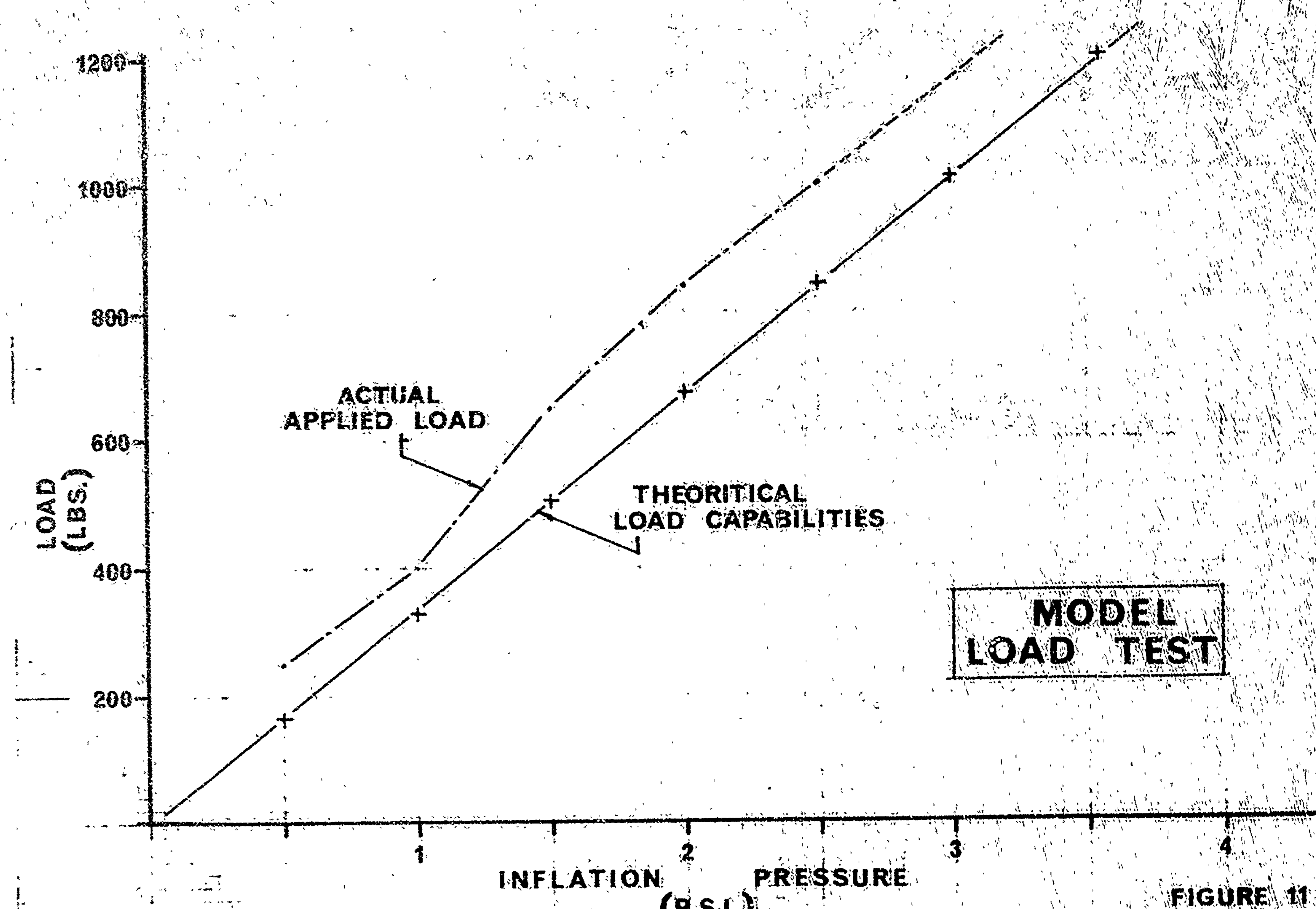


PHOTO 6



1200
1000
800
600
400
200
LOAD
(LBS.)
ACTUAL
APPLIED LOAD
THEORITICAL
LOAD CAPABILITIES
MODEL
LOAD TEST
1
2
3
4
INFLATION PRESSURE
(P.S.I.)

FIGURE 11

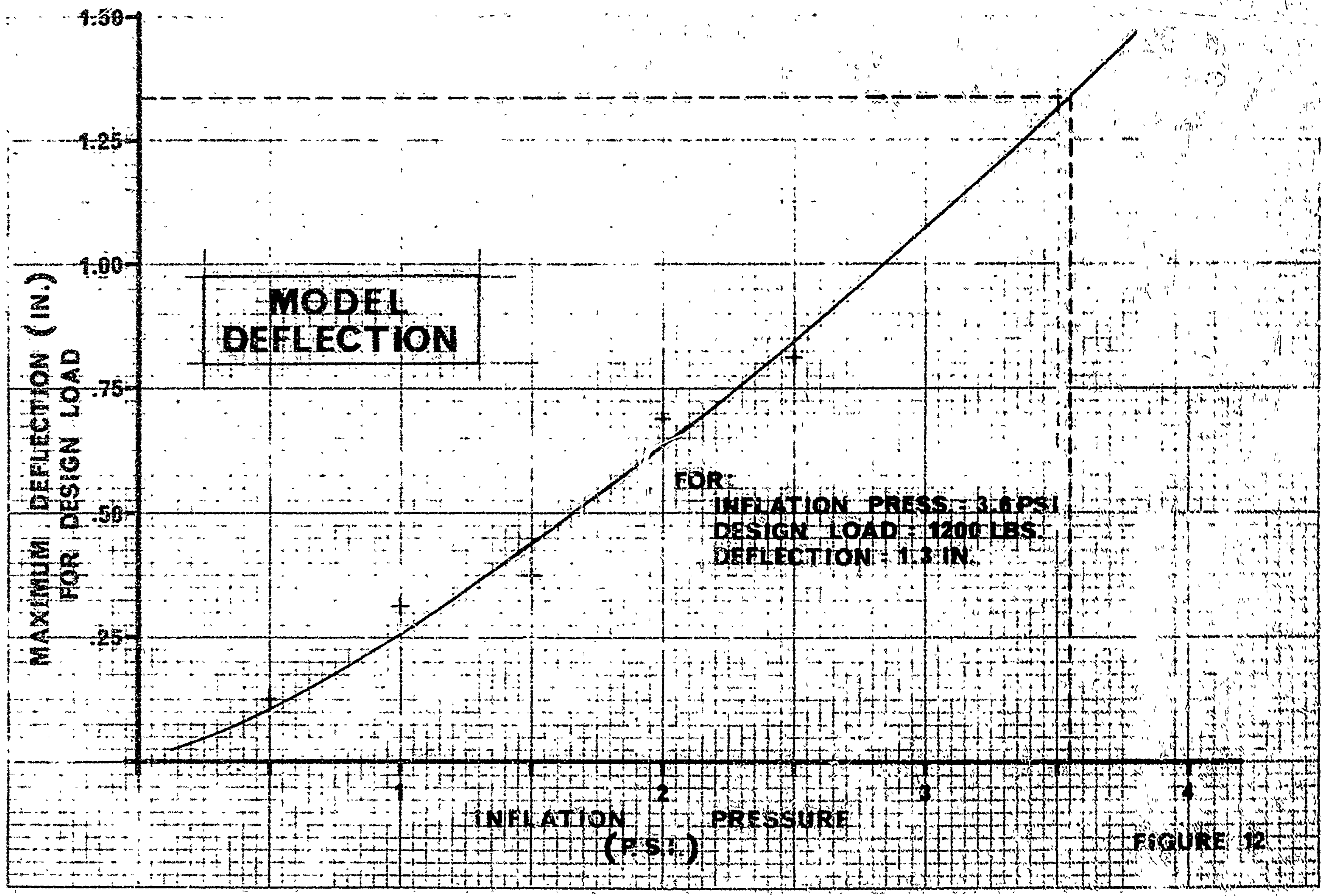

MODEL
DEFLECTION
MAXIMUM DEFLECTION (IN.)
FOR DESIGN LOAD
1.50
1.25
1.00
.75
.50
.25
FOR:
INFLATION PRESS.: 3.6 PSI
DESIGN LOAD: 1200 LBS.
DEFLECTION: 1.3 IN.
1
2
3
4
INFLATION PRESSURE
(P.S.I.)

FIGURE 12

Upon running the test and loading the model under different loads for increasing pressures, the following results were obtained. See Figures 11 and 12. In all cases investigated for varying inflation pressures, the model was able to support a load in excess of the theoretical design load. Since the model was only tested up to 2.5 psi, a projected curve indicates that under 3.6 psi the model will easily support the 1200-pound load (see Figure 11).

Deflection of the model under various loads and inflation pressures was also recorded. Figure 12 shows the maximum deflection of the bottom side of the model with the maximum design load at midspan. Again projecting this curve indicates that under an inflation pressure of 3.6 psi and the load of 1200 pounds, an anticipated deflection would be 1.3 inches. It was also observed that when the ramp was overloaded, local failure or buckling of the deck in the immediate area of the load was created. When the load was removed, the deck sprang back to its original position with no apparent damage to the structure.

Relating the information gathered from the scale model back to the full size inflatable ramp, it was concluded that the theory used to analyze the structure, as far as load-carrying capacity was concerned, is conservative and correct. The maximum deflection to be anticipated on the inflatable bow ramp when under the 60-ton tank loading, however, is approximately 13 inches. This does not agree with the elastic beam theory used earlier which indicated a 1 1/2 inch deflection. The difference here might be explained by the fact that elastic beam theory excludes shear deflection from its equations. Extensive discussion on bending or elastic deflection versus shear deflection is noted in Appendix F. In any event, the value of 13 inches falls between the value obtained from elastic theory and the value obtained by the shear deflection equations.

Since Concept No. 10, from a design point of view, appears to be feasible, some further discussion on fabric types and pressurization systems that meet the requirements is necessary.

Fabric Selection

The selection of a coated fabric composite is dependent on many criteria. The most important of these are breaking strength, tear resistance, air-holding, sea water resistance, and maximum retention of properties over extended periods of use and/or storage. The selection of Concept 10 makes the choice of a composite a bit easier, eliminating the new and exotic fibers required to fulfill the unusually high strength requirements of the other preliminary conceptual designs.

The ultimate coated fabric chosen is identified by Birdair's designation: 2N5H42 for the webs, and 2N14N58 for the side and bottom closures. The first digit indicates that the composite is made of two plies of coated fabric, in this case one is placed at a 45° bias to the straight ply (in the case of a single ply material the first digit is not used). The second digit indicates the base fabric used (e.g., N = nylon). The next digit(s) is the weight of the uncoated fabric in oz./sq. yd. The next digit is the coating (e.g., N = Neoprene; H = Hypalon; V = Vinyl). The next digit(s) is the total coated weight of the composite (in oz./sq. yd.).

The type of fiber selected is determined by the properties of the fabricated end item. Natural fibers (cotton, wool) are not considered because of their very low strength and poor wet properties. There are many synthetics to choose from: polyamide (commonly known as nylon) and polyester (typically, Dacron, Trevira, Diolen) being the strongest.

Their availability in continuous filament also is in their favor. Fiberglass, especially the more flexible beta-glass fiber, is also a possible choice. Nylon was chosen primarily because of its ready availability in the weight range desired, cost, and satisfactory past performance. Tables 1, 2, 3, and 4 at the end of this section describe the properties and construction of this 5 oz./sq. yd. and 14 oz./sq. yd. nylon fabric.

The neoprene coating selected was chosen from those most commonly used in coated fabric composites used in inflatables, specifically urethane (poly-), vinyl (polyvinyl chloride), Hypalon (chlorosulfinated polyethylene) and neoprene. Urethane coatings with the correct balance of properties are used in life rafts, vests, and emergency slides. They exhibit excellent air-holding properties, but are typically used in very thin film (approximately 0.001 in. thick) type coatings on fine lightweight fabrics. Actually, thicker films as dictated by the end use requirements and use on a heavier base fabric would (1) be excessive in cost and (2) tend to degrade because of their thicker cross-section.

Vinyls provide a good balance of properties with their ease of fabrication and low cost being the major considerations. These are the main reasons this material is used in thousands of commercial air-supported structures (swimming pool enclosures, tennis court covers, warehouses, fieldhouses, etc.). However, vinyl does not lend itself to two-plying, mentioned earlier and described more fully later on in this section, and its abrasion resistance, though good, is second to the elastomers mentioned in the next two paragraphs.

Hypalon (chlorosulfinated polyethylene) offers the best combination of properties for this application. Detrimental factors are: (1) high cost of coated fabric due to difficult coating process, (2) difficulty in fabrication, and (3) stiffness of end product.

As stated previously, neoprenes (2N5N42 and 2N14N58) are the current choices. They lie somewhere between vinyl and Hypalon in all properties and yet offer outstanding performance through a wide temperature range. They allow two-plying and though seaming is not easy, by the same token it is not excessively difficult, producing breaking strengths equivalent across a seam at a minimum equal to the strength of the base fabric itself.

Two-plying has been mentioned several times. Essentially, this involves bonding of layers of fabric together. Sometimes, as in the case of two straight plies, this is done to increase the tensile strength of the composite twofold over a single ply of fabric. For this project, one layer is laid and bonded at an angle of 45° to another straight ply. While increasing the strength slightly, it offers the optimum of resistance to tear propagation in the event the unit is punctured. This is due to the bias ply stretching around the puncture and allowing the stresses to distribute themselves around the hole. Typically, tear resistance as tested by the trapezoidal tear test method are in excess of 300 lbs.

BIRDAIR STRUCTURES, INC
PRODUCT SPECIFICATION RECORD

SPEC. NO.	REV
115	A

TYPE							SHT 1 OF 1
PURCHASE SPECIFICATION							
SUBJECT: 5 oz./sq. yd. NYLON FABRIC							
BY	QC	ENG	MFG	OTHER	REV. DATE	REV. DATE	ISSUE DATE
JEB	DOL		ATB			5/29/60	9/22/64

BASE FABRIC

Style:	West Point Pepperell SN 520, or equivalent
Type:	Filament Nylon
Weight:	5 oz./sq. yd.
Thread Count:	22 x 22 1/2
Yarn Numbers:	840/1
Weave:	Plain
Grab tensile (nominal):	410 x 430
Gauge (approx.):	.013
Finish:	Scoured and heat set in tenter frame

TABLE I

bts

FORM 153

BIRDAIR STRUCTURES, INC
PRODUCT SPECIFICATION RECORD

SPEC. NO.	REV
2N5142	

TYPE							SHT 1 OF 1
PERFORMANCE SPECIFICATION							
SUBJECT: 2 PLY, 45° BIAS, NEOPRENE-COATED NYLON FABRIC							
BY	QC	ENG	MFG	OTHER	REV. DATE	REV. DATE	ISSUE DATE
JEJ	DGL	HBP JG	ATB				9/23/69

COATED FABRIC

The fabric shall be coated to provide a black, non-staining, cementable, soft and pliable coated fabric base, coated for high adhesion. The two ply, 45° bias material shall be overlapped as required to develop full strength of the base fabric across the bias seam. Distance between bias lap centers must be held uniform within ±2 inches. No accumulation is allowed.

PROPERTIES		REQUIREMENT	TEST METHOD
Coated weight, oz./sq. yd.		42 +3 -0	Birdair LP-60 Fed. Std. 191, Mtd 5041
Coating Distribution, oz./sq. yd.		20-8-4	
Gauge (approx.), in.		0.034	
Coating Adhesion, lbs./in.		10 Min.	Birdair LP-62 Fed. Std. 191, Mtd 5970
Ply Adhesion, lbs./in.		10 Min.	Birdair LP-63 Fed. Std. 191, Mtd 5950
Strip Tensile, Warp & Fill, lbs./in.		300 Min.	Birdair LP-51 Fed. Std. 191, Mtd 5102
Elongation, 24 hrs., % @ 30 lbs./in. load	W	3.0 Max.	Birdair LP-59
	F	6.0 Max.	
Trapezoidal Tear, W & F, lbs.		200 Min.	Birdair LP-54 Fed. Std. 191, Mtd 5136
Dead Load, 1 in. wide, 1 1/2" lap joint			
150 lbs. W & F at R.T., hrs.		4 Minimum	Birdair LP-56
75 lbs. W & F at 160° F., hrs.		4 Minimum	Birdair LP-57
H_2O absorption, %		6 Max.	Birdair LP-66

OTHER REQUIREMENTS

Surface to be essentially dust free to facilitate cementability. If dust is used, it is to be a 25/75 mixture of talc and zinc stearate.

Staining is evaluated by painting with 0.003 in. of white Radalon paint. Painted surface is exposed for 48 hrs., 6 inches from No. RS-276W G.E. sunlamp. Color should not be darker than Fed. Std. No. 595, Color No. 37778.

This material is to be uniformly coated with flat and smooth surfaces, free from stains, bare spots, or other defects that would impair physical strength or weatherability.

bts

TABLE 2

FORM 153

BIRDAIR STRUCTURES, INC
PRODUCT SPECIFICATION RECORD

SPEC. NO.	REV
N14	

TYPE							SHT 1 OF 1
PURCHASE SPECIFICATION							
SUBJECT							
14 oz./sq. yd. NYLON FABRIC							
BY	QC	ENG	MFG	OTHER	REV. DATE	REV. DATE	ISSUE DATE
JEB	DOL		ATB				10/1/71

BASE FABRIC

Style:	J. P. Stevens Style 38601, or equivalent
Type:	Filament Nylon
Weight:	14 oz./sq. yd.
Thread Count:	43 x 42
Yarn Numbers:	840/1
Weave:	Plain
Strip Tensile (nominal):	625 x 525
Gauge (approx.):	0.024
Finish:	Scoured and heat set in tenter frame.

TABLE 3

hts

BIRDAIR STRUCTURES, INC
PRODUCT SPECIFICATION RECORD

SPEC. NO.	REV
2N14N58	

TYPE							SHT 1 OF 1
PERFORMANCE SPECIFICATION							
SUBJECT: 2 PLY, NEOPRENE-COATED NYLON, 1 PLY, 45° BIAS							
BY	QC	ENG	MFG	OTHER	REV. DATE	REV. DATE	ISSUE DATE
JEB							10/1/71

2N14N58 is a composite material manufactured from two plies (1 ply 45° bias) of 14 oz./sq. yd. (approx.) woven nylon fabric coated with a black, non-staining, cementable, soft and pliable neoprene compound to a total weight of 58 oz./sq. yd. The neoprene coating is manufactured to provide good joint strength, flexibility, low R.F. loss, maximum retention of physical properties and good weatherability. The two ply, 45° bias material is overlapped as required to develop full strength of the base fabric across the bias seam. The Tedlar PVF film is used to prolong the useful life of the neoprene-coated fabric and to promote water runoff during rainfall.

PROPERTIES		REQUIREMENT	TEST METHOD
Gauge (approx.), in.		0.055	-----
Strip Tensile, lbs./in., Warp & Fill		800 min.	Birdair LP-51, 51A
Coating Adhesion, Dry & Wet, lbs./in.		15	Birdair LP-62 F.T.M.S. 191 Mtd. 5970
Ply Adhesion, lbs./in.		15 min.	Birdair LP-63 F.T.M.S. 191, Mtd. 5950
Elongation, 24 hrs., % (@ 50 lbs./in. load)	W F	5 max. 8 max.	Birdair LP-59
Trapezoidal Tear, W & F, lbs.		250 min.	Birdair LP-54 F.T.M.S. 191 Mtd. 5136
Water Absorption, %		1.5 max.	Birdair LP-66
Dead Load, 1 in. wide, 2 3/4 in. lap joint			
400 lbs. W & F at R.T., hrs.		4 minimum	Birdair LP-56
200 lbs. W & F at 160° F., hrs.		4 minimum	Birdair LP-57
Cold Flexibility (180° over 1/8" diameter rod at -40° F.)		No cracks evident under 5X magnification	Birdair LP-68

TABLE 4

bts

FORM 153

Inflation System

The inflation system for the ramp of Concept 10 will require a blower capable of producing a relatively large volume of air at the necessary pressure. Several fans can be immediately discarded as not suited. The propeller and axial type fans are incapable of the required pressures. Centrifugal fans of the **ventilation** type are also incapable of the pressure required.

The positive displacement class of air handling machines in general do not produce suitable volumes.

A blower suited to the inflation requirements is a centrifugal, multi-stage blower employing backward curved, forward curved wheels, or combinations of these wheels. The blower can be assembled with the proper selection of wheels to match the performance requirements quite closely.

The characteristics of performance with respect to overload tendencies, stability, etc. are determined by the necessary wheel combination. For purposes of this investigation, a Hoffman blower, Model 38404, has been selected. This unit requires 60 HP input at 3000 cfm.

As pointed out, the actual characteristics of the machine are dictated by the combination of forward and backward curved wheels required. The use of all backward curved wheels will result in self-limiting load characteristics. All forward curved wheels will not be load limiting. In each case the stability characteristics of pressure delivery at the low flow level must be determined after the unit is assembled.

Control of the inflation system is relatively simple, consisting of a motor starting device, pressure indicator, and any necessary duct restrictors, as determined by the blower characteristics. The blower will operate continuously for the time the ramp is in use.

It should be noted that the volume requirement can change rapidly as in the case of projectile puncture, and that greater volume from the main inflation system would be required to maintain operable pressures. Therefore, an equivalent secondary blower would be desirable for emergency standby service. The ship air system is not suitable as an inflation source because of the very limited volume available.

The manifold ducting for inflation purposes can also be used for deflation of the ramp. It is assumed at this time that a manual exchange of ducts would be made to interchange the intake and discharge connections to the inflatable.

Blower Size

The flow capacity necessary to satisfy the 10 minute requirement can be determined, assuming 65% of the inflation period will be used to fill the cell with air and the remaining 35% of the time is allowed for pressurizing the unit.

$$\frac{V}{T} = CFM$$

$$CFM = \frac{17954}{10\ (.65)}$$

$$CFM = 2762$$

Because of the possibility of overload characteristics, a restricting orfice will be assumed in the duct system. The diameter of the orifice is determined for the free flow condition, or when the entire blower pressure output is across the orifice. This condition exists during the filling period.

$$D_o = \sqrt{\frac{Q}{(5.976)\ (K)\ \sqrt{h/\rho}}}$$

$$= \sqrt{\frac{2762}{(5.976)\ (.6)\ \sqrt{\frac{3.6}{(.03613)\ (.075)}}}}$$

$= 4.59$, use $4.625''$

D_o = Orifice diameter

Q = Flow CFM

K = .6

h = pressure " H_2O

ρ = density of air

A blower capable of 3.6 psig and 2800 cfm is shown on the following sheets (Figures 13 and 14).

The time required for inflation can be estimated using successive increments of pressure from 0 psig to full inflation of 3.6 psig. The example of calculating the required time for inflation is shown in Appendix G.

The time necessary to inflate the cell from flat to a fully pressurized condition can be estimated by obtaining the time required by the blower to supply the air necessary to fill and then pressurize the cell over a finite pressure increase. This time was found to be 9.2 min.

The total weight of air required to fill and pressurize the ramp is:

$$W = \frac{PV}{RT}$$

W = weight of air in pounds

P = absolute pressure psf

V = Volume of the inflatable

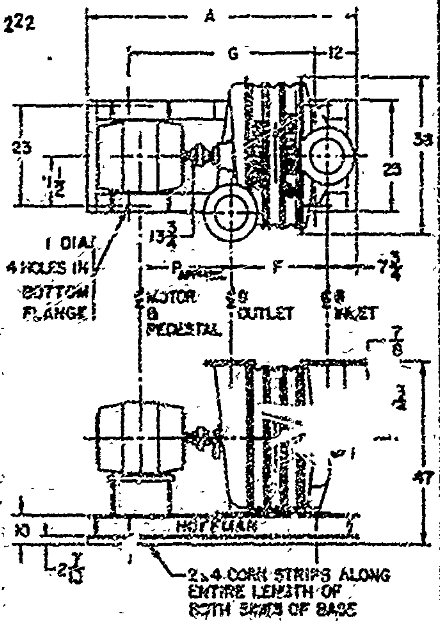
R = gas constant - air = 53.3

T = temperature °R

UNITS 38401-38407 38401A-38407A

GENERAL DIMENSIONS IN INCHES

UNIT SIZE	MOTOR FRAME	BASE	PEDESTAL	A	F	G	P
38401	213T	384076	384082	60	11 3/4	36	17 1/2
	215T	384076	384082	60	11 3/4	36	18 1/4
	254T	384078	384083	60	11 3/4	36	20 1/8
	256T	384078	384083	60	11 3/4	36	21 1/8
38402	215T	384076	384082	60	16 1/16	36	15 1/4
	254T	384076	384083	60	16 1/16	36	20 1/4
	256T	384078	384083	60	16 1/16	36	21 1/8
	284TS	384078	384084	60	16 1/16	36	20 5/8
	286TS	384078	384084	60	16 1/16	36	21 3/8
	324TS	384078	384085	64	16 1/16	38	22 1/8
	326TS	384077	384085	72	16 1/16	48	22 7/8
38403	254T	384077	384083	60	20 3/8	36	20 1/4
	256T	384077	384083	72	20 3/8	48	21 1/8
	284TS	384077	384084	72	20 3/8	48	20 5/8
	286TS	384077	384084	72	20 3/8	48	21 3/8
	324TS	384077	384085	72	20 3/8	48	22 1/8
	326TS	384077	384085	72	20 3/8	48	22 7/8
	364TS	384077	384086	72	20 3/8	48	23 1/8
	365TS	384077	384086	72	20 3/8	48	23 5/8
38404	256T	384077	384083	72	24 11/16	48	21 1/8
	284TS	384077	384084	72	24 11/16	48	20 5/8
	286TS	384077	384084	72	24 11/16	48	21 3/8
	324TS	384077	384085	72	24 11/16	48	22 1/8
	326TS	384077	384085	72	24 11/16	48	22 7/8
	364TS	384077	384086	72	24 11/16	48	23 1/8
	365TS	384078	384086	84	24 11/16	60	23 5/8
	404TS	384078	384087	84	24 11/16	60	24 7/8
	405TS	384078	384087	84	24 11/16	60	25 5/8
38405	284TS	384077	384084	72	29	48	20 5/8
	286TS	384077	384084	72	29	48	21 3/8
	324TS	384078	384085	84	29	60	22 1/8
	326TS	384078	384085	84	29	60	22 7/8
	364TS	384078	384086	84	29	60	23 1/8
	365TS	384078	384086	84	29	60	23 5/8
	404TS	384078	384087	84	29	60	24 7/8
	405TS	384078	384087	84	29	60	25 5/8
	444TS	384079	384088	96	29	72	27 3/8
38406	286TS	384078	384084	84	33 5/16	60	21 3/8
	324TS	384078	384085	84	33 5/16	60	22 1/8
	326TS	384078	384085	84	33 5/16	60	22 7/8
	364TS	384078	384086	84	33 5/16	60	23 1/8
	365TS	384078	384086	84	33 5/16	60	23 5/8
	404TS	384078	384087	84	33 5/16	60	24 7/8
	405TS	384079	384087	96	33 5/16	72	25 5/8
	444TS	384079	384088	96	33 5/16	72	27 3/8
	445TS	384079	384088	96	33 5/16	72	28 3/8
38407	286TS	384078	384084	84	37 5/8	60	21 3/8
	324TS	384078	384085	84	37 5/8	60	22 1/8
	326TS	384078	384085	84	37 5/8	60	22 7/8
	364TS	384079	384086	96	37 5/8	72	23 1/8
	365TS	384079	384086	96	37 5/8	72	23 5/8
	404TS	384079	384087	96	37 5/8	72	24 7/8
	405TS	384079	384087	96	37 5/8	72	25 5/8
	444TS	384079	384088	96	37 5/8	72	27 3/8
	445TS	384079	384088	96	37 5/8	72	28 3/8



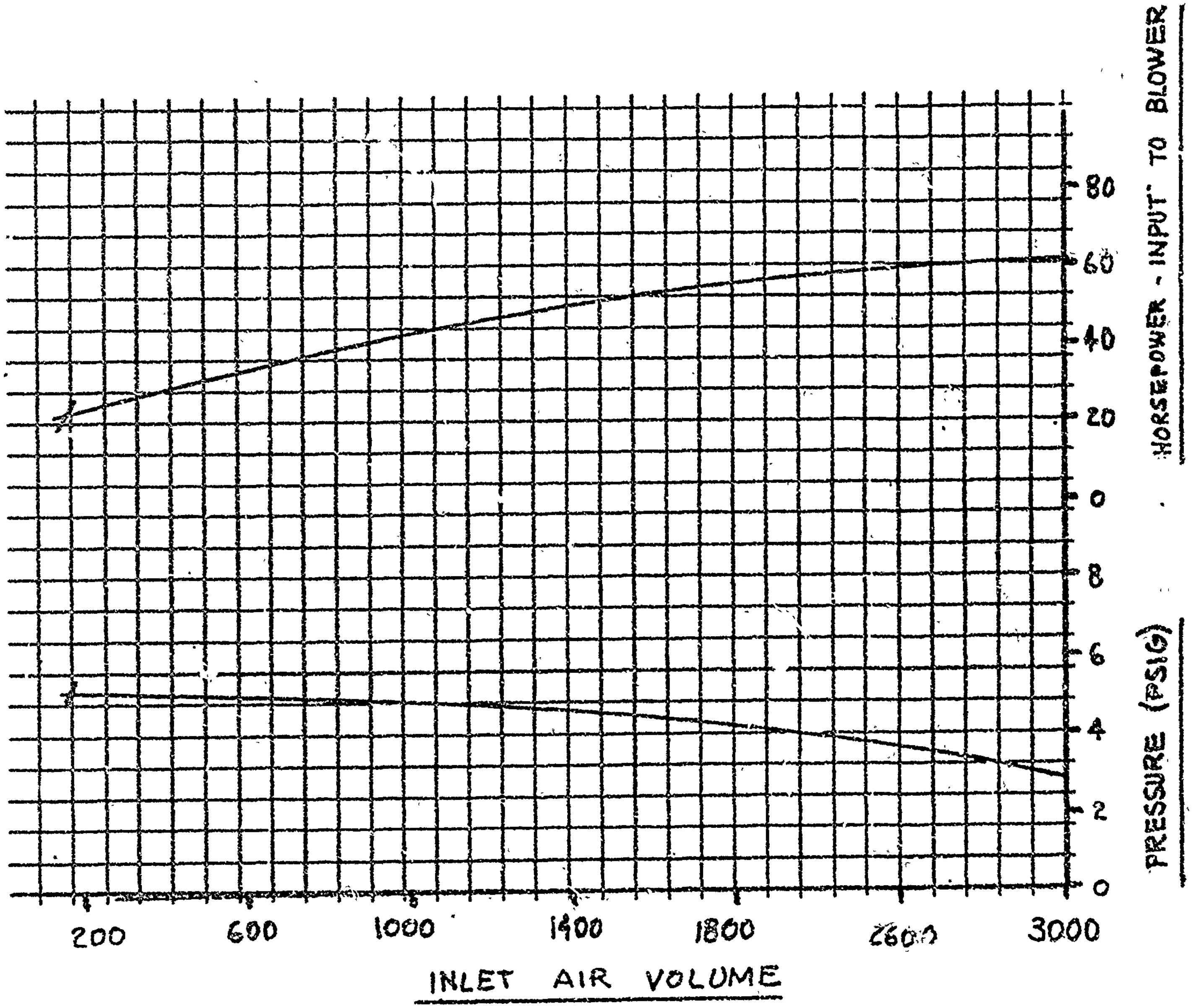
NOTES:

1. UNIT SHAFT SIZE 1 7/8 DIA. 3/8 X 3/16 KWY.
2. UNIT CONNECTIONS (INLET & OUTLET) 8 I.D., 13 1/2 O.D., 3/4 - 10 TAP 8 HOLES ON 11 - 3/4 B.C. STRADDLING ℄'S.
3. P DIMENSION BASED ON COUPLING WITH 1/8 GAP.
4. PEDESTAL IS WELDED TO BASE.
5. FOR MOTOR FRAME SIZES NOT LISTED CONSULT HOME OFFICE.

FIGURE 13

HOFFMAN AIR & FILTRATION DIV.
CLARKSON INDUSTRIES, INC., NEW YORK, NY

DR.	DATE	DRAWING NUMBER
J. J. H.	1-25-68	AX-1338



PERFORMANCE CURVES
CENTRIFUGAL BLOWER 38404A
FRAME 384A
SPEED 3550 RPM
ATMOSPHERE 14.7; 68°F

FIGURE 14

CONCLUDING REMARKS

To analyze the overall feasibility of Concept No. 10, the advantages and disadvantages of the concept are listed below with specific reference to the design parameters.

Advantages

1. Fabric strengths required can be handled with fabric types that are presently available and within the proper limits of workability and handling.
2. Pressurization requirements are well within the range of systems available to meet these requirements.
3. The cellular construction created by the webs enables the system to be compartmentized. That is, if damage occurs in one area, only that cell will be affected, and the remaining ones will remain inflated.
4. The deck material, while performing a structural function in the system, will also satisfy the rigid requirements for the effects of traction under track and wheel loading.
5. The maximum deflection under a 60-ton tank loading falls within allowable limits and will not increase the gradient significantly.
6. When the inflatable ramp is stowed on the main deck, it will occupy an area approximately 110 ft. long, 18 ft. wide, and 2 ft. high. It can be easily anchored for the effects of green seas.
7. The size of the inflation blowers required are rather small (84" L x 38" W x 47" H) and can be stowed in a compact location.
8. The system does not require intermediate support mechanisms, enabling the inflatable ramp to assume various angles of inclination.

9. Vehicle clearance at transition areas on each end of the ramp appears to be satisfactory.

10. The total weight of the inflatable ramp is 20.7 short tons, compared to 36.6 short tons in the existing ramp, which is effecting 43% weight reduction in ramp structure.

Disadvantages

1. The method of operation required to deploy and retract the inflatable bow ramp is basically the same as the method used on the existing bow ramp. The main cells of the ramp must, however, be inflated and deflated when resting on the deck level of the ship. Handling prior to this operation will severely damage the structure because of its lack of stiffness. The side closure panels must be inflated and deflated when in the extended position because of clearance problems when retracting the ramp between the derricks of the ship (see Figure 4). These requirements, however, pose no serious problems, other than a nuisance in the cycle of operation.

2. The sliding of the inflatable ramp along the ship's deck when being deployed or retracted could cause severe abrasion to the fabric belly. Possibly a sliding mechanism could be placed under the belly of the ramp when being winched along the ship's main deck.

3. The method of attaching the inflatable ramp to the ship would be similar to the method presently used. This idea is relatively simple and allows the ramp to accommodate the various rotational angles that are required.

4. The one design parameter that requires negative buoyancy of the extended end in 4 ft. of water with 5 ft. breaking waves and 30-knot winds acting on the structure is difficult to attain (negative buoyancy not required when using the causeway). Since the structure wants to float, it is necessary to actually anchor the end down when there is no load on the ramp. As the vehicles approach the extended end, they will in turn sink the ramp to the bottom.

It is our opinion then, after reviewing the advantages and disadvantages of Concept No. 10, that from a design point of view, the idea of creating an inflatable ramp which will span 110 feet and carry a 60-ton load is feasible. The method of attaching the inflatable ramp to the ship and operating the ramp does present some problems, however.

In complying with the contractual requirements, a preliminary cost and time schedule was developed for Concept No. 10. **See Tables 5 and 6 on the following pages.**

FORM NO. PC1

BIRDAIR STRUCTURES, INC.
COST/PRICE BREAKDOWN

CUSTOMER U.S. NAVY DATE 4/17/73 EST. BY AR

DESCRIPTION INFLATABLE BOW RAMP – DESIGN, DEVELOP AND MANUFACTURE (1) PROTOTYPE

RFQ. OR DWG. NO.

DIRECT ENG.	RATE	MH	COST	RATE	MH	COST	RATE	MH	COST
PRINCIPAL ENG.									
PROJECT ENG.	7.45	1700	12,665						
DRAFTING	5.05	1700	8,585						
QUAL. ASSURANCE	5.25	120	630						
SUB-TOTAL									
O.H. @ %									
DIRECT MFG.									
ENG. TECH.	4.55	100	455						
SHOP	3.90	6000	23,400						
LAB	4.15	200	830						
SUB-TOTAL			46,565						
O.H. @ 200 %			93,130						
MATERIALS & PURCH. PARTS			80,000						
OTHER DIRECT CHARGES COMM.									
IN-FRT .7% Material			560						
O.T. PREMIUM 4% D.L.			1,863						
RENTALS									
PER DIEM									
TRAVEL									
TOTAL COSTS			222,118						
Fee – 10%			22,212						
TOTAL PRICE			$244,330						TABLE 5

PRELIMINARY SCHEDULE

DESIGN & DEVELOPMENT OF PROTOTYPE BOW RAMP

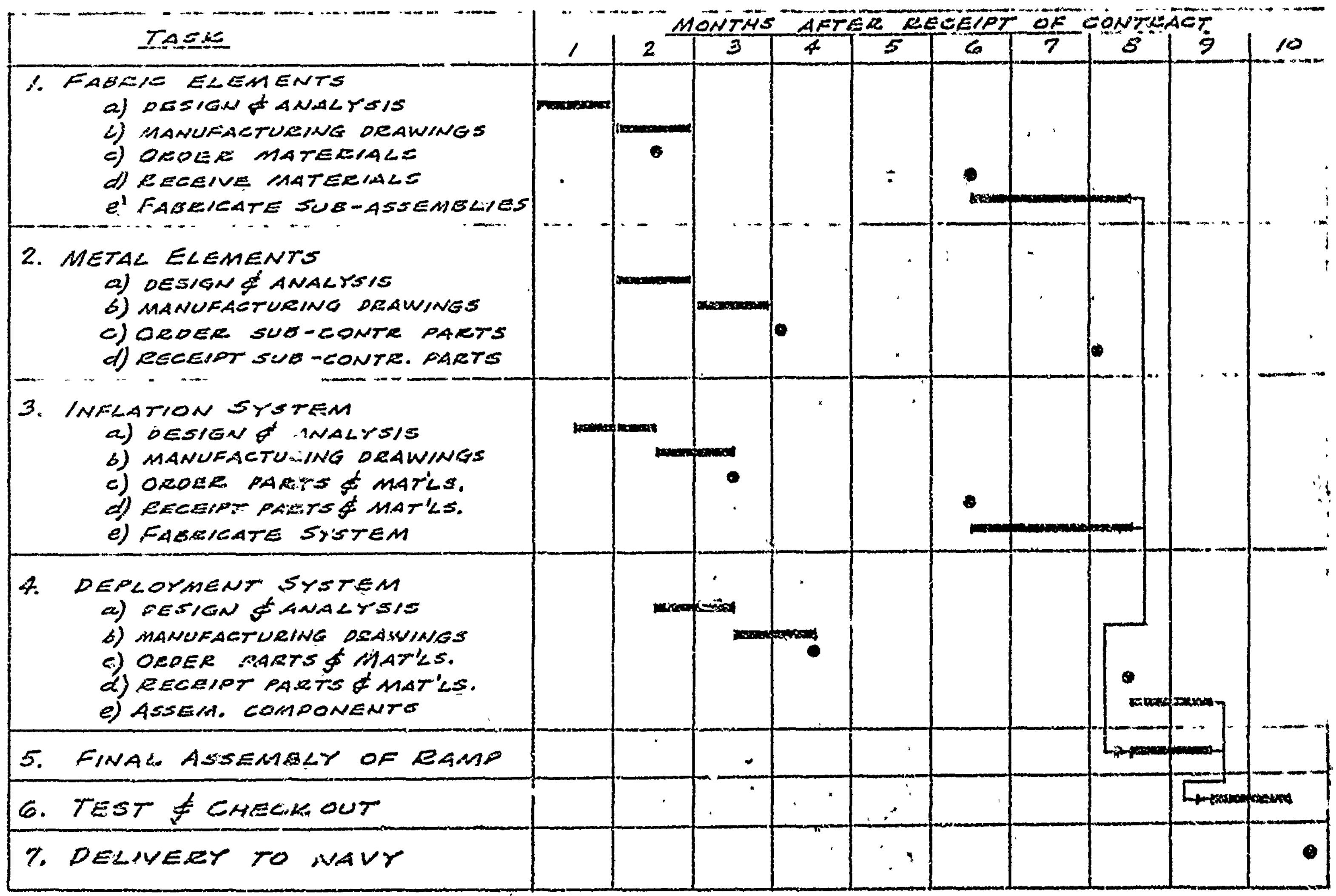


TABLE 6

GENERAL CONCLUSION

In complying with the design parameters that were outlined at the beginning of the report, ten conceptual configurations of an inflatable bow ramp were developed, with two of the concepts undergoing a refined and more detailed design analysis.

With reference to Figure 3, all of the concepts except Nos. 2 and 10 were dropped from further design analysis and considered infeasible for the reasons listed earlier in the report. Conc : Nos. 2 and 10 underwent a refined design analysis and their feasibility was evaluated by listing the advantages and disadvantages of each.

As noted on Page 25, after reviewing the advantages and disadvantages of Concept 2, it is our opinion that this concept (dual-wall beam with supports) is infeasible with respect to its present application. If, however, shorter spans with reduced loads were considered, this concept might prove to be very feasible.

Upon reviewing the advantages and disadvantages of Concept No. 10 (compression deck with inflatable bladder), it was concluded that the concept does have some possibilities. From a design point of view, the concept appears to be feasible insofar as developing an inflatable bow ramp system which will carry the 60-ton load over the 110 ft. span. It should also be noted that this concept allows a 43% savings in weight over the existing ramp. The feasibility of this concept was further strengthened by building and testing a 1/10th scale model which carried loads in excess of the design loads.

The method of attaching this concept to the ship and operating the inflatable ramp, although not infeasible, does present some problems. The methods recommended for attaching and operating the inflatable ramp are similar to that used on the existing bow ramp.

Therefore, it is our opinion that from an operational point of view, Concept No. 10 is impractical in that no improvements or advantages over and above the methods being used to deploy and retract the existing bow ramp are evident. Possibly, further study in this area will create new and easier operational techniques.

If, however, easier operational techniques were developed, it would be feasible to develop an inflatable bow ramp similar to Concept No. 10 which will support a 60-ton load moving over a 110 ft. span.

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44

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APPENDIX – A

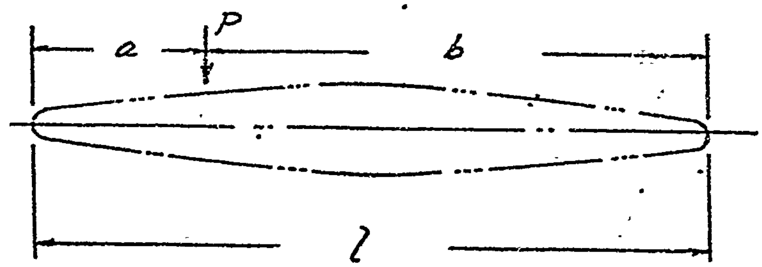
LOAD

AND

MOMENT

CALCULATIONS

INVESTIGATE BENDING MOMENT AS LOAD MOVES ACROSS THE RAMP.



$$\text{MOMENT (MAX)} = \frac{Pab}{l} = PK_1 l$$

(@ PT. OF LOAD)

a	b	l	$K_1 = ab$
.1	.9	1	.09
.2	.8	1	.16
.3	.7	1	.21
.4	.6	1	.24
.5	.5	1	.25

CONSIDER 60 TON TANK MOVING ALONG RAMP:
L = 110 FT. = 1320 IN. P = 120,000 LBS.

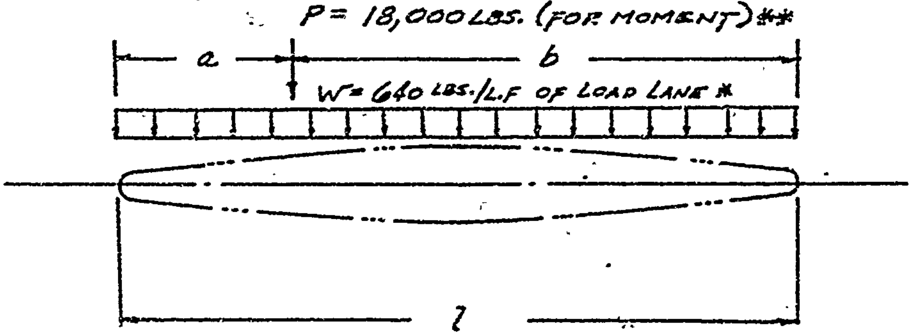
PT. ALONG RAMP

a	K_1	$M = PK_1 l$ (IN-LBS.)
11'	.09	14,256,000
22'	.16	25,344,000
33'	.21	33,264,000
44'	.24	38,016,000
55'	.25	39,600,000

SINCE MANY VEHICLES HAVE A WEIGHT OF AROUND 60,000 LBS., THE MOMENT IN BENDING PRODUCED BY THESE VEHICLES IS 1/2 OF THE MOMENT BASED ON THE 120,000 LB. LOAD.

INVESTIGATE A.A.S.H.O. H 20 LOADING FOR MAXIMUM BENDING MOMENT.

(LOAD INFORMATION REFERENCED FROM "STANDARD SPECIFICATIONS FOR HIGHWAY BRIDGES, AASHO - NINTH EDITION 1965, PAR. 1.2.5)



H20-44 } STD. LOADING
HS20-44 } DESIGNATION

* STANDARD LOAD LANE 10 FT. WIDE.
** 26,000 LB. CONCENTRATED LOAD FOR SHEAR.

MOMENT MAX. = M(UNIFORM) + M(MOVING CONCENTRATED)

$$M_{(MAX.)} = \frac{(W)(a)(b)}{2} + \frac{P(a)(b)}{l}$$

$W = 640$ LBS/L.F. = 53.33 #/L.I.

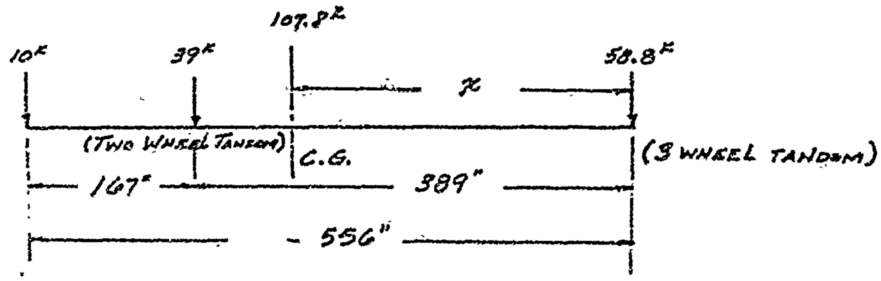
$$= \frac{W l^2}{2} K_1 + P K_1 l$$

a	K_1	$\frac{W K_1 l^2}{2}$	$P K_1 l$	M_{TOTAL} (IN-LBS.)
11'	.09	4,179,000	2,138,000	6,317,000
22'	.16	7,430,000	3,802,000	11,232,000
33'	.21	9,751,000	4,990,000	14,741,000
44'	.24	11,144,000	5,702,000	16,846,000
55'	.25	11,616,000	5,940,000	17,556,000

INVESTIGATE MAXIMUM BENDING MOMENT CREATED BY TRACTOR, LOW BOY, DOZER COMBINATION.

a) DISTRIBUTION OF LOADS:

	FRONT AXIL TRACTOR	REAR AXIAL TRACTOR	REAR AXIAL TRAILER
WT. OF TRACTOR	10^k	10.5^k	
WT. OF TRAILER		5.0^k	11.8^k
WT. OF DOZER (2/3 TO REAR AXIL)		23.5^k	47.0^k
TOTAL	10^k	39.0^k	58.8^k



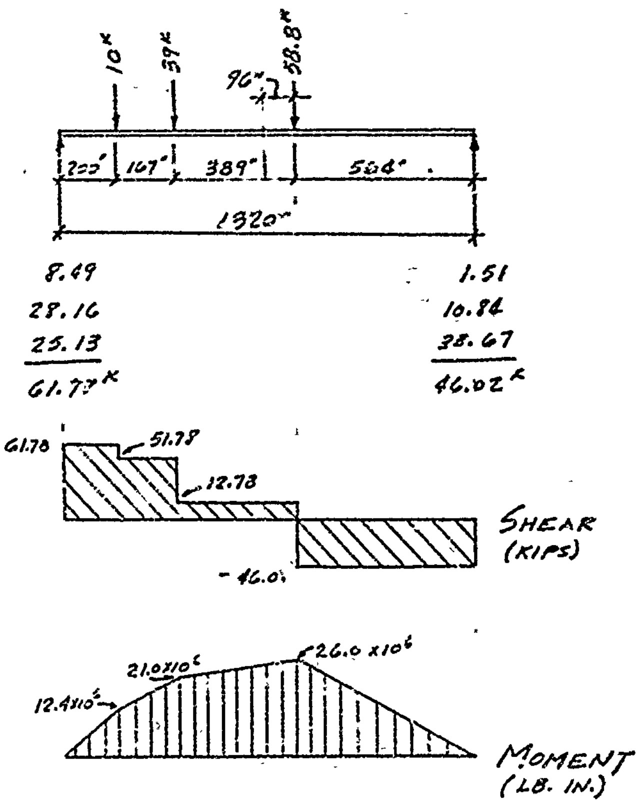
LOCATE CENTER OF GRAVITY OF LOADS:

FORCE (k)	LEVER ARM (")	MOMENT (k")
39	389	15,171
10	556	5,560
		20,731

$$x = \frac{20,731}{107.8^k} = 192.3''$$

FOR MAXIMUM BENDING MOMENT, THE CENTER LINE OF THE RAMP SHOULD BE MIDWAY BETWEEN THE CENTER OF GRAVITY AND THE NEAREST CONCENTRATED LOAD.

b) SHEAR & MOMENT DIAGRAM:



110' x 12 = 1320"

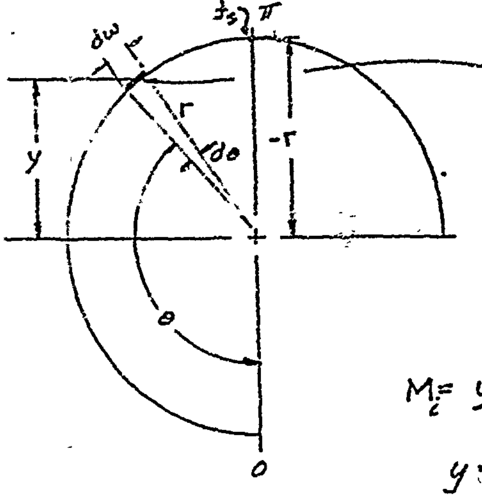
[NOTE: MAX. SHEAR OCCURES WITH LARGEST WHEEL LOAD AT SUPPORT]

* NOTE: IF LOAD IS CONSIDERED AS A CONCENTRATED FORCE AT MIDSPAN, MAX. BENDING MOMENT IS:

$$M = \frac{PL}{4} = \frac{(107.8^K)(110 FT.)}{4} = 2964 \text{ KIP-FT}$$

$$= 35.6 \times 10^6 \text{ LB.-IN.}$$

DERIVATION OF DUAL WALL EQUATIONS:



$f_s(y/r)$ (STRESS IS A FUNCTION OF THE DISTANCE FROM THE NEUTRAL AXIS.)

$$d\omega = r\,d\theta$$

$$M_i = y\,(y/r)\,f_s\,d\omega = (y^2/r)\,f_s\,r\,d\theta = y^2 f_s\,d\theta$$

$$y = r\cos\theta$$

WHERE:

f_s = FABRIC STRESS

M_i = INCRIMENTAL MOMENT

M_r = TOTAL RESISTIVE MOMENT

$$M_i = f_s r^2 \cos^2\theta\,d\theta$$

$$M_r = \int_0^{\pi} f_s r^2 \cos^2\theta\,d\theta$$

$$= r^2 f_s \int_0^{\pi} \cos^2\theta\,d\theta$$

$$= r^2 f_s \left[\tfrac{1}{2}\sin\theta\cos\theta + \tfrac{1}{2}\theta\right]_0^{\pi}$$

$$= r^2 f_s \left[\pi/2\right]$$

$$M_r = r^2 f_s \pi/2$$

OR

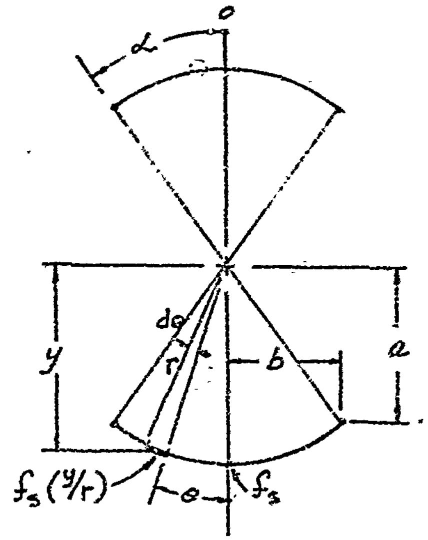
$$= (d/2)^2 f_s \pi/2$$

$$M_r = \frac{d^2 \pi f_s}{8}$$

FOR FULL CIRCLE (OR BOTH SIDES)

$$M_r = 2\left(\frac{d^2 \pi f_s}{8}\right)$$

$$M_r = \frac{d^2 \pi f_s}{4}$$



$$M_i = f_s(y/r)\,y\,(r\,d\theta)$$

$$= f_s y^2 d\theta$$

$$y = r\cos\theta$$

(FOR 1/4 CELL) $$M_i = f_s r^2 \cos^2\theta\, d\theta$$

(PER CELL) $$M_r = 4 f_s r^2 \int_0^{\alpha} \cos^2\theta\, d\theta$$

$$M_r = 4 f_s r^2 \left[\tfrac{1}{2}\sin\theta\cos\theta + \tfrac{1}{2}\theta \right]_0^{\alpha}$$

$$M_r = 2 f_s r^2 \left[\sin\theta\cos\theta + \theta \right]_0^{\alpha}$$

$$\alpha = \sin^{-1}(b/r) \quad \text{OR} \quad \alpha = \cos^{-1}(a/r)$$

$$M_r = 2 f_s r^2 \left[(b/r)(a/r) + \sin^{-1}(b/r) \right]$$

$$M_r = 2 f_s r^2 \left[ab/r^2 + \sin^{-1}(b/r) \right]$$

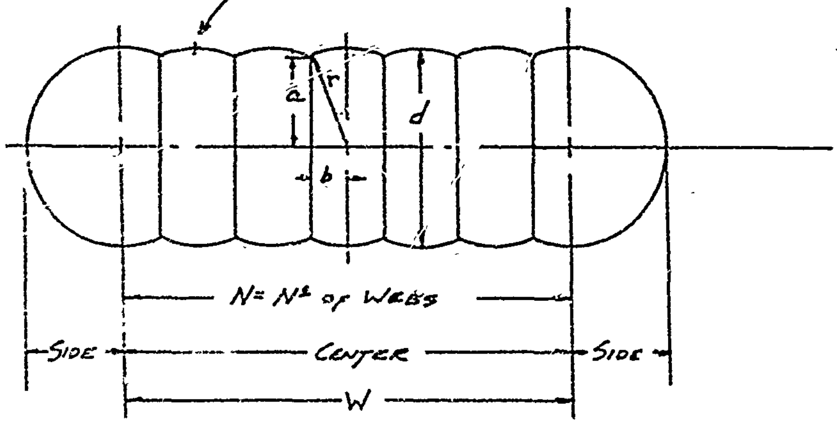
(PER CELL) $$M_r = 2 f_s \left[ab + r^2 \sin^{-1}(b/r) \right]$$

OR

$$f_s = \frac{M_r}{2\left[ab + r^2 \sin^{-1}(b/r) \right]}$$

TOTAL RESISTIVE BENDING MOMENT -

NO HORIZONTAL REACTION IN WEBS:
(∴ MAX. BENDING RESISTANCE AS ALL PRESSURIZATION PRETENSION IS CARRIED BY SKINS AT MAX. MOMENT DISTANCE FROM THE NEUTRAL AXIS)



$$\text{TOTAL } M_r = \underbrace{N\,2 f_s\left[ab + r^2 \sin^{-1}(b/r)\right]}_{\text{CENTER SECTION}} + \underbrace{\frac{\pi d^2 f_s}{4}}_{\text{SIDES}}$$

$$= \underbrace{N\,2b}_{\text{WIDTH OF CENTER}}\left[f_s a + f_s \, r^2/b \, \sin^{-1}(b/r)\right] + \frac{\pi d^2 f_s}{4}$$

$$M_r = W\left[f_s a + f_s (r^2/b) \sin^{-1}(b/r)\right] + \frac{\pi d^2}{4}(f_s)$$

OR

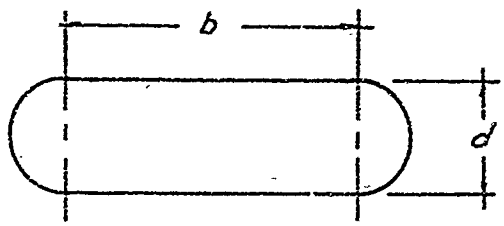
$$f_s = \frac{M_r}{W\left[a + (r^2/b)\sin^{-1}(b/r)\right] + \pi d^2/4}$$

COMPARISON TO FLAT PLATE THEORY USED BY THE MILITARY AND ENGINEERING ESTABLISHMENT OF CHRISTCHURCH, ENGLAND.

(REFER TO REF. No. 1)

BASIC FLAT PLATE THEORY

REF. No. 1 PG. 7



ASSUMPTION:
NEGLECT EFFECTS OF WEBS TO CARRY BENDING MOMENT.

MOMENT OF RESISTANCE TO BENDING IS MADE UP OF TWO COMPONENTS:

1) FLAT TOP AND BOTTOM PORTIONS OF SKIN

$$M_r = f_s \times b \times d$$

M_r = MOMENT OF RESISTANCE
f_s = STRESS IN SKIN PER UNIT WIDTH OF FABRIC (TENSION OR COMPRESSION)

2) SEMI-CIRCULAR EDGES OF SKIN

$$M_r = f_s \times \pi d^2/4$$

∴ TOTAL RESISTIVE MOMENT = $f_s(bd + \pi d^2/4)$

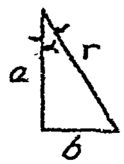
(FLAT PLATE THEORY)

BIRDAIR'S DUALWALL EQUATION:

$$M_r = W\left[f_s a + f_s (r^2/b) \sin^{-1}(b/r)\right] + \frac{\pi d^2}{4}(f_s)$$

(REFER TO PAGE B-3 FOR NOMENCLATURE)

COMPARISON OF DUAL WALL EQUATION TO FLAT PLATE THEORY



$$r^2 \underbrace{\sin^{-1}(b/r)}_{\alpha} = r^2\alpha$$

IN FLAT PLATE THEORY

$$r \rightarrow a$$
$$\alpha \rightarrow 0$$

AS $r \rightarrow a$

$$r^2\alpha = ar\alpha$$

AS $\alpha \rightarrow 0$

$$b = r\alpha$$
$$ar\alpha \rightarrow ab$$

$$M_r = W\left[f_s a + f_s (r^2/b) \sin^{-1}(b/r)\right] + \frac{\pi d^2}{4}(f_s)$$

SINCE $r^2 \sin^{-1}(b/r) \rightarrow ab$

$$M_r = W\left[f_s a + f_s\, ab/b\right] + \frac{\pi d^2}{4}(f_s)$$

SINCE W = WIDTH = b

$$M_r = b(f_s a + f_s a) + \frac{\pi d^2}{4}(f_s)$$

SINCE $a = d/2$

$$M_r = f_s(bd + \pi d^2/4)$$

AGREES WITH FLAT PLATE THEORY.

APPENDIX – C

PRELIMINARY

DESIGN

CALCULATIONS

CONCEPT № 1

AND

CONCEPT № 2

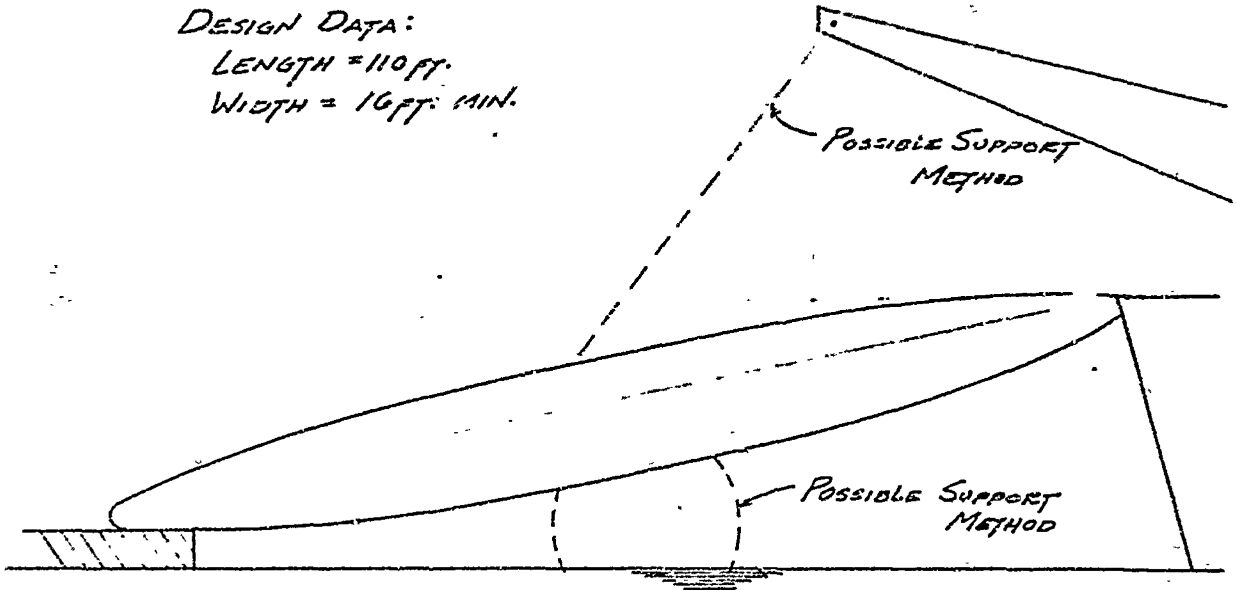
DUAL-WALL BEAM

WITH OR WITHOUT

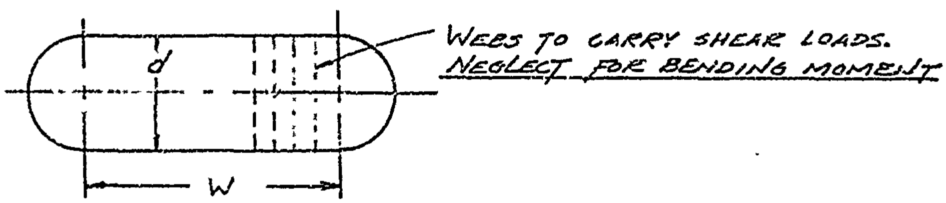
INTERMEDIATE SUPPORTS

DUAL-WALL BEAM CONCEPT:

DESIGN DATA:
LENGTH = 110 FT.
WIDTH = 16 FT. MIN.



ANALYZE FIRST AS A FLAT PLATE WITH NO SUPPORT MECHANISM



$F = p A$

$A = wd + \pi d^2/4$

C = CIRCUMFERENCE = $2w + \pi d$

S_l (INFLATION STRESS - LONGITUDINAL) = $\frac{F}{C}$

$$S_l = \frac{(wd + \pi d^2/4)p}{2w + \pi d}$$

S_t (INFLATION STRESS - TRANSVERSE) = $p\,d/2$

STRESS DUE TO BENDING MOMENT:

$$f_s = \frac{M}{A} = \frac{M}{wd + \pi d^2/4}$$

TO PREVENT WRINKLING $S_i = f_s$ (LONGITUDINAL)

$$\frac{(wd + \pi d^2/4)p}{2w + \pi d} = \frac{M}{wd + \pi d^2/4}$$

$W = 16\text{ FT} = 192\text{ IN.}$

$$\frac{(192d + \pi d^2/4)p}{384 + \pi d} = \frac{M}{192d + \pi d^2/4}$$

$$M = \frac{(192d + \pi d^2/4)^2 p}{384 + \pi d}$$ (FLAT PLATE APPROACH) (MOST EFFICIENT)

MAX. LONGITUDINAL FABRIC STRESS = $S_i + f_s$

SINCE $S_i = f_s$

MAX. LONGITUDINAL FABRIC STRESS = $2S_i$

BENDING MOMENTS:

SIMPLY SUPPORTED - 60 TON LOAD @ MIDSPAN:

$$M = \frac{Pl}{4} = \frac{(120{,}000\text{ LBS})(110\text{ FT})(12)}{4} = \underline{39{,}600{,}000\text{ LB.-IN.}}$$

SIMPLY SUPPORTED WITH SUPPORT @ CENTER - 60 TON LOAD @ QUARTER SPAN

$$M = \frac{13}{64}(P)(l/2) = \left(\frac{13}{64}\right)(120{,}000)(55)(12) = \underline{16{,}088{,}000\text{ IN-LBS.}}$$

```
X:SUJERSEARCH
01/10/  '73 10:18
!LOGIN: 1507BRD,C,
ID= F
!BASIC
>10 PRINT"M(IN-LBS)=";
>20 INPUT M
>30 FOR D=50 TO 300 STEP 50
>40 F=M/((192*D)+((3.14*D*D)/4))
>50 P=(F*(384+(3.14*D)))/((192*D)+(3.14*D*D/4))
>60 S1=P*(D/2)
>70 S=2*F
>80 PRINT D,F,S,S1,P
>90 NEXT D
>100 END
>RUN
10:22   01/10
M(IN-LBS)=  ?39600000
```

Depth (in.)	f_s Fabric Stress Bending Mom. (lbs./in.)	f_t Max. Fabric Stress (lbs./in)	S_Y Trans. Fabric Stress (lbs./in.)	P Inf. Press. (lbs./in²)
50	3424.86	6849.73	4006.17	160.247
100	1463.96	2927.91	1888.80	37.7760
150	852.300	1704.60	1176.30	15.6840
200	567.335	1134.67	822.555	8.22555
250	407.985	815.969	614.210	4.91368
300	308.772	617.544	478.867	3.19245

```
100 HALT
>RUN
10:23   01/10
M(IN-LBS)=  ?16088000
```

50	1391.39	2782.79	1627.56	65.1022
100	594.750	1189.50	767.349	15.3470
150	346.258	692.515	477.886	6.37181
200	230.487	460.974	334.173	3.34173
250	165.749	331.498	249.530	1.99614
300	125.442	250.885	194.546	1.29697

```
100 HALT
>SYS

!BYE
01/10/  '73 10:24
CLT 5
CCU 0.006
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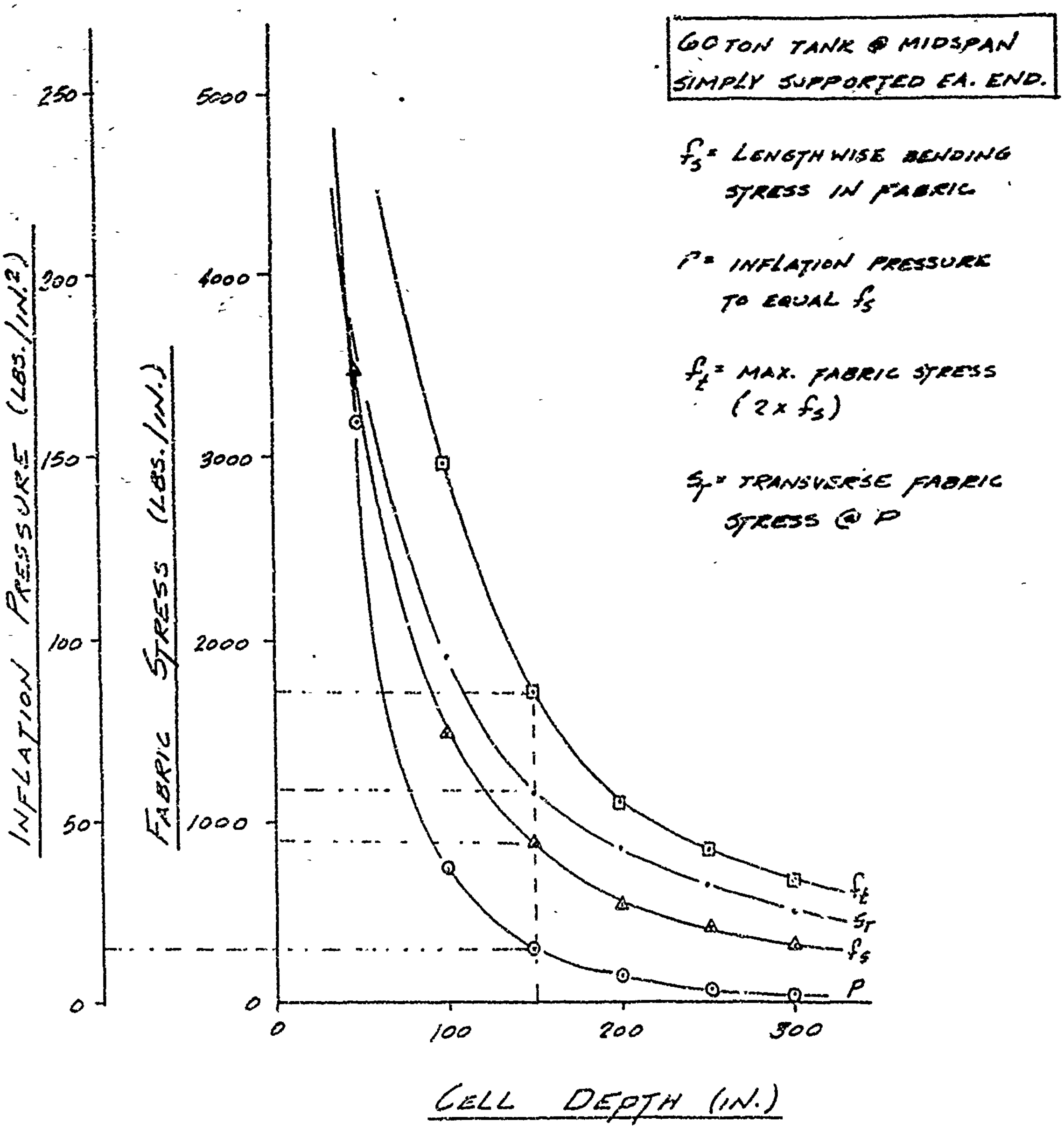
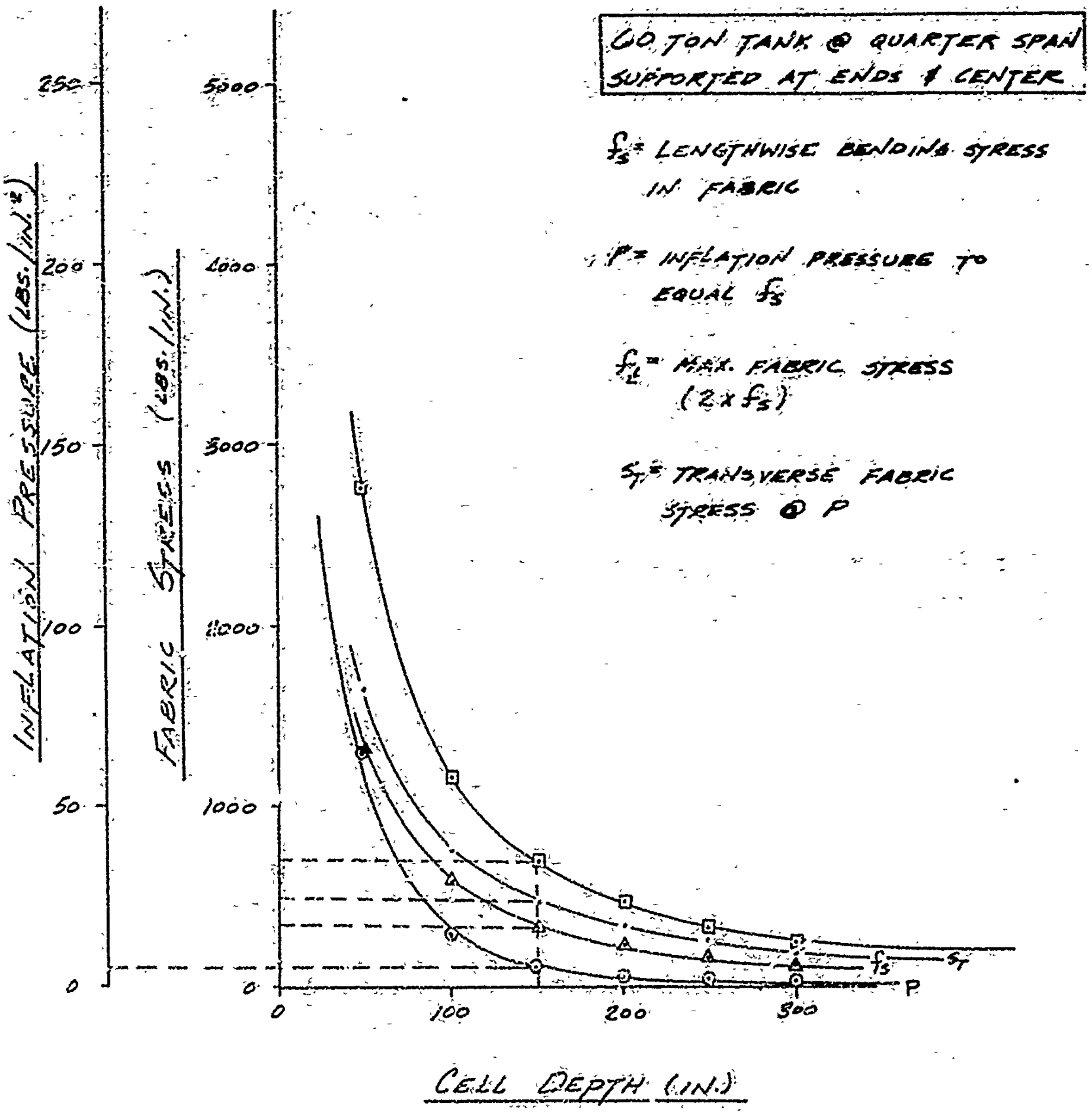


FOR D = 150 IN.

f_s = 852 LBS./IN.
P = 15.7 LBS./IN²
f_t = 1704 LBS./IN.
S_T = 1176 LBS/IN.



FOR D = 150 IN.

f_s = 346 LBS./IN.
P = 6.6 LBS./IN.^{2}
f_t = 692 LBS./IN.
S_T = 478 LBS./IN. C-5

```
COMPUTERSEARCH
01/10/  '73 13:20
!LOGIN: 15G7BRD,C,
ID= C
!BASIC
>10 PRINT"P(PSI)=";
>20 INPUT P
>30 FOR D=20 TO 300 STEP 20
>40 X=(192*D+.7854*D↑2)↑2
>50 Y=384+3.14159*D
>60 M=X*P/Y
>70 PRINT D,M
>80 NEXT D
>90 END
>RUN
```

13:24 01/10
P(PSI)= ?16 Moment (in.-lbs.)

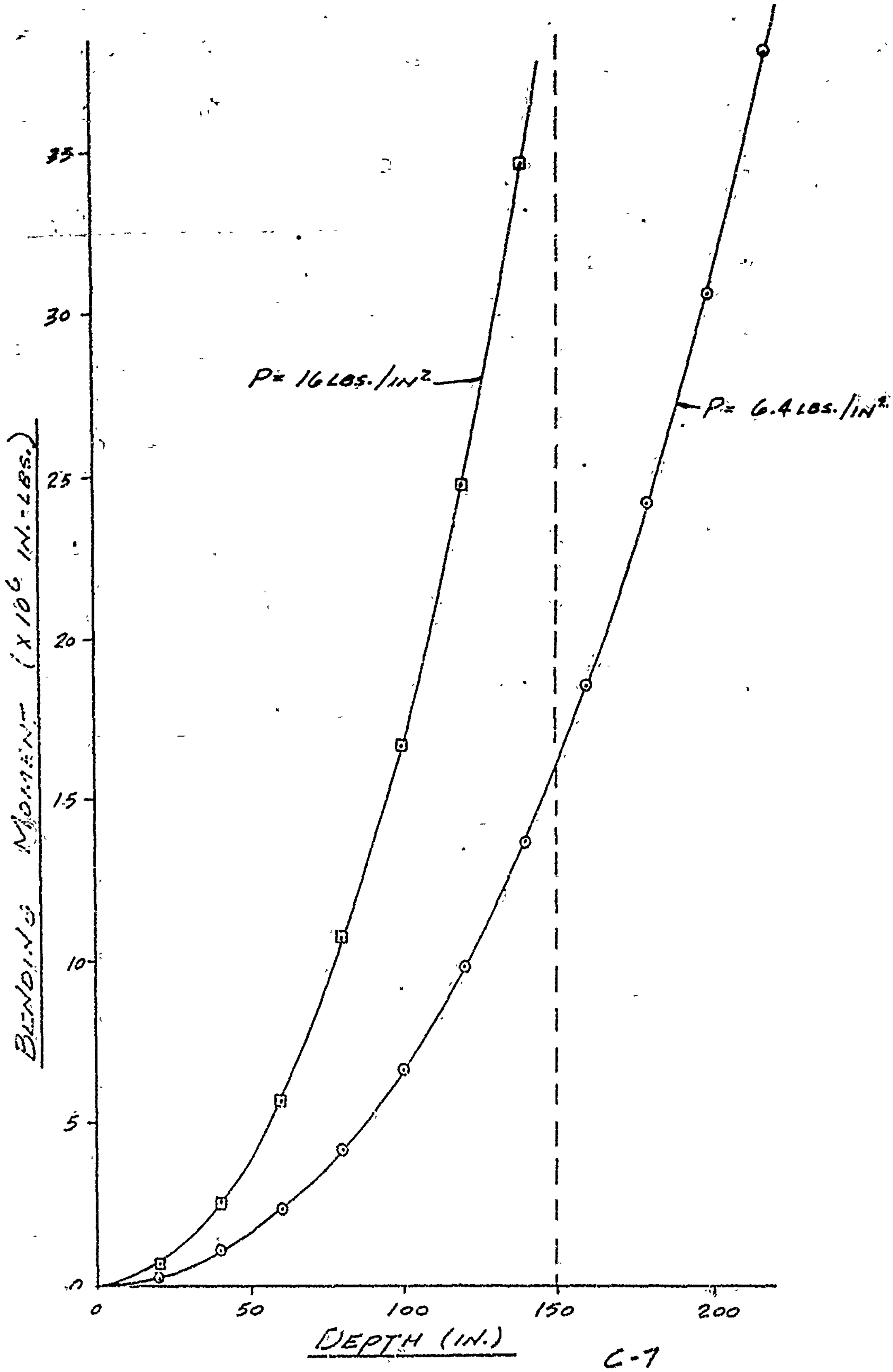
Depth (in.)	
20	617934.
40	2.50718E+06
60	5.75303E+06
80	1.04667E+07
100	1.67737E+07
120	2.48078E+07
140	3.47080E+07
160	4.64167E+07
180	6.06785E+07
200	7.70394E+07
220	9.58468E+07
240	1.17249E+08
260	1.41393E+08
280	1.68430E+08
300	1.98508E+08

90 HALT
>RUN
13:25 01/10
P(PSI)= ?6.4

20	247174.
40	1.00287E+06
60	2.30121E+06
80	4.18669E+06
100	6.70948E+06
120	9.92311E+06
140	1.38832E+07
160	1.86467E+07
180	2.42714E+07
200	3.08158E+07
220	3.83387E+07
240	4.68994E+07
260	5.65573E+07
280	6.73721E+07
300	7.94033E+07

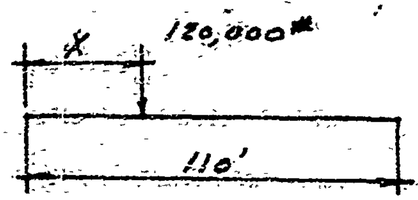
90 HALT
>SYS

!BYE
01/10/ '73 13:26
CIT 6


P= 16 LBS./IN²
P= 6.4 LBS./IN²
BENDING MOMENT (X 10⁶ IN.-LBS.)
DEPTH (IN.)
0
50
100
150
200
5
10
15
20
25
30
35

C-7

VNXXXXOC




```
UJERSEARCH
01/10/  '73 14:45
!LØGIN: 1507BRD,C,
 ?
!LØGIN: 1507BRD,C,
ID= D
!BASIC
>10 FØR X=0 TØ 720 STEP 120
>20 M=((120000*X)*(1320-X))/1320
>30 PRINT X,M
>40 NEXT X
>50 END
>RUN
14:47     01/10
```

$p = 16$ LBS./IN^2

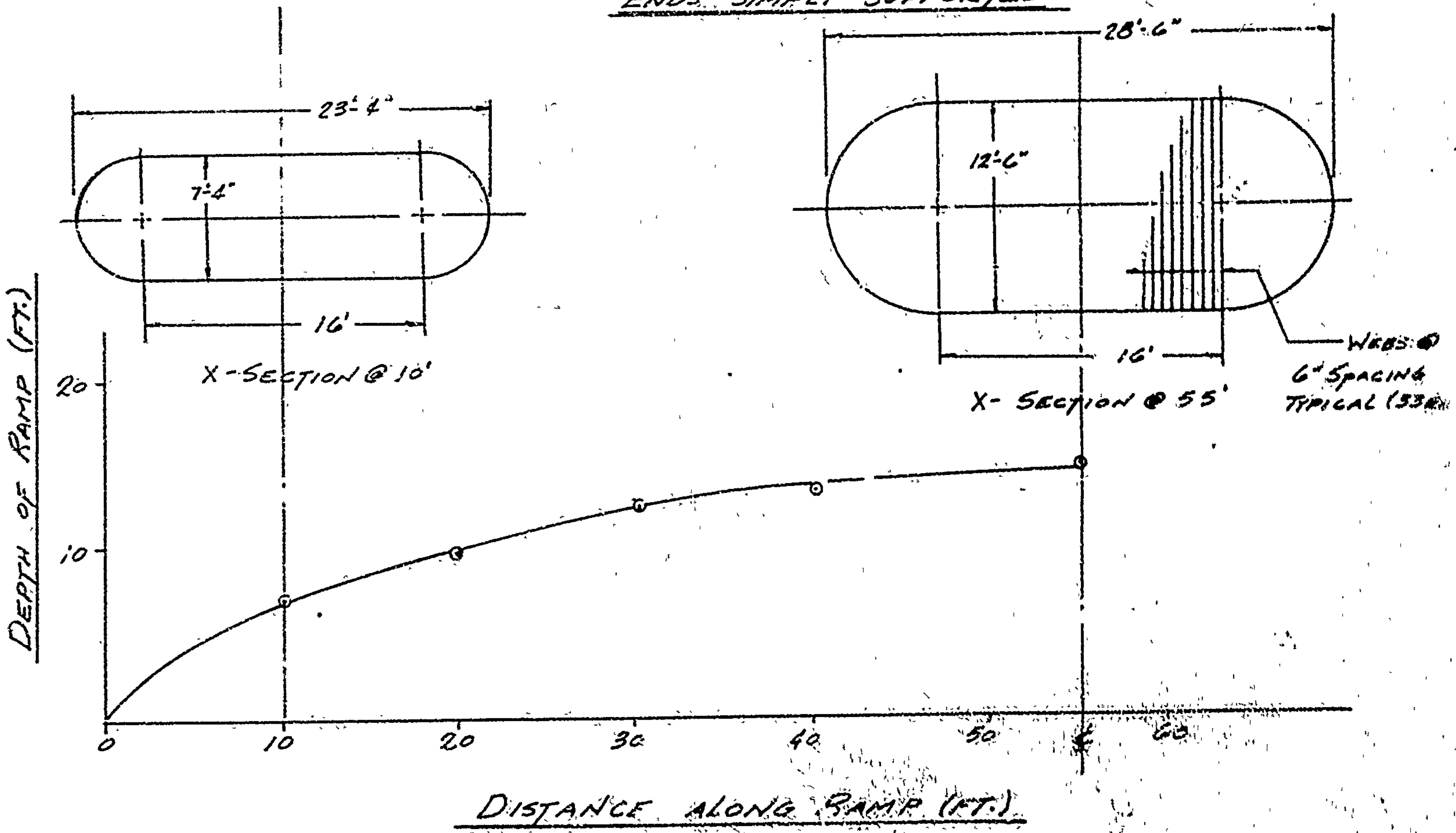
Distance along ramp	X	Moment (in-lbs.)	Depth (from graph)
	0	0	
10'	120	1.30909E+07	88" = 7.33'
20'	240	2.35636E+07	118" = 9.83'
30'	360	3.14182E+07	135" = 11.25
40'	480	3.66545E+07	142" = 11.83
50'	600	3.92727E+07	150" ≅ 12.50 } MAX.
60'	720	3.92727E+07	150" ≅ 12.50 } MAX.

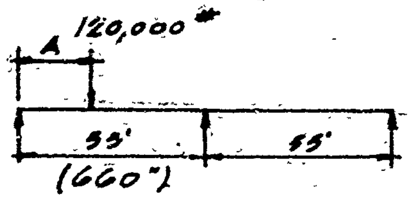
```
50 HALT
>SYS

!BYE
01/10/  '73 14:47
CLT 1
CCU 0.010
```

RAMP SIZE TO CARRY BENDING MOMENT

- INITIAL WRINKLE THEORY
- INFLATION PRESS. = 16 LBS./IN²
- MAX. LOAD = 60 TONS (CONCENTRATED ANY PLACE ALONG RAMP)
- ENDS SIMPLY SUPPORTED






```
COMPUTERSEARCH
01/11/  '73 08:41
!LOGIN: 1507BRD,C,
ID= B
!BASIC
>10 FOR A=0 TO 660 STEP 60
>20 X=(120000*A*(660-A))/(4*660↑3)
>30 Y=((4*660↑2)-(A*(660+A)))
>40 M=X*Y
>50 X1=(120000*A*(660-A))/(4*660↑2)
>60 Y1=660+A
>70 M1=X1*Y1
>80 PRINT A,M,M1
>90 NEXT A
>100 END
>RUN
08:44    01/11
```

p = 6.4 LBS./IN²

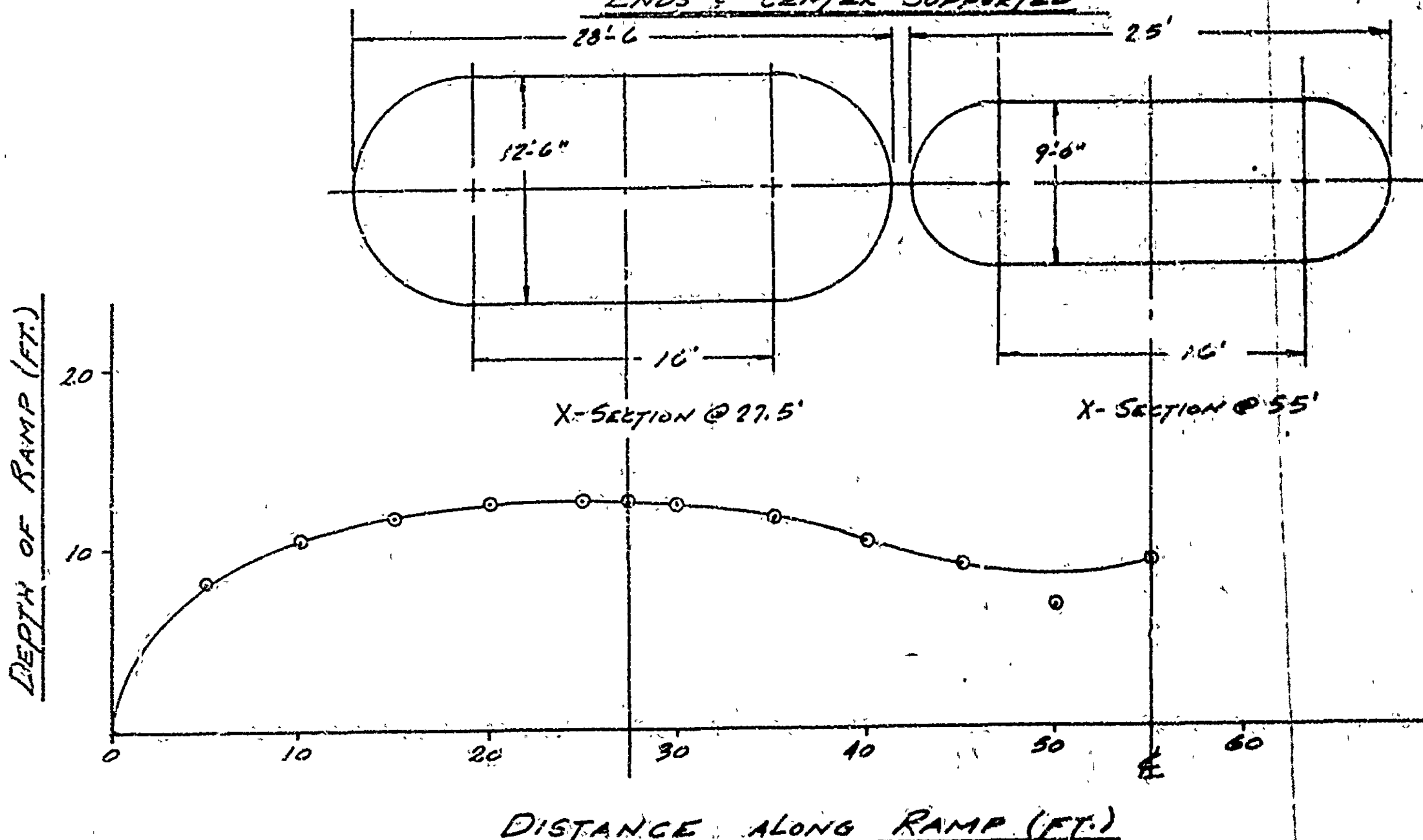
A	M @ LOAD (LB.-IN.)	M @ CNTR. (LB-IN.)	DEPTH REQD. AT POINT OF LOAD	MAX. DEPTH @ CNTR. FOR MAX. MOMENT @ CNTR.
0	0	0		
60 5'	6.38317E+06	1.78512E+06	97" = 8.08'	
120 10'	1.11489E+07	3.48099E+06	128" = 10.67'	
180 15'	1.43459E+07	4.99835E+06	142" = 11.83'	
240 20'	1.60553E+07	6.24793E+06	150" = 12.50'	
300 25'	1.63907E+07	7.14050E+06	150" = 12.50'	
360 30'	1.54981E+07 →	7.58678E+06	148" = 12.33'	107" = 8.92'
420 35'	1.35561E+07	7.49752E+06	138" = 11.50'	
480 40'	1.07757E+07	6.78347E+06	125" = 10.42'	
540 45'	7.40015E+06	5.35537E+06	105" = 8.75'	
600 50'	3.70548E+06	3.12397E+06	75" = 6.25'	
660 55'	0	0		

```
100 HALT
>SYS

!BYE
01/11/  '73 08:45
CLT 4
CCU 0.013
```

RAMP SIZE TO CARRY BENDING MOMENT

- INITIAL WRINKLE THEORY
- INFLATION PRESS. = 6.4 LBS./IN.²
- MAX. LOAD = 60 TONS (CONCENTRATED ANYPLACE ALONG RAMP)
- ENDS & CENTER SUPPORTED



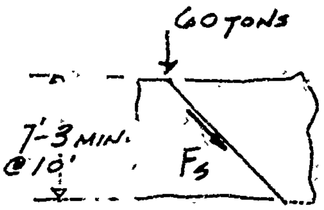
SHEAR STRESSES:

MAX. SHEAR OCCURS NEAR THE SUPPORT

MAX. VERTICAL SHEAR FORCE AT ULTIMATE CONDITIONS = 60 TONS

TENSILE LOAD AT 45°

$LOAD = \sqrt{2} \times 60\ TONS \times 2000\ LBS/TON = 169{,}705\ LBS. = F_S$



IF WEBS ARE SPACED AT 6"

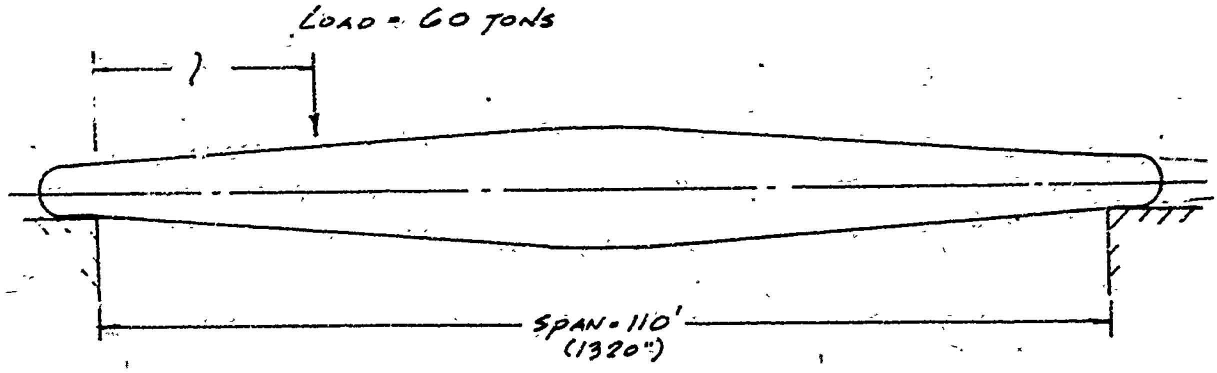
$N^{\underline{o}}\ OF\ SPACES = \frac{16 \times 12}{6} = 32$

$N^{\underline{o}}\ OF\ WEBS = 32 + 1 = 33\ WEBS$

$FORCE\ IN\ EA.\ WEB = 169{,}705/33 = 5143\ LBS.$

$STRESS\ PER\ WEB\ (ON\ BIAS) = \frac{5143\ LBS.}{(\sqrt{2})(87")} = 41.80\ LBS./IN.$

DEFLECTION FOR DUAL WALL BEAM-CONCEPT Nº 1



$$\delta = \frac{(P)(l)}{p A}$$

δ = DEFLECTION

WHERE:

P = SHEAR FORCE

A = CROSS-SECTIONAL AREA AT POINT OF LOAD

p = INFLATION PRESSURE

l = DISTANCE FROM LOAD TO SUPPORT

$$P \text{ (SHEAR FORCE)} = \frac{(\text{LOAD})(110 - l)}{110} = \frac{(\text{LOAD})(1320 - l)}{1320}$$

FOR MAX. BENDING MOMENT, INFLATION PRESS. REQD. IS 16 LBS./IN.^{2}

MAX. FABRIC STRESS (LONGITUDINAL) = 1704 LBS./IN.

FOR DEPTH OF SECTION, REFERENCE FIGURE Nº 1

$$A = (192")(D") + \pi D^2/4 \qquad D = \text{DEPTH OF SECTION}$$

$$\delta = \frac{(\text{LOAD})(1320 - l)(l)}{(1320)(p)[192D + \pi D^2/4]}$$

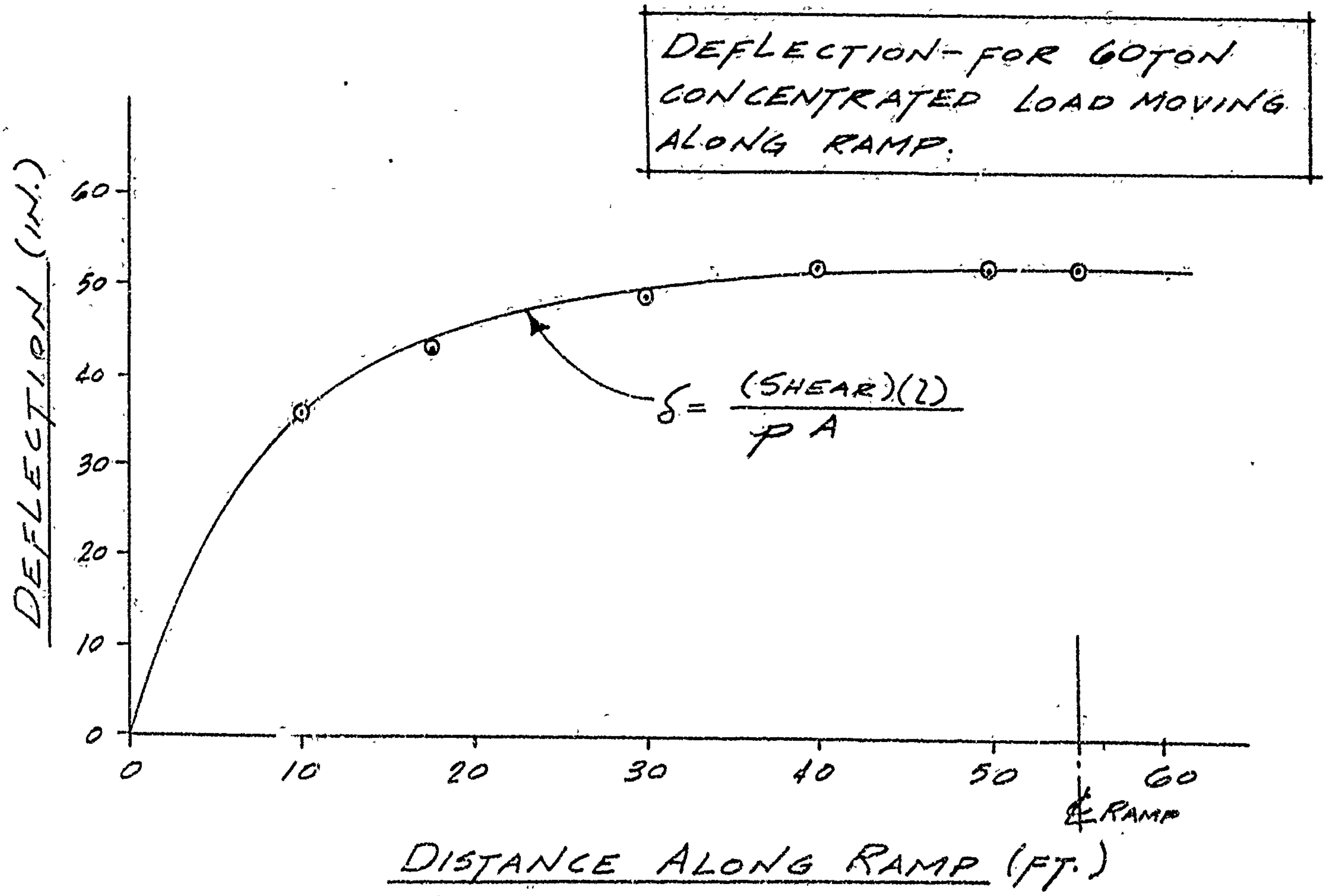
SUBSTITUTING FOR p = 16 LBS./IN^2

LOAD = 120,000 LBS

$$\delta = \frac{5.682\,l\,(1320 - l)}{192\,D + .785\,D^2}$$

FROM FIGURE No. 1

l (IN.)	D (IN.)	δ (IN.)
120	88	35.6
240	118	43.4
360	135	48.8
480	143	52.7
600	150	52.8
660	150	53.3



CONCEPT Nº. 1

OVERALL DIMENSIONS: 28'-6" WIDE × 12'-6" DEEP
FABRIC STRESS: 1704 LBS./IN.
INFLATION PRESS: 16 LBS./IN.^{2}

VOL. = (16)(12.5) + (π)(12.5)^2/4 = 323
(16)(7.25) + (π)(7.25)^2/4 = 157
480 ÷ 2 = 240 × 110 = 26,400 C.F.

SURFACE AREA: (32) + (π)(12.5) = 71.3
(32) + (π)(7.25) = 54.8
126.1 ÷ 2 = 63 × 110 = 6930 S.F.

CONCEPT Nº 2

OVERALL DIMENSIONS: 28'-6" WIDE × 12'-6 DEEP
FABRIC STRESS: 692 LBS./IN.
INFLATION PRESS: 6.4 LBS./IN.^{2}

VOL. = (16)(12.5) + (π)(12.5)^2/4 = 323
(16)(9) + (π)(9)^2/4 = 207
530 ÷ 2 = 265 × 110 = 29,150 C.F.

SURFACE AREA: 32 + (π)(12.5) = 71.3
32 + (π)(9) = 60.3
131.6 ÷ 2 = 65.8 × 110 = 7238 S.F.

CONCEPT Nº 3

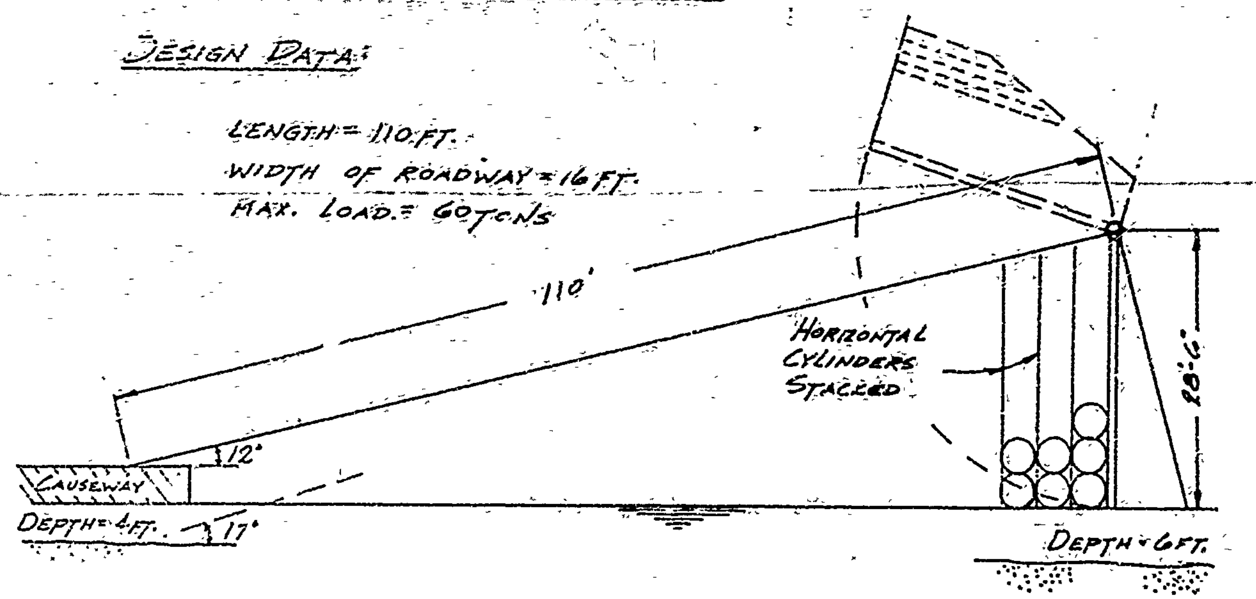
DUAL-WALL WEDGE

C-15a

DUAL WALL WEDGE CONCEPT:

DESIGN DATA:

LENGTH = 110 FT.
WIDTH OF ROADWAY = 16 FT.
MAX. LOAD = 60 TONS



DESIGN ASSUMPTIONS:

1) AVERAGE WATER DEPTH = 5 FT.
2) INFLATION PRESSURE REQD. TO RESIST LOCAL BENDING ONLY, CREATED BY TIRE OR TRACK FOOTPRINT LOADS.

CRITICAL LOADINGS:

60 TON TANK - 13 LBS./IN² = 346 LBS./IN. (PER TRACK LENGTH)
50,000 LB. TRUCK CRANE - 60-70 LBS./IN² (TIRE PRESSURE)
SCRAPER (MODEL 627 CAT) - 45-50 LBS./IN² (TIRE PRESSURE)

WHEEL LOADING CRITICAL - ASSUME 60 LBS./IN² REQD. FOR LITTLE OR NO LOCAL DEFLECTION.

VOLUMN OF WEDGE: (APPROX.)

$\frac{1}{2}(110)(30)(20) = 33{,}000\ FT^3$

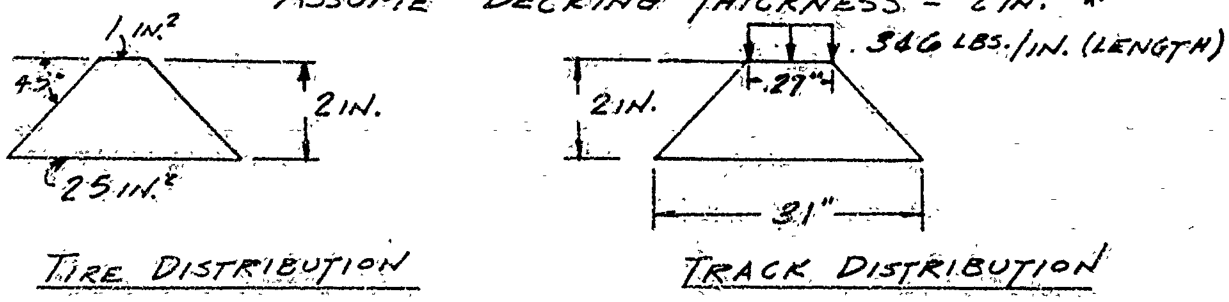
MAXIMUM FABRIC STRESS IN A CYLINDER DUE TO INFLATION LOAD IS:

$S = pr$ p = INFLATION PRESSURE
r = RADIUS OF CYLINDER

SINCE INFLATION PRESSURE (60 LBS./IN²) IS RELATIVELY HIGH, VERY SMALL DIAMETER CYLINDERS WILL BE REQUIRED IN ORDER TO KEEP THE FABRIC STRESS WITHIN LIMITS.

DECREASE INFLATION PRESSURE BY DISTRIBUTING WHEEL LOADS THROUGH A DECKING OR ROADWAY SURFACE.

ASSUME DECKING THICKNESS = 2 IN. *



$$\text{TIRE PRESSURE} = 60 \text{ LBS./UNIT IN}^2 \div 25 \text{ IN}^2 = 2.4 \text{ LBS./IN}^2$$

$$\text{TRACK PRESSURE} = \frac{(346 \text{ LBS/IN})(.27 \text{ IN.})}{31 \text{ IN.}} = 301.4 \text{ LBS./IN}$$

$$= \frac{301.4 \text{ LBS./IN.}}{31 \text{ IN.}} = 9.7 \text{ LBS./IN}^2$$

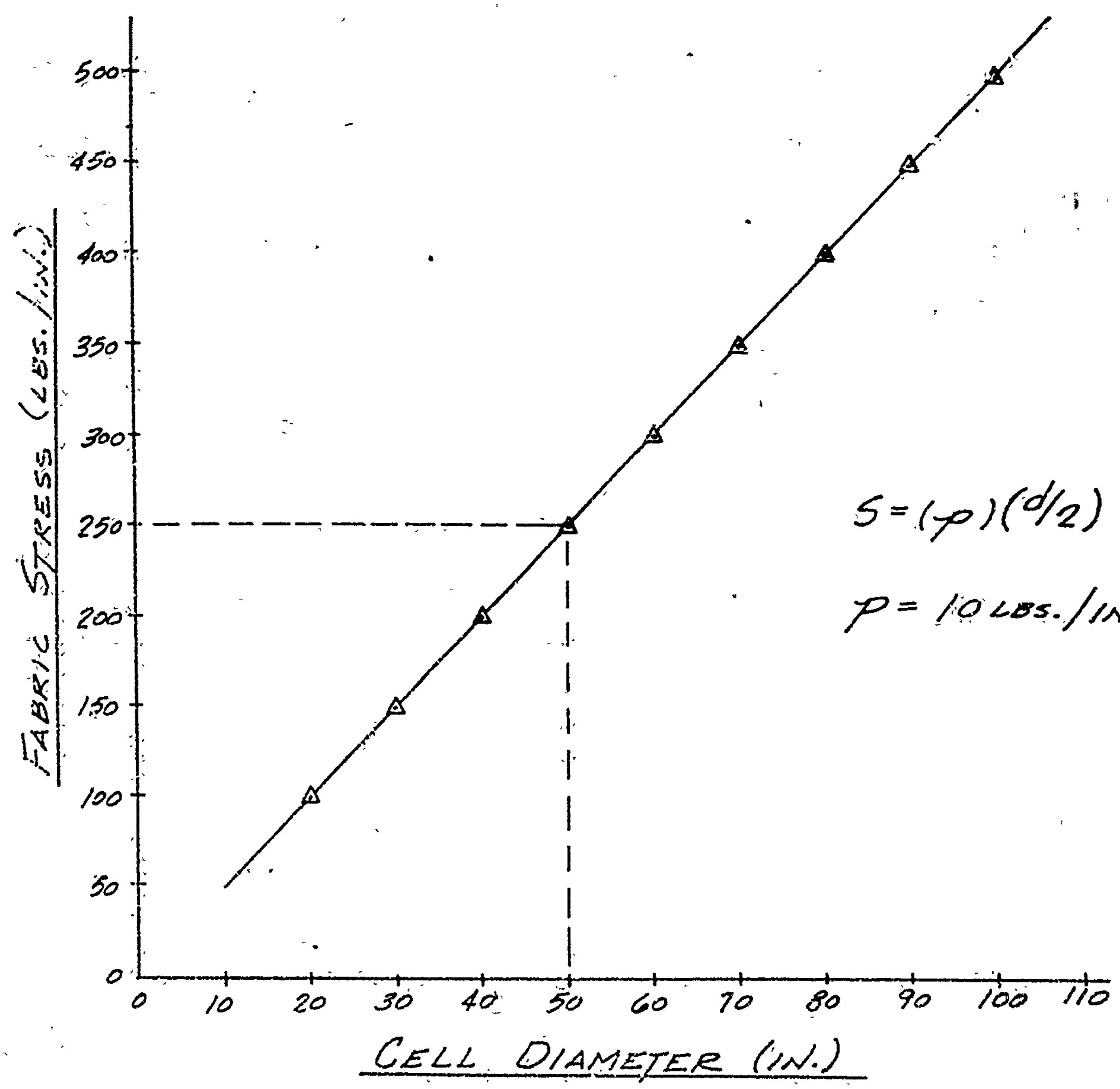
∴ CRITICAL INFLATION PRESSURE IS 10 LBS./IN²

* IT IS ASSUMED THAT THE DECK DOES NOT DISTRIBUTE THE LOCAL LOADING ACROSS THE WIDTH OF THE RAMP

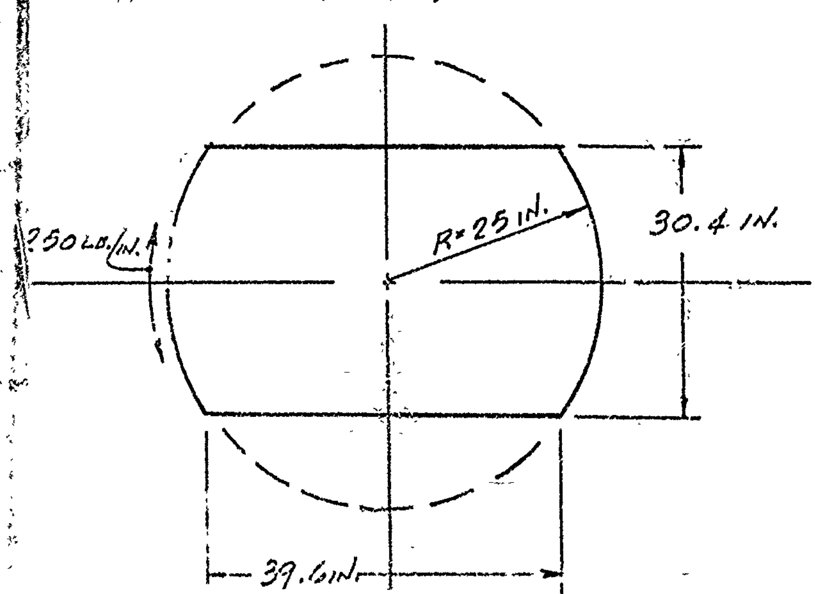
```
COMPUTERSEARCH
12/19/  '72 10:40
!LOGIN: 1507BRD,C,
ID= D
!BASIC
>10 FOR D= 20 TO 100 STEP 5
>20 LET S=10*(D/2)
>30 PRINT D,S
>40 NEXT D
>50 END
>RUN
10:42    12/19     FABRIC STRESS (LBS./IN.)
 20  CELL DIA.     100
 25    (IN.)       125
 30                150
 35                175
 40                200
 45                225
 50                250
 55                275
 60                300
 65                325
 70                350
 75                375
 80                400
 85                [illegible]
 90                450
 95                [illegible]
 100               500

50 HALT
>SYS

!BYE
12/19/  '72 10:42
CLT 2
CCU 0.009
```



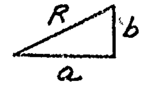
CELL CONFIGURATION:



DUAL WALL ANALYSIS:

RATIO $a/b = 1.3$ OR GREATER

$a = 1.3b$



$R^2 = a^2 + b^2$

$R^2 = (1.3b)^2 + b^2$

$R^2 = 1.69b^2 + b^2$

$R^2 = 2.69b^2$

$b = (R^2/2.69)^{1/2}$

$b = ((25)^2/2.69)^{1/2}$

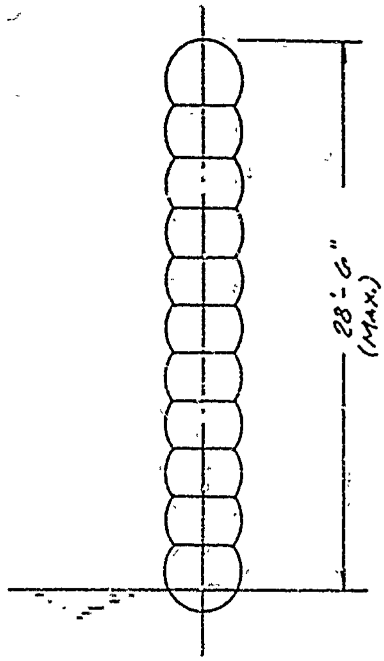
$b = 15.24$ IN.

$a = 19.82$ IN.

SIZE LIMITATIONS:

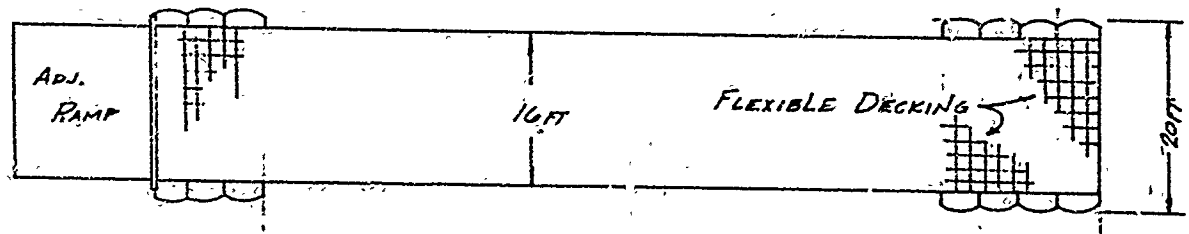
MAX. HEIGHT = 23'-6 = 342 IN.
MIN. HEIGHT = 50 IN.

10 WEB SPACES @ 30.4 = 304 IN.
2 ENDS @ 25 = 50 IN.
354 IN.

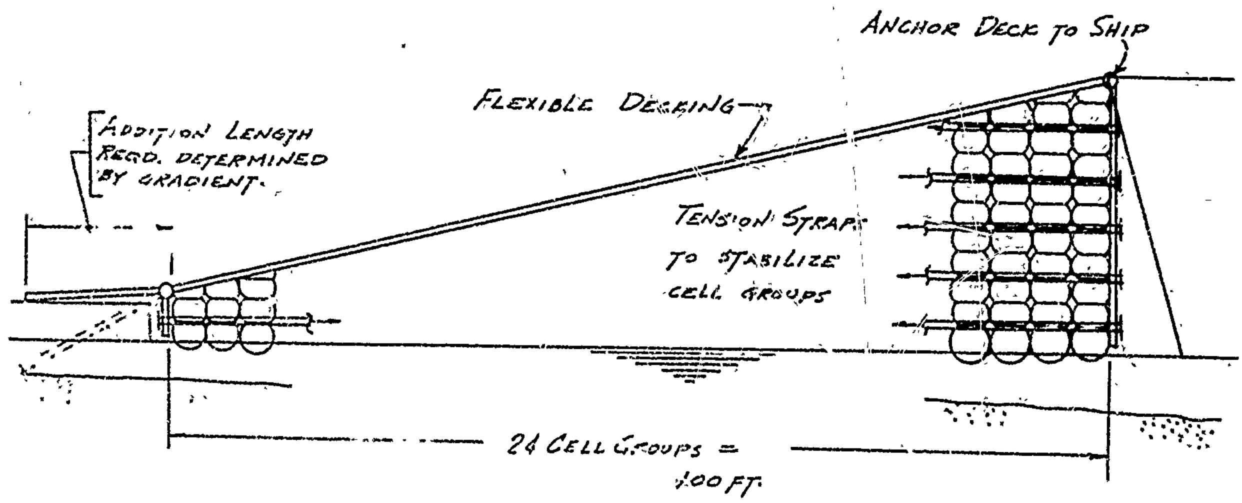


WIDTH OF EACH DUAL WALL PANEL = 20 FT.
(16 FT. MIN. ROADWAY REQD.)

LENGTH OF RAMP
(24 CELL PANELS)(50 IN/PANEL) = 1200 IN. = 100 FT.



ADJ. RAMP
16FT
FLEXIBLE DECKING
20FT



ANCHOR DECK TO SHIP
FLEXIBLE DECKING
ADDITION LENGTH REQD. DETERMINED BY GRADIENT.
TENSION STRAPS TO STABILIZE CELL GROUPS
24 CELL GROUPS = 100 FT.

EFFECTS OF WIND AND WAVES:

WIND:

30 KNOTS × 1.15 = 34.5 M.P.H.

IMPACT PRESSURE = .02 LBS./IN^2 × 144 = 2.88 #/FT^2

(FROM GRAPH W1.1 IN HANDBOOK)

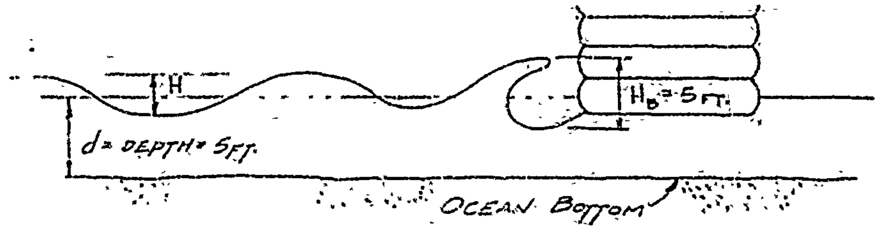
APPROX. AREA OF CONTACT = (1/2)(28.5)(110) = 1570 FT.^{2}

WAVES:

ASSUMPTIONS:

1) 5 FT. BREAKING WAVES
2) 5 FT. AVERAGE DEPTH OF WATER
3) PERIOD BETWEEN CRESTS IS 10 SEC.

(REF. ENCLOSURE ON DYNAMIC FORCES ON WATERFRONT STRUCTURES)



$H_b = d = 5$ FT.

$H_b = 1.3H \qquad H = \frac{5}{1.3} = 3.83$ FT.

1) FIG. C
$L = 130$ FT.

2) FIG. B
$V = 12.5$ FT./SEC.

3) FIG. D
$E = 12,000$ FT. LBS./FT.

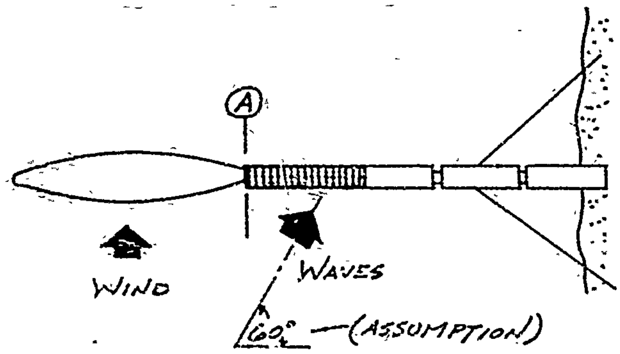
WAVES (CONT.)

$\therefore F = \frac{KE}{V^2}$ $K = 96.6$

$= \frac{(96.6)(12{,}000)}{(12.5)^2}$

$F = 7400$ LBS/LIN. FT.

DYNAMIC FORCE OF WAVES HITTING THE RAMP BROADSIDE. (90°)



MOMENT AT POINT A WITH SHIP HELD STATIONARY AND RAMP FREE TO ROTATE AT CAUSEWAY OR BEACH END.

$M = (2.88)(1570)(110/3) + (7400)(\sin 60°)(110)(55)$

$= 165{,}792 + 38{,}771{,}957$

(WIND) (WAVES)

$M = 38{,}937{,}749$ LB.-FT.

ANCHORING SYSTEM REQD. TO HOLD RAMP IN POSITION

WATERFRONT STRUCTURES—DYNAMIC FORCES

DYNAMIC FORCES ON STRUCTURES DUE TO BREAKING WAVES — SIMPLIFIED METHOD*

EXAMPLE

Observations Required

1. H — maximum wave height, feet.
2. t_1, t_2, t_3 — range of time for two successive crests to pass a given point during periods of maximum waves — seconds.
3. Obtain depths from hydrographic charts.

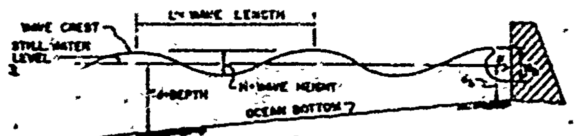


FIG. A

Formulas

d_b = 1.3H in feet

H_b = 1 to 2.5H in feet

$F = \frac{KE}{V^2}$ in lb. per lin. ft.

K = 1.5×2g = 96.6

Given: 9-ft. waves passing at intervals of 7 to 11 seconds.

Nomenclature

d_b = breaker depth

H_b = breaker height

F = dynamic wave force on structure

L = wave length

E = wave energy per foot of crest, ft.-lb./ft.

V = velocity of wave, f.p.s.

Procedure

1. Compute breaking depth of wave 1.3×9 = 11.7 ft. Waves will break on structure located in 11.7 ft. of water.
2. With values of t and d_b, find length of breaking waves, L, on Fig. C.
3. Using values of t and d_b, find velocity of breaking waves, V, on Fig. B.
4. Using values of L and H, find wave energy, E, from Fig. D.
5. Using previous values, find dynamic wave force, F, lb. per lin. ft. of width of structure.

Wave Forces:

1. Breaking on structure:
   (a) Dynamic — approaches initial force of wave.
   (b) Hydrostatic — Height of wave.
2. Broken waves:
   (a) Dynamic — Dissipated force of broken wave.
   (b) Hydrostatic — Height of wave.
3. Unbroken wave:
   (a) Hydrostatic — Standing wave.

GIVEN		FIND				
		(1)	(2)	(3)	(4)	(5)
H, ft.	t, sec.	d_b = 1.3H ft.	L = ft, Fig. B.	V = f.p.s., FIG. C.	E = ft./lb. FIG. D.	F = $\frac{KE}{V^2}$ = lb./lin.ft.
9	7	11.7	130	18.3	84,000	24,200
9	9	11.7	170	18.9	93,500	25,400
9	11	11.7	210	18.9	105,000	28,200

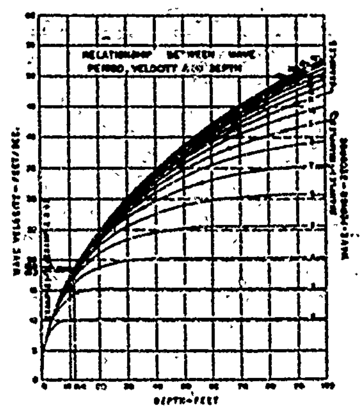


FIG. B

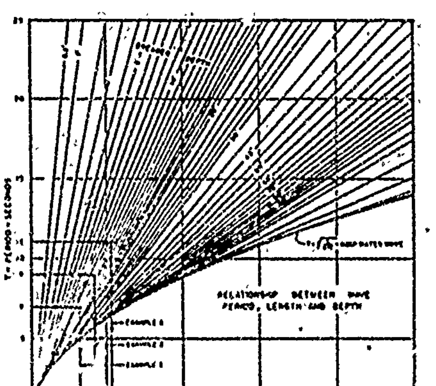


FIG. C

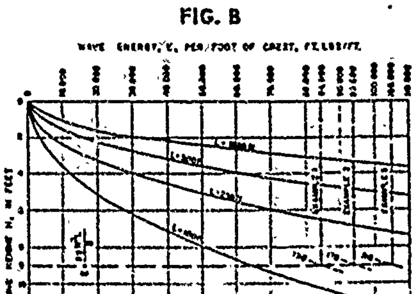
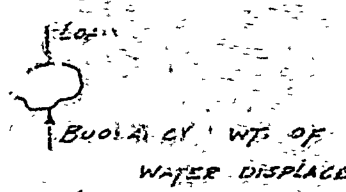


FIG. D

*By the author. For more exact methods of computing wave forces, see Technical Report No. 4, Beach Erosion Board, Office of the Chief of Engineers, Dept. of the Army.

INVESTIGATE BUOYANCY



∴ LOAD = VOL. OF WATER DISPLACED × DENSITY OF WATER

$L = V\gamma$

$\gamma_{(SEA\ WATER)} = 64\ LBS./FT^3$

FOR PRELIMINARY DESIGN, NEGLECT WT. OF FABRIC, AND DECK. ASSUME STRUCTURE FLOATS AT WATER SURFACE.

$V = L/\gamma$ $\quad V = (W)(L')(S)$

W = WIDTH OF SUBMERGED RAMP
L' = LENGTH OF SUBMERGED RAMP
S = SUBMERGED DEPTH

ASSUME LOAD IS DISTRIBUTED OVER 45° ANGLE SPREAD THROUGH THE AIR STRUCTURE, (USED TO DETERMINE L') AS LOAD MOVES ALONG THE RAMP.
THEREFORE, GREATEST SUBMERGENCE OCCURS AT BEACH OR CAUSEWAY END OF THE RAMP.

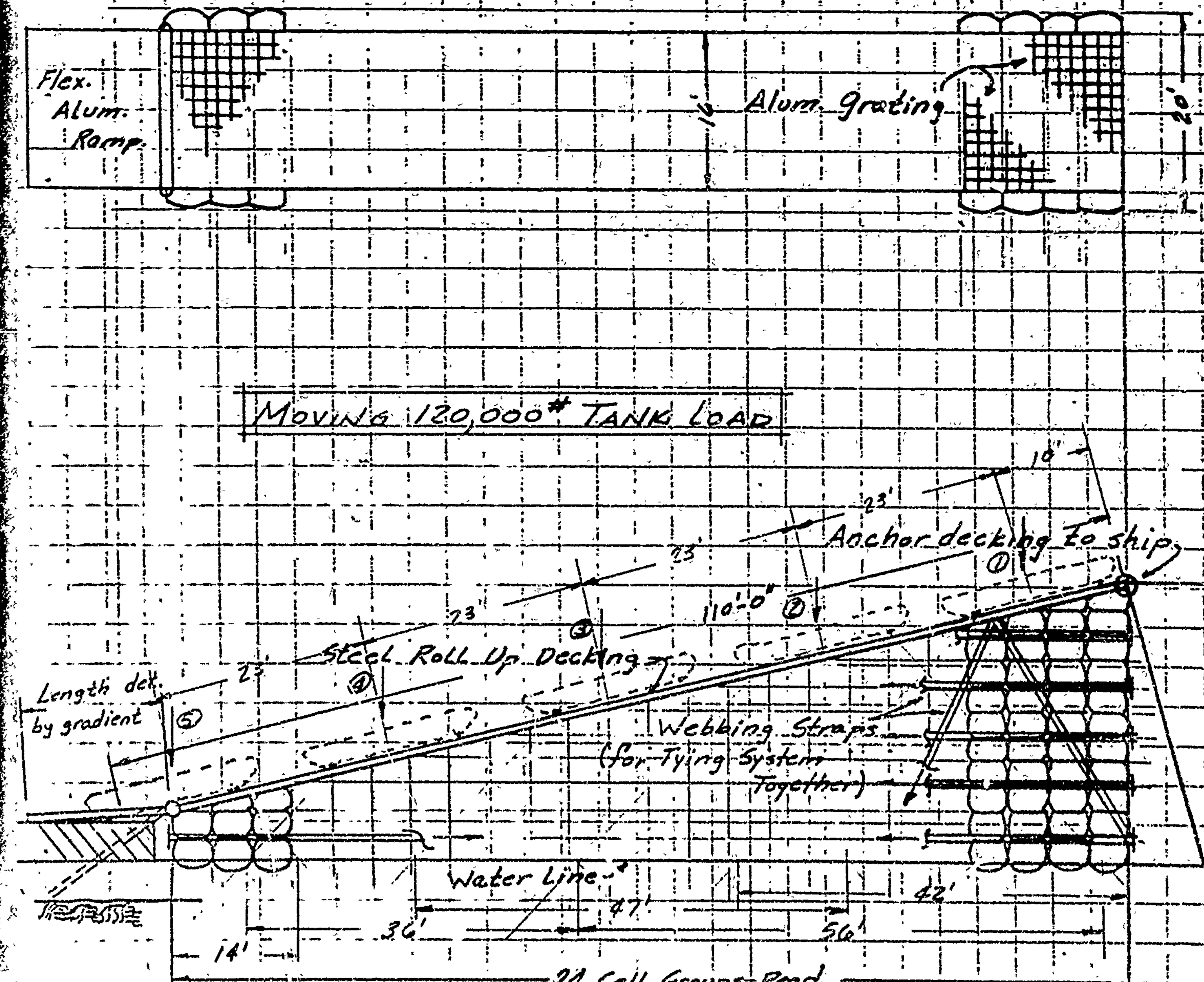
$V_1 = L/\gamma = 120{,}000\ LBS./64\ LBS./FT^3 = 1875\ FT^3$ (LOAD CONDITION № 1)

$V_2 = 60{,}000\ LBS./64\ LBS./FT^3 = 937\ FT^3$ (LOAD CONDITION № 2)

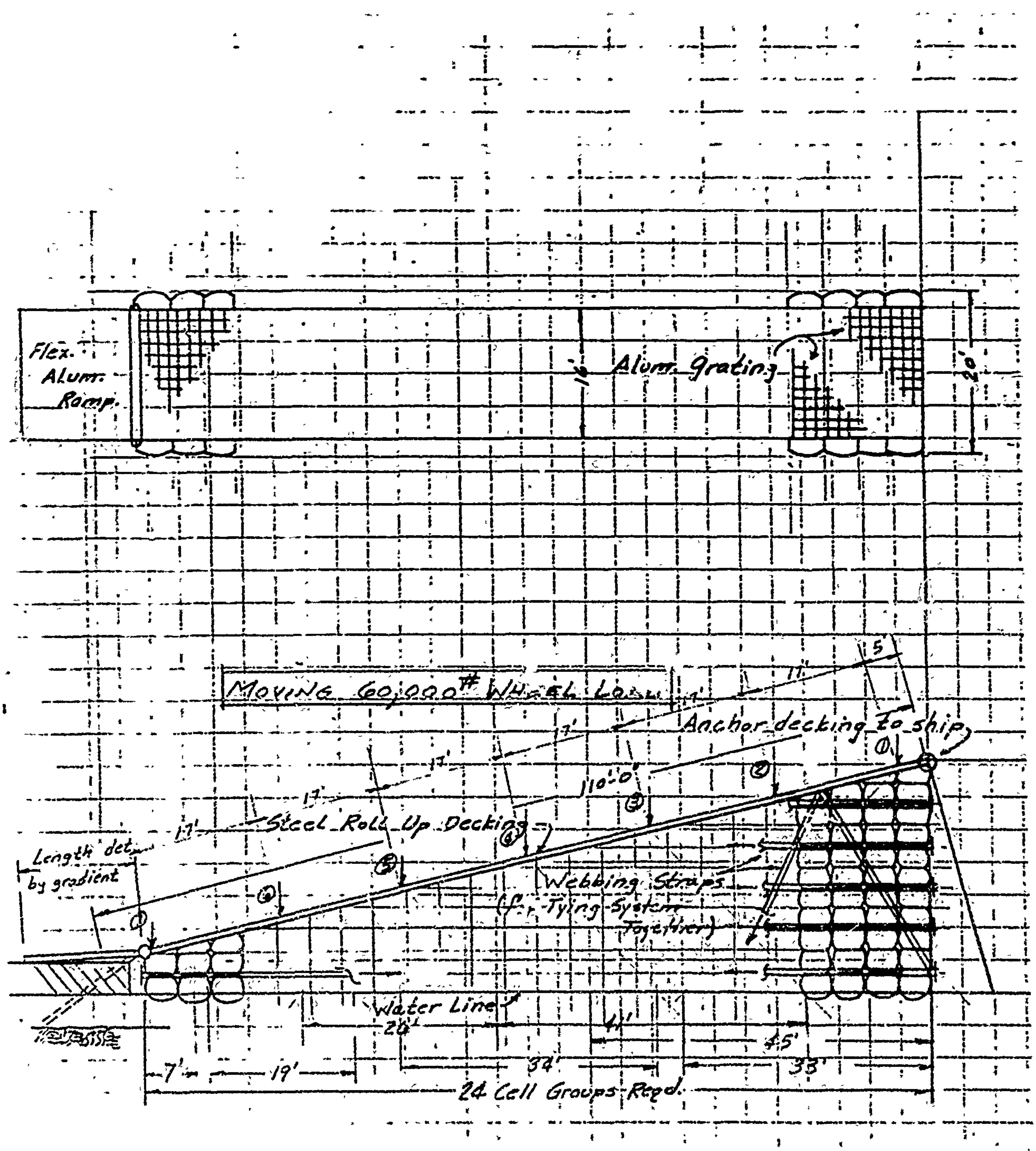
$S = V/(20)(L')$

LOAD CONDITION № 1 (120,000 LBS.)

LOAD LOCATION	L' (FT.)	S (FT.)
1	42	2.2
2	56	1.7
3	47	2.0
4	36	2.6
5	14	6.7


Flex. Alum. Ramp
Alum. Grating
20'
MOVING 120,000# TANK LOAD
10'
23'
Anchor decking to ship
①
23'
110'-0"
②
23'
③
Steel Roll Up Decking
23'
④
Length det. by gradient
⑤
Webbing Straps (for Tying System Together)
Water Line
47'
42'
36'
56'
14'
24 Cell Groups Reqd.

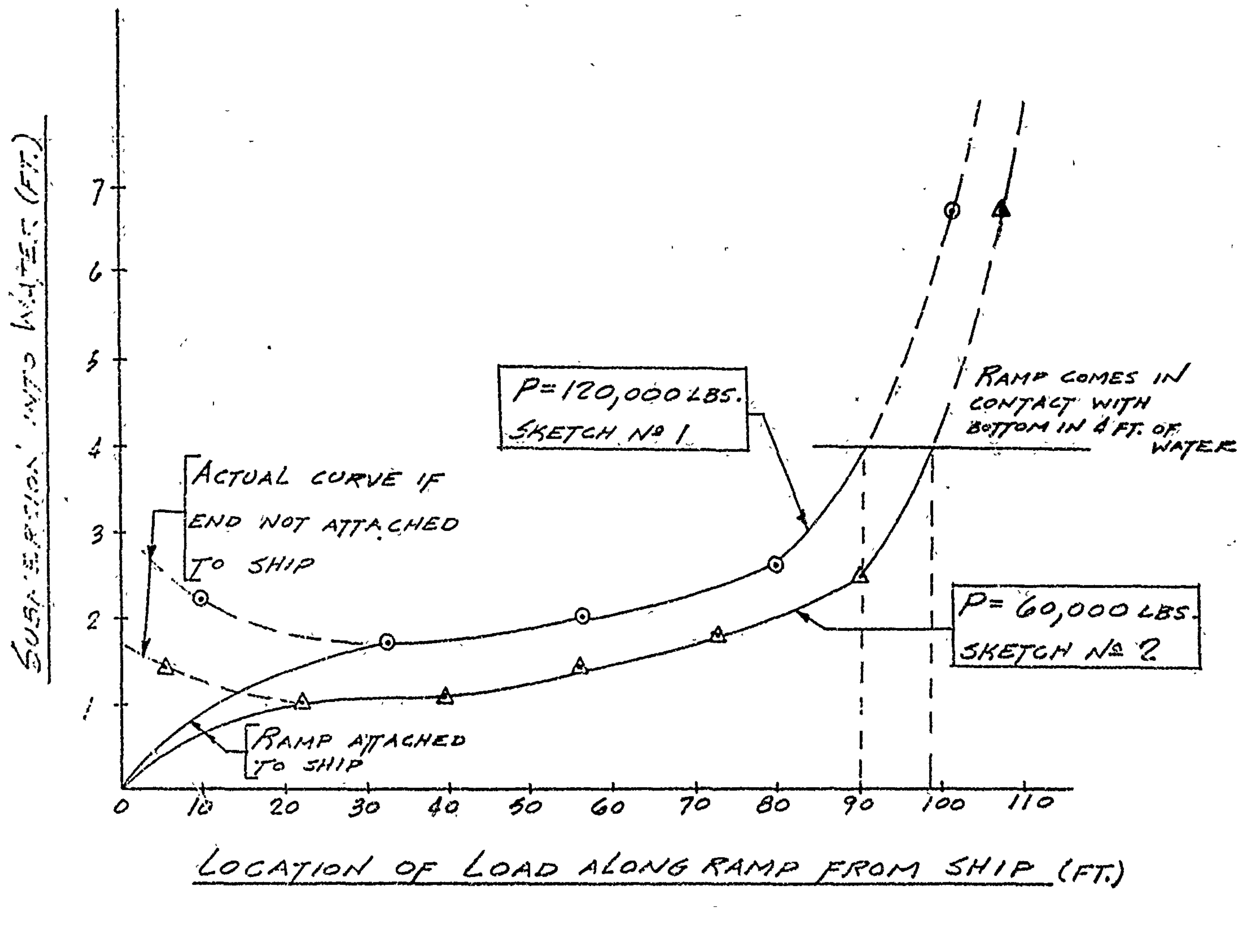
SKETCH No. 1


Flex. Alum. Ramp.
Alum. Grating
20'
Moving 60,000# Wheel Load
Anchor decking to ship
Steel Roll Up Decking
Webbing Straps (For Tying System Together)
Length det. by gradient
Water Line
20'
7'
19'
34'
41'
45'
33'
24 Cell Groups Reqd.
10'-0"
17'
11'
5

Sketch No. 2

LOAD CONDITION Nº 2 (60,000 LBS.)

LOAD LOCATION	L' (FT.)	S (FT.)
1	33	1.4
2	45	1.0
3	41	1.1
4	34	1.4
5	26	1.8
6	19	2.5
7	7	6.7



OVERALL DIMENSIONS - 20 FT WIDE x 28'-6" H.
FABRIC STRESS - 250 LBS./IN
INFLATION PRESS. = 10 LBS./IN^2
VOL. = $\frac{1}{2}(110)(30)(20) = 33{,}000$ FT^3
SURFACE AREA = $(24)(2)(17)(20) + (2)(\frac{1}{2})(110)(30) = 19{,}620$ S.F.

CONCEPT Nº 4

DUAL-WALL TUNNEL

DUAL WALL TUNNEL CONCEPT

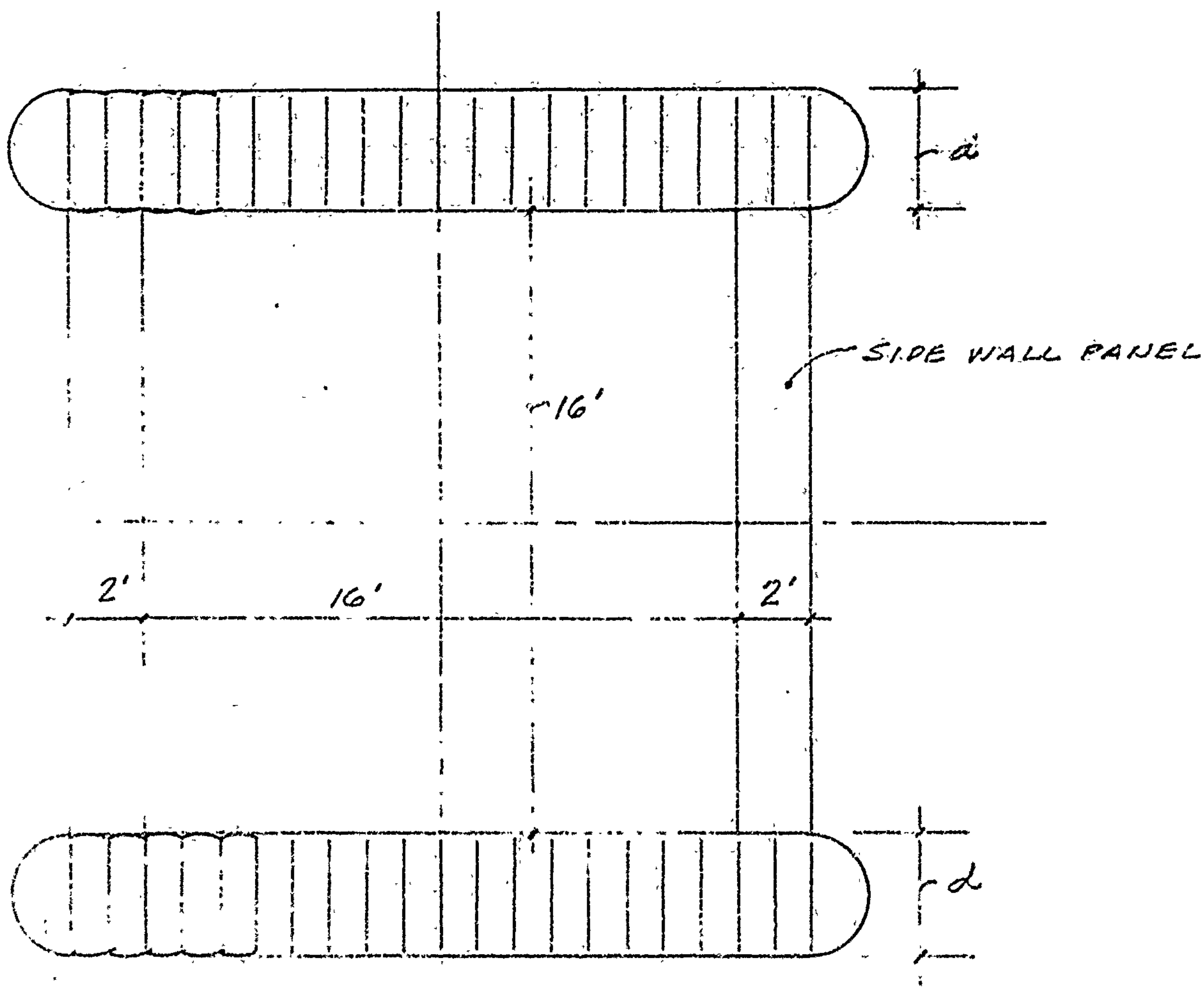
DESIGN DATA:

INSIDE WIDTH – 16 FT.
INSIDE HEIGHT – 16 FT.
LENGTH – 110 FT.
LOAD – 60 TONS

MAXIMUM BENDING MOMENT WITH TANK AT MID SPAN IS

$$M = \frac{PL}{4} = \frac{120000(110)}{4} = 3{,}300{,}000 \text{ FT. LBS.}$$

TUNNEL CROSS SECTION:

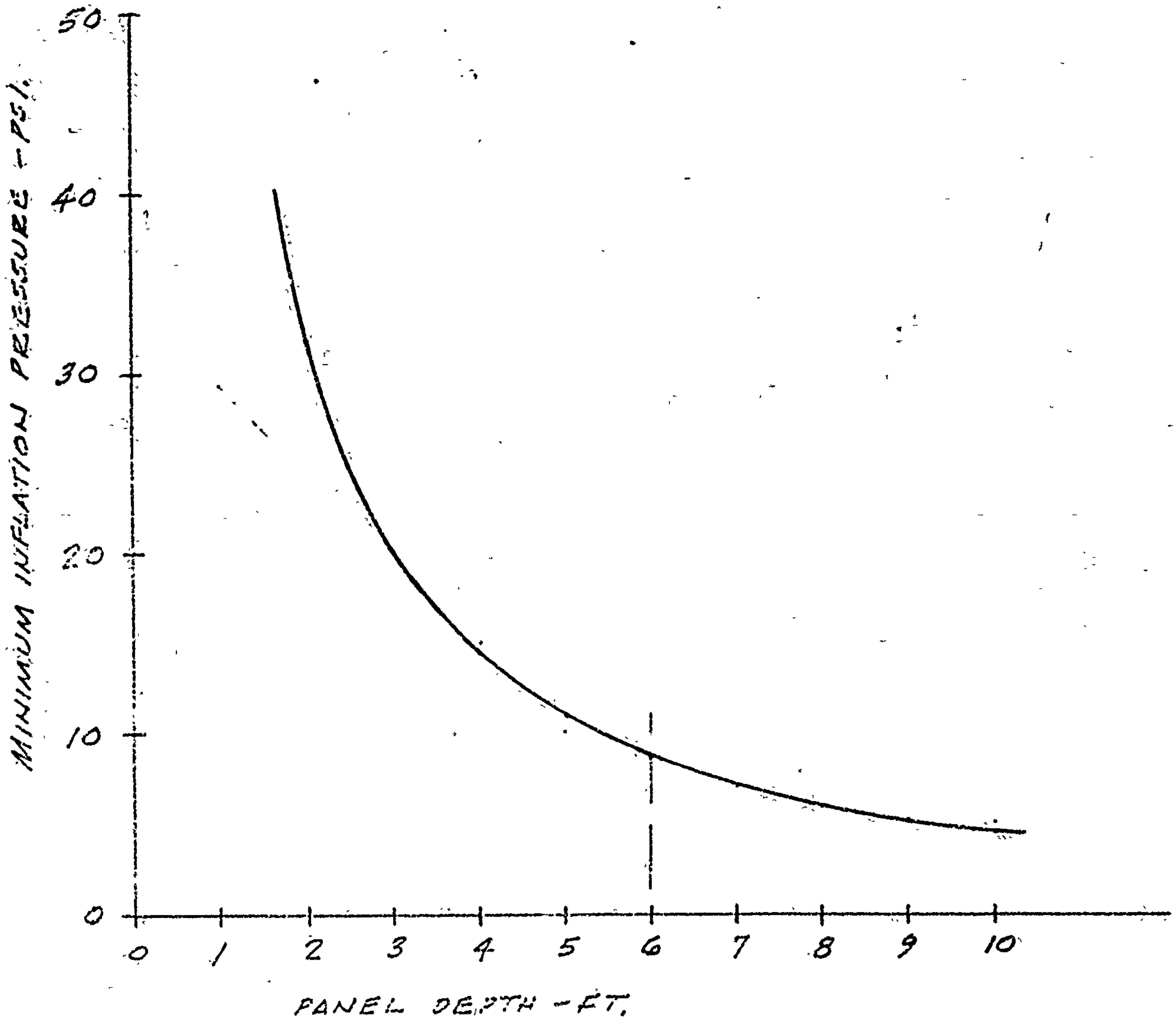


MOMENT CAPABILITY –

$$M = P(20)\,d\,(16-d) = 3{,}300{,}000$$

$$P = \frac{3300000}{20(d)(16+d)} = \frac{165{,}000}{d(16+d)} \text{ IN PSF.}$$

$$P = \frac{1145.83}{d(16+d)}$$



TRANSVERSE FABRIC STRESS

$$S_T = 12'' \frac{Pd}{2} = 6Pd$$

LONGITUDINAL STRESS (MAX.)

$$S_{L_M} = 12'' Pd$$

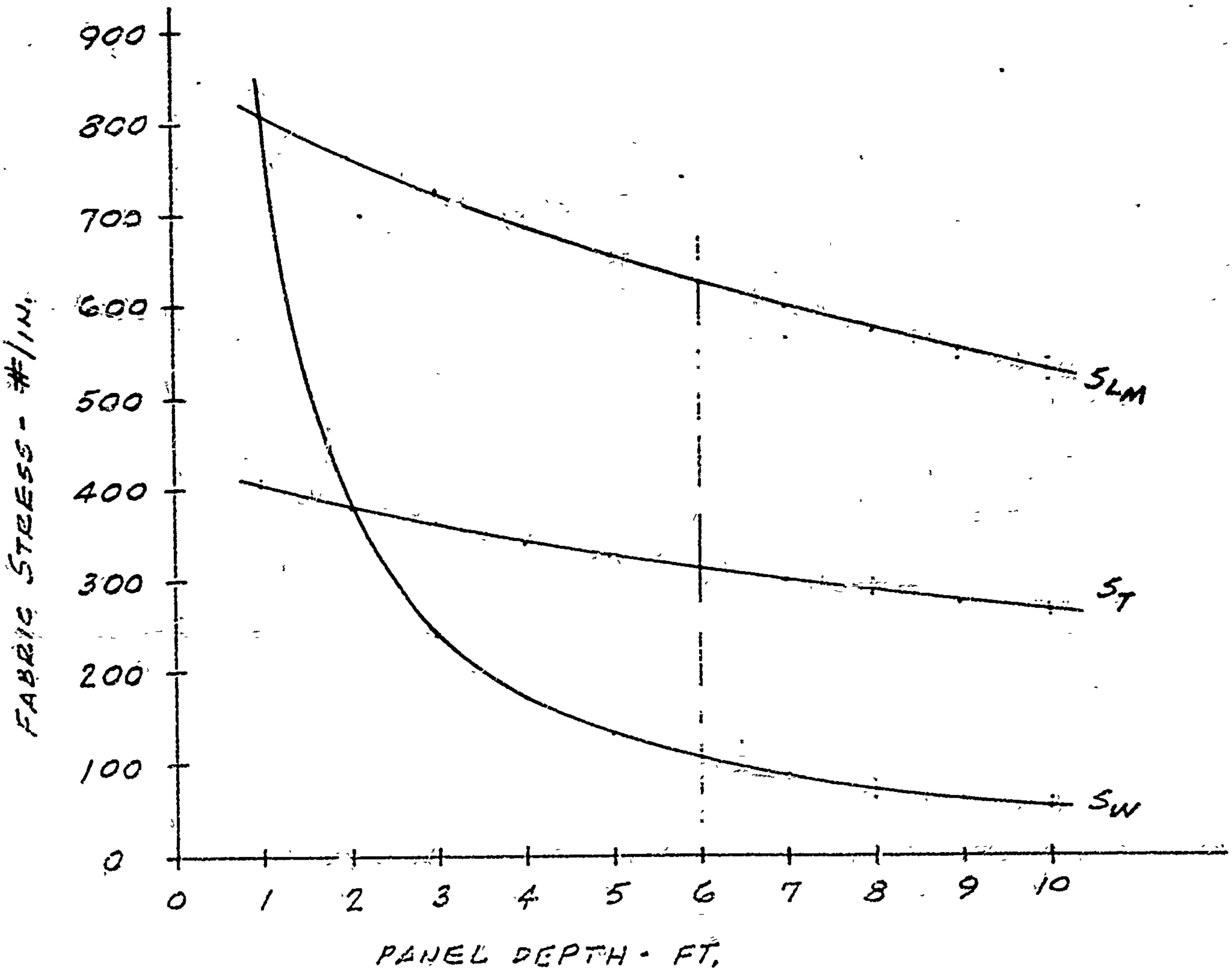
WEB STRESS

$$S_W = 12P$$

```
ZRSEARCH
12/06/  '72 15:40
!LØGIN: 1507BRD,C,
ID= D
!BASIC
>10 FØR D = 1 TØ 10
>20LET P = 1145.83/(D*(16+D))
>30 LET S1 = 6*P*D
>40 LET S2 = 12*P*D
>50 LET S3 = 12*P
>60 PRINT D,P,S1,S2,S3
>70 NEXT D
>80 END
>RUN
15:44    12/06          D              S_T             S_LM            S_W
 1             67.4018        404.411         808.821         808.821
D- 2           31.8286        381.943         763.887         381.943
 3             20.1023        361.841         723.682         241.227
 4             14.3229        343.749         687.498         171.874
 5             10.9127        327.380         654.760         130.952
 6             8.68053        312.499         624.998         104.166
 7             7.11696        298.912         597.824         85.4035
 8             5.96786        286.457         572.915         71.6144
 9             5.09258        274.999         549.998         61.1109
 10            4.40704        264.422         528.845         52.8845

80 HALT
>SYS

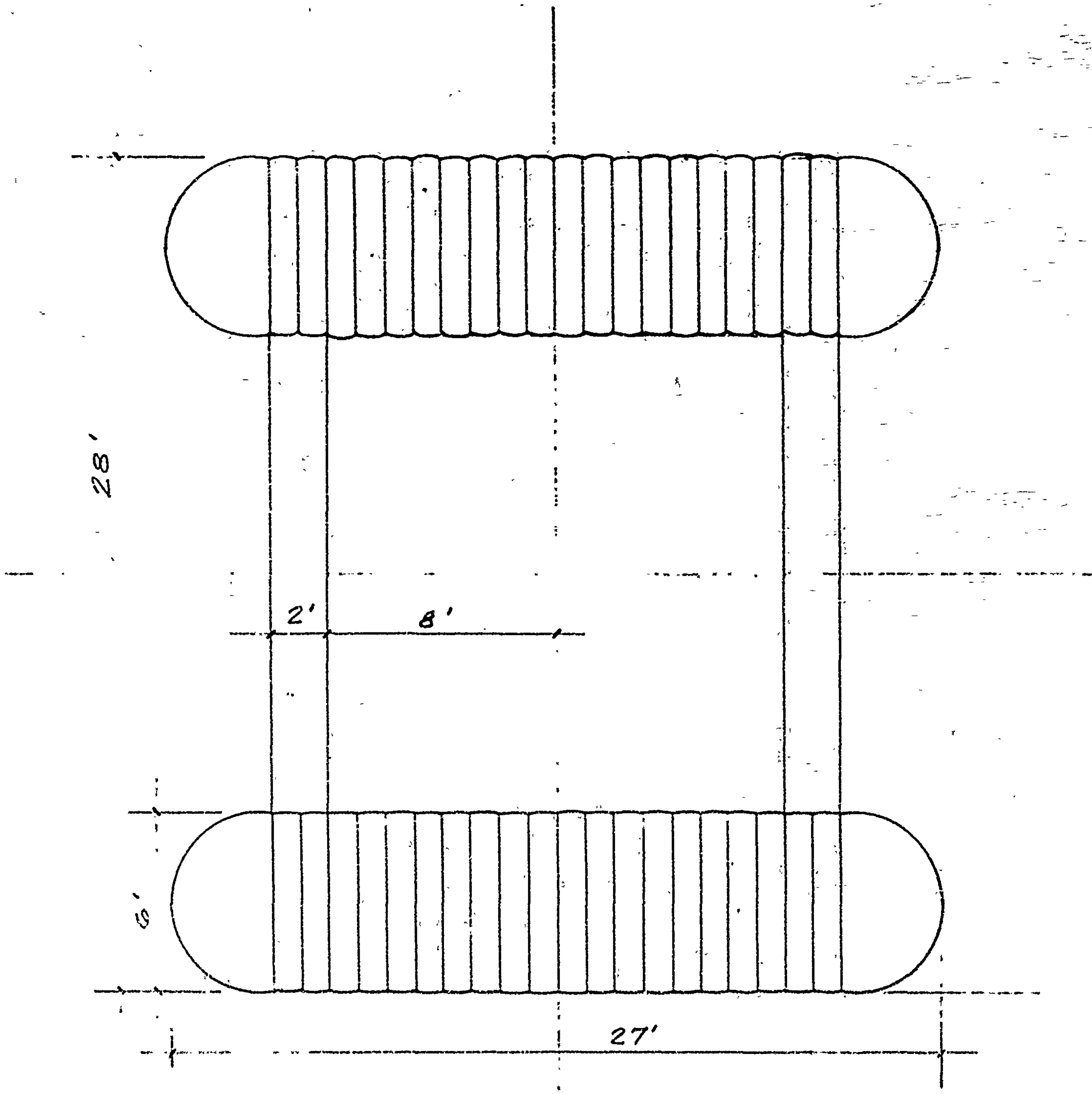
!BYE
12/06/  '72 15:45
CLT 5
CCU 0.012
```



IN CONSIDERATION OF PRESSURE AND STRESSES, AN "OPTIMUM" CELL DEPTH WOULD APPEAR TO BE APPR. 6 FT. CABLES COULD BE USED IN THE LOWER PANEL TO REDUCE S_{LM} BELOW S_T THUS S_T IS THE CONTROLLING FACTOR IN DETERMINING FABRIC STRENGTH REQ'M'TS.

FOR A 6 FT. PANEL DEPTH:

PRESSURE = 8.68 PSI. MIN.
FABRIC STRESS = 312 #/"
FABRIC STRENGTH (F.S. = 4) = 1250 #/"
WEB LOAD = 104 #/"



CROSS SECTION OF RAMP

[illegible] DIMENSIONS - 27 FT. W X 28 FT. HT.

[illegible] STRESS - (NO CABLES) = 624 LBS./IN.

[illegible] PRESSURE - 8.68 LBS./IN^2

VOLUME = $[(21)(6) + (\pi)(6)^2/4] \times (110) \times 2 + (2)(2)(16)(110) = 40{,}980\ FT^3$

SURFACE AREA = $[42+(\pi)(6)](110)(2) + (32)(110)(2) = 20{,}427\ FT^2$

CONCEPT Nº 5

ARCH

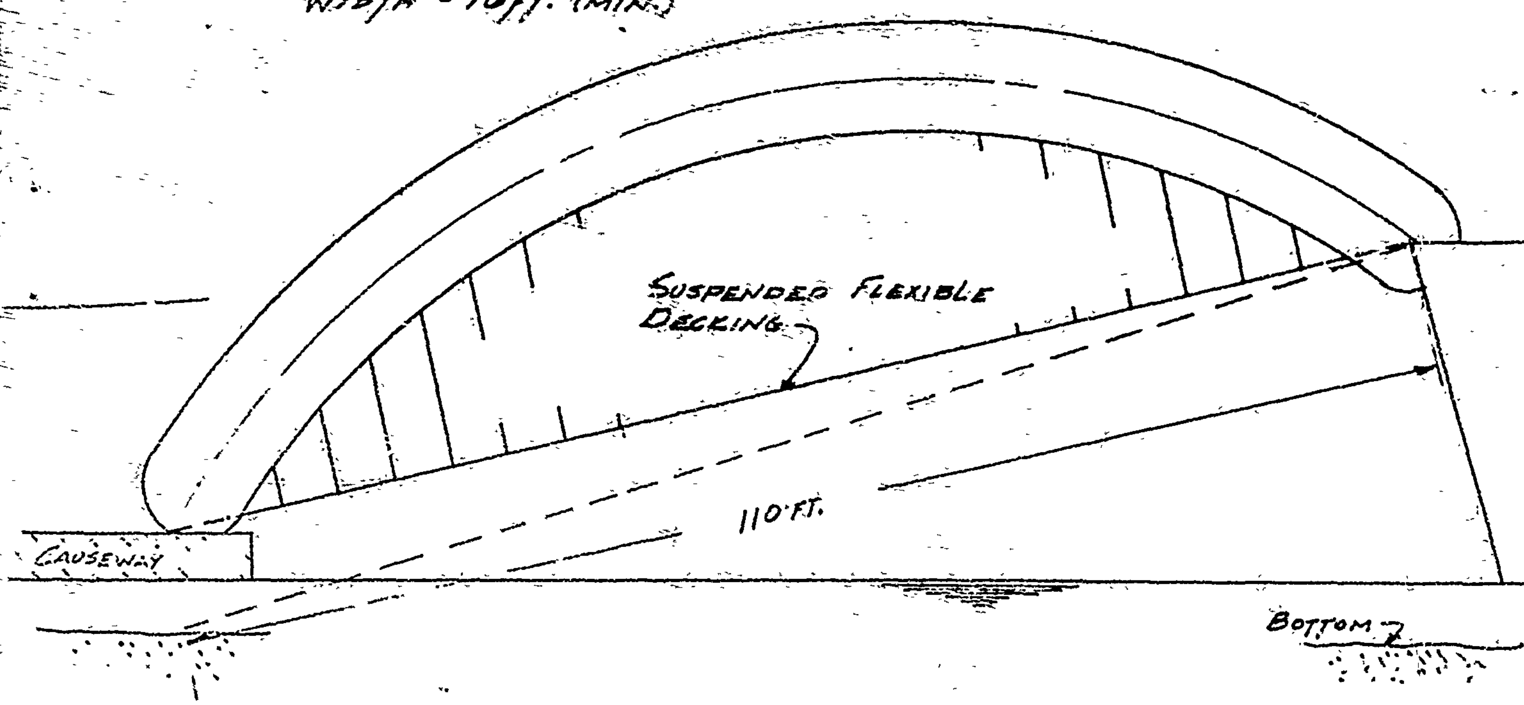
WITH

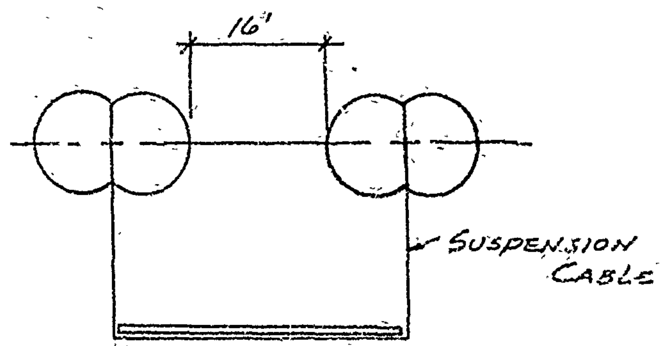
SUSPENDED DECK

C-34a

INFLATABLE ARCH CONCEPT:

DESIGN DATA:
LENGTH = 110 FT.
WIDTH = 16 FT. (MIN.)





GEOMETRY:

MOST ECONOMICAL RISE TO SPAN RATIO VARIES .25 TO .50

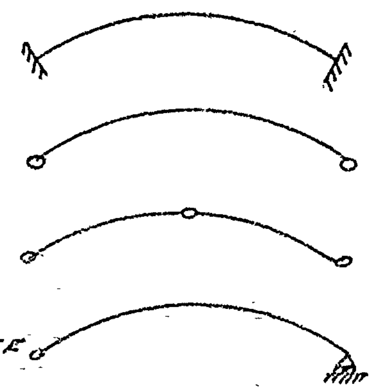
TYPES OF ARCHES:

a) NO HINGE

b) TWO HINGE — MOST APPLICABLE (RESTRAIN ENDS FROM HOR. MOVEMENT WITH DECK SYSTEM)

c) THREE HINGE

d) HINGE & ROLLER



ANALYSIS OF A TWO HINGED PARABOLIC ARCH - REF. TEXT "FRAMES AND ARCHES" BY LEONTOVICH 1959 McGRAW HILL

ASSUME HEIGHT TO SPAN RATIO = .25
FOR L = 110 FT. f = HEIGHT = 27.5 FT.

S (LENGTH OF PARABOLIC ARCH) = 1.148 (110) = 126 FT (pg. 451)

CRITICAL LOADING:

ASSUME 1/2 OF LOAD CARRIED BY EACH ARCH

60 TON TANK - TRACK LENGTH = 14.5 FT. ±

120,000 LBS./14.5 FT. = 8275 LBS./FT. ÷ 2 = 4138 LBS./FT. PER ARCH
ASSUME D.L. OF DECK = 362 LBS./FT.
4500 LBS./FT. TOTAL LOAD

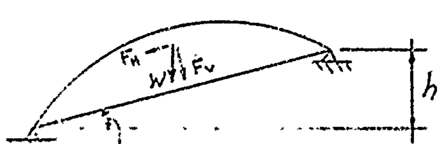
CABLE SPACING:

- TRY 5'-0"

LOAD PER CABLE = (4500 LBS./FT.)(5 FT.) = 22,500 LBS.

3/4" 6x19 IPS CABLE - BREAKING STRENGTH = 46.4 KIPS

$$F.S. = \frac{46,400}{22,500} = 2.06$$

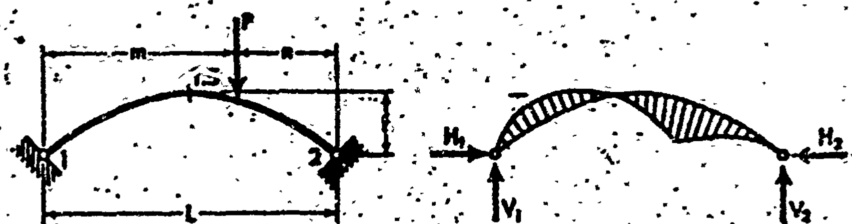


NOTE:
AS h GOES TO ZERO, F_V APPROACHES W WHICH CREATES MAX. MOMENT & SHEAR.

AS h INCREASES, F_H REACHES A MAX. @ 20° AND MUST BE CARRIED IN THE DECK.

[illegible] FORCE: DESIGN LOAD = 22,500 LBS. PER CABLE - 3 CABLES LOADED AT ONE TIME W/ TANK MOVING ALONG RAMP

9-12. Vertical Concentrated Load on Arch



$$H_1 = H_2 = \frac{5PL}{8f}\frac{m}{L}\left[1 - 2\left(\frac{m}{L}\right)^2 + \left(\frac{m}{L}\right)^3\right]$$

$$V_2 = \frac{Pm}{L} \qquad V_1 = P - V_2$$

When $x \leqq m$ $\quad M_x = \frac{Pnx}{L} - H_1 y$

When $x > m$ $\quad M_x = Pm\left(1 - \frac{x}{L}\right) - H_1 y$

When $x \leqq m$ and $\frac{L}{2}$

$$N_x = H_1 \cos\varphi + P\frac{n}{L}\sin\varphi$$

$$Q_x = -H_1 \sin\varphi + P\frac{n}{L}\cos\varphi \qquad (9\text{-}16)$$

When $x \leqq m$, but $\geqq \frac{L}{2}$

$$N_x = H_1 \cos\varphi - P\frac{n}{L}\sin\varphi$$

$$Q_x = H_1 \sin\varphi + P\frac{n}{L}\cos\varphi \qquad (9\text{-}17)$$

When $x \geqq m$, but $\leqq \frac{L}{2}$

$$N_x = H_1 \cos\varphi - P\frac{m}{L}\sin\varphi$$

$$Q_x = -H_1 \sin\varphi - P\frac{m}{L}\cos\varphi \qquad (9\text{-}18)$$

For Notations and Constants, see Arts. 9-1 and 9-2

When $x \geqq m$ and $\frac{L}{2}$

$$N_x = H_1 \cos\varphi + P\frac{m}{L}\sin\varphi$$

$$Q_x = H_1 \sin\varphi - P\frac{m}{L}\cos\varphi \qquad (9\text{-}19)$$

```
      IMPLICIT REAL(A-H,K-Z),INTEGER(I,J)
      OUTPUT(6)'                              ARCH2H'
      OUTPUT(6)'1                         WALLACE-PHILLIPS'
      OUTPUT(6)'                            NOV.28,1971'
      OUTPUT(6)'          THIS PROGRAM ANALYZES A TWO HINGED'
      OUTPUT(6)'          PARABOLIC ARCH WITH A CONCENTRATED LOAD'
      OUTPUT(6)'          MOVING ACROSS THE ARCH. REF. TEXT "FRAMES'
      OUTPUT(6)'          AND ARCHES", BY LEONTOVICH, 1959,MCGRAW-'
      OUTPUT(6)'          HILL,PG 135, FOR DIAGRAMS AND EQUATIONS.'
      OUTPUT(6)'          SM=SMALL M=LOCATION OF P FROM LT.SUPT.(FT)'
      OUTPUT(6)'          X=INCREMENT FROM LT. SUPPORT TO RT.(FT)'
      OUTPUT(6)'          M=MOMENT AT INCREMENT X(KIP-FT)'
      OUTPUT(6)'          N=AXIAL FORCE IN ARCH (KIPS) AT INCREMENT X'
      OUTPUT(6)'          Q=SHEARING FORCE IN ARCH (KIPS) AT INCRMT X'
      OUTPUT(102)'ENTER DATA IN FORM-P,L,F,SMI,XI'
      OUTPUT(102)'P,L,F,SMI,XI'
      READ(101,999)P,L,F,SMI,XI
      OUTPUT(102)P,L,F,SMI,XI
999   FORMAT(5F)
      SM=SMI
  2   C1=(SM/L)
      H=((5.*P*L*SM)/(8*F*L))*(1-(2*((C1)**2))+((C1)**3))
      V2=P*SM/L
      V1=P-V2
      WRITE(6,1007)
      WRITE(6,1005)P,SM
      WRITE(6,1008)
      WRITE(6,1002)H
      WRITE(6,1003)V1
      WRITE(6,1004)V2
      WRITE(6,1006)
      X=0
  5   Y=4*F*(1-(X/L))*(X/L)
      SN=L-SM
      THETA=ATAN((4*F/L)*(1-(2*X/L)))
      K1=P*SM/L
      K=P*SN/L
      IF (X-SM)10,10,20
 10   IF (X-(L/2))30,30,40
 20   IF (X-(L/2))50,50,60
 30   M=(P*SN*X/L)-(H*Y)
      N=(H*COS(THETA))+(K*SIN(THETA))
      Q=(-H*SIN(THETA))+(K*COS(THETA))
      GO TO 70
 40   M=(P*SN*X/L)-(H*Y)
      N=(H*COS(THETA))-(K*SIN(THETA))
      Q=(H*SIN(THETA))+(K*COS(THETA))
      GO TO 70
 50   M=(P*SM*(1-(X/L)))-(H*Y)
      N=(H*COS(THETA))-(K1*SIN(THETA))
      Q=(-H*SIN(THETA))-(K1*COS(THETA))
      GO TO 70
```

```
      GØ TØ 70
   60 M=(P*SM*(1-(X/L)))-(H*Y)
      N=(H*CØS(THETA))+(K1*SIN(THETA))
      Q=(H*SIN(THETA))-(K1*CØS(THETA))
      GØ TØ 70
   70 WRITE(6,1001)SM,X,M,N,Q
      X=X+XI
      IF (X-L)5,5,80
   80 SM=SM+SMI
      TEST=(L/2)+SMI
      IF (SM-TEST)2,2,100
 1001 FØRMAT(5X,F6.1,5X,F6.1,5X,F8.2,5X,F8.3,5X,F8.3,/)
 1002 FØRMAT('THE HØRIZØNTAL REACTIØN H1=H2=',F8.3,'KIPS'//)
 1003 FØRMAT('THE SHEAR AT THE LEFT SUPPØRT V1=',F8.3,'KIPS'//)
 1004 FØRMAT('THE SHEAR AT THE RIGHT SUPPØRT V2=',F8.3,'KIPS'//)
 1005 FØRMAT(1H1'WHEN THE LØAD P',F8.3,'IS',F6.1,'FT FRØM LT. SUPT.'//)
 1006 FØRMAT(8X,'SM',10X,'X',9X,'M',14X,'N',12X,'Q',//)
 1007 FØRMAT(//)
 1008 FØRMAT('**********************************************************')
  100 END
```

ARCH2H

1 WALLACE-PHILLIPS

NOV.28,1972

THIS PROGRAM ANALYZES A TWO HINGED PARABOLIC ARCH WITH A CONCENTRATED LOAD MOVING ACROSS THE ARCH. REF. TEXT FRAMES AND ARCHES , BY LEONTOVICH, 1959,MCGRAW-HILL,PG 135, FOR DIAGRAMS AND EQUATIONS.

SM=SMALL M=LOCATION OF P FROM LT.SUPT.(FT)

X=INCREMENT FROM LT. SUPPORT TO RT.(FT)

M=MOMENT AT INCREMENT X(KIP-FT)

N=AXIAL FORCE IN ARCH (KIPS) AT INCREMENT X

Q=SHEARING FORCE IN ARCH (KIPS) AT INCRMT X

1WHEN THE LOAD P 22.500IS 5.0FT FROM LT. SUPT.

****

THE HORIZONTAL REACTION H1=H2= 2.546KIPS

THE SHEAR AT THE LEFT SUPPORT V1= 21.477KIPS

THE SHEAR AT THE RIGHT SUPPORT V2= 1.023KIPS

SM	X	M	N	Q
5.0	.0	.00	16.987	13.386
5.0	10.0	79.12	1.323	-2.404
5.0	20.0	50.38	1.599	-2.230
5.0	30.0	26.26	1.895	-1.985
5.0	40.0	6.77	2.188	-1.657
5.0	50.0	-8.09	2.443	-1.249
5.0	60.0	-18.31	2.443	-1.249
5.0	70.0	-23.91	2.188	-1.657
5.0	80.0	-24.88	1.895	-1.985
5.0	90.0	-21.22	1.599	-2.230
5.0	100.0	-12.92	1.323	-2.404

RCH2H 12/28/72 9:30

5.0	110.0	.00	1.077	-2.524

1WHEN THE LOAD p 22.500IS 10.0FT FROM LT. SUpT.

****

THE HORIZONTAL REACTION H1=H2= 5.033KIPS

THE SHEAR AT THE LEFT SUPPORT V1= 20.455KIPS

THE SHEAR AT THE RIGHT SUPPORT V2= 2.045KIPS

SM	X	M	N	Q
10.0	.0	.00	18.022	10.505
10.0	10.0	158.79	16.848	12.644
10.0	20.0	101.73	3.148	-4.428
10.0	30.0	53.83	3.735	-3.945
10.0	40.0	15.07	4.317	-3.298
10.0	50.0	-14.54	4.827	-2.493
10.0	60.0	-34.99	4.827	-2.493
10.0	70.0	-46.29	4.317	-3.298
10.0	80.0	-48.45	3.735	-3.945
10.0	90.0	-41.45	3.148	-4.428
10.0	100.0	-25.30	2.600	-4.770
10.0	110.0	.00	2.112	-5.005

1WHEN THE LOAD p 22.500IS 15.0FT FROM LT. SUpT.

****

THE HORIZONTAL REACTION H1=H2= 7.405KIPS

THE SHEAR AT THE LEFT SUPPORT V1= 19.432KIPS

THE SHEAR AT THE RIGHT SUPPORT V2= 3.068KIPS

SM	X	M	N	Q
15.0	.0	.00	18.976	8.504
15.0	10.0	127.00	13.036	10.351
15.0	20.0	154.97	4.600	-6.564
15.0	30.0	83.90	5.471	-5.857
15.0	40.0	25.29	6.336	-4.908
15.0	50.0	-17.85	7.096	-3.726
15.0	60.0	-48.54	7.096	-3.726
15.0	70.0	-65.75	6.336	-4.908
15.0	80.0	-69.51	5.471	-5.857
15.0	90.0	-59.80	4.600	-6.564
15.0	100.0	-36.63	3.788	-7.064
15.0	110.0	.00	3.066	-7.405

1WHEN THE LOAD P 22.500IS 20.0FT FROM LT. SUPT.

****

THE HORIZONTAL REACTION H1=H2= 9.613KIPS

THE SHEAR AT THE LEFT SUPPORT V1= 18.409KIPS

THE SHEAR AT THE RIGHT SUPPORT V2= 4.091KIPS

SM	X	M	N	Q
20.0	.0	.00	19.814	6.220

RCF24 12/26/72 .130

20.0	10.0	96.70	15.097	8.161
20.0	20.0	210.89	27.593	10.375
20.0	30.0	117.58	7.058	-7.702
20.0	40.0	41.68	8.197	-6.476
20.0	50.0	-16.71	9.203	-4.944
20.0	60.0	-57.62	9.203	-4.944
20.0	70.0	-81.05	8.197	-6.476
20.0	80.0	-87.00	7.058	-7.702
20.0	90.0	-75.48	5.913	-8.612
20.0	100.0	-46.48	4.849	-9.251
20.0	110.0	.00	3.904	-9.690

WHEN THE LOAD P 22.500IS 25.0FT FROM LT. SUPT.

****

THE HORIZONTAL REACTION H1,H2= 11.613KIPS

THE SHEAR AT THE LEFT SUPPORT V1= 17.386KIPS

THE SHEAR AT THE RIGHT SUPPORT V2= 5.114KIPS

SM	X	M	N	Q
25.0	.0	.00	20.506	4.082
25.0	10.0	68.29	19.998	6.102
25.0	20.0	157.69	19.132	8.433
25.0	30.0	156.71	8.457	-9.461
25.0	40.0	62.34	9.859	-7.989
25.0	50.0	-9.31	11.103	-6.144

25.0	60.0	-61.05	11.103	-6.144
25.0	70.0	-91.07	9.859	-7.989
25.0	80.0	-99.98	8.457	-9.461
25.0	90.0	-87.77	7.052	-10.549
25.0	100.0	-54.44	5.750	-11.312
25.0	110.0	.00	4.596	-11.828

1WHEN THE LOAD P 22.500IS 30.0FT FROM LT. SUPT.

1**

THE HORIZONTAL REACTION H1=H2= 13.370KIPS

THE SHEAR AT THE LEFT SUPPORT V1= 16.364KIPS

THE SHEAR AT THE RIGHT SUPPORT V2= 6.136KIPS

SM	X	M	N	Q
30.0	.0	.00	21.025	2.117
30.0	10.0	42.09	20.710	4.198
30.0	20.0	108.49	20.065	6.627
30.0	30.0	199.20	18.943	9.364
30.0	40.0	89.22	11.284	-9.438
30.0	50.0	3.55	12.760	-7.322
30.0	60.0	-57.82	12.760	-7.322
30.0	70.0	-94.87	11.284	-9.438
30.0	80.0	-107.62	9.632	-11.119
30.0	90.0	-96.05	7.985	-12.355
30.0	100.0	-60.18	6.462	-13.216
30.0	110.0	.00	5.115	-13.793

1WHEN THE LOAD P 22.500IS 35.0FT FROM LT. SUPT.

****

THE HORIZONTAL REACTION H1=H2= 14.850KIPS

THE SHEAR AT THE LEFT SUPPORT V1= 15.341KIPS

THE SHEAR AT THE RIGHT SUPPORT V2= 7.159KIPS

SM	X	M	N	Q
35.0	.0	.00	21.348	.347
35.0	10.0	18.41	21.208	2.469
35.0	20.0	63.81	20.765	4.970
35.0	30.0	136.22	19.867	7.821
35.0	40.0	123.13	12.443	-10.814
35.0	50.0	24.54	14.141	-8.474
35.0	60.0	-47.05	14.141	-8.474
35.0	70.0	-91.64	12.443	-10.814
35.0	80.0	-109.23	10.557	-12.662
35.0	90.0	-99.82	8.685	-14.013
35.0	100.0	-63.41	6.960	-14.945
35.0	110.0	.00	5.439	-15.563

1WHEN THE LOAD P 22.500IS 40.0FT FROM LT. SUPT.

****

THE HORIZONTAL REACTION H1=H2= 16.029KIPS

:THE SHEAR AT THE LEFT SUPPORT V1= 14.318KIPS

:THE SHEAR AT THE RIGHT SUPPORT V2= 8.182KIPS

SM	X	M	N	Q
40.0	.0	.00	21.458	-1.209
40.0	10.0	-2.53	21.472	.932
40.0	20.0	24.08	21.210	3.474
40.0	30.0	79.83	20.517	6.402
40.0	40.0	1[illegible].73	19.231	9.596
40.0	50.0	53.77	15.222	-9.599
40.0	60.0	-28.05	15.222	-9.599
40.0	70.0	-80.73	13.311	-12.111
40.0	80.0	-104.26	11.206	-14.081
40.0	90.0	-98.65	9.130	-15.508
40.0	100.0	-63.90	7.224	-16.482
40.0	110.0	.00	5.549	-17.119

:1WHEN THE LOAD P 22.500IS 45.0FT FROM LT. SUPT.

:***

:THE HORIZONTAL REACTION H1=H2= 16.885KIPS

:THE SHEAR AT THE LEFT SUPPORT V1= 13.295KIPS

:THE SHEAR AT THE RIGHT SUPPORT V2= 9.205KIPS

SM	X	M	N	Q
45.0	.0	.00	21.341	-2.538

45.0	10.0	-20.54	21.487	-.402
45.0	20.0	-10.38	21.383	2.152
45.0	30.0	10.47	20.873	5.117
45.0	40.0	102.03	19.788	8.384
45.0	50.0	91.78	15.982	-10.695
45.0	60.0	-.26	15.982	-10.695
45.0	70.0	-61.61	13.868	-13.323
45.0	80.0	-92.26	11.562	-15.366
45.0	90.0	-92.20	9.303	-16.830
45.0	100.0	-61.45	7.239	-17.816
45.0	110.0	.00	5.431	-18.448

1WHEN THE LOAD P 22.500IS 50.0FT FROM LT. SUPT.

****

THE HORIZONTAL REACTION H1=H2= 17.404KIPS

THE SHEAR AT THE LEFT SUPPORT V1= 12.273KIPS

THE SHEAR AT THE RIGHT SUPPORT V2= 10.227KIPS

SM	X	M	N	Q
50.0	.0	.00	20.985	-3.628
50.0	10.0	-35.49	21.742	-1.522
50.0	20.0	-39.34	21.277	1.010
50.0	30.0	-11.54	20.923	3.971
50.0	40.0	47.90	20.020	7.261
50.0	50.0	138.98	18.444	10.647
50.0	60.0	36.71	16.407	-11.761

RCF2 12/28/72 9:30

SM	X	M	N	Q
50.0	70.0	-39.92	14.100	-14.546
50.0	80.0	-72.91	11.612	-16.512
50.0	90.0	-80.25	9.192	-17.972
50.0	100.0	-55.95	6.994	-18.936
50.0	110.0	.00	5.075	-19.538

1WHEN THE LOAD P 22.500IS 55.0FT FROM LT. SUPT.

****

THE HORIZONTAL REACTION H1=H2= 17.578KIPS

THE SHEAR AT THE LEFT SUPPORT V1= 11.250KIPS

THE SHEAR AT THE RIGHT SUPPORT V2= 11.250KIPS

SM	X	M	N	Q
55.0	.0	.00	20.385	-4.475
55.0	10.0	-47.30	20.729	-2.424
55.0	20.0	-62.64	20.870	.054
55.0	30.0	-46.02	20.658	2.968
55.0	40.0	2.56	19.919	6.228
55.0	50.0	83.10	18.524	9.612
55.0	60.0	83.10	16.487	-12.795
55.0	70.0	2.56	13.999	-15.479
55.0	80.0	-46.02	11.347	-17.515
55.0	90.0	-62.64	8.790	-18.928
55.0	100.0	-47.30	6.481	-19.838
55.0	110.0	.00	4.475	-20.385

:WHEN THE LOAD P 22.50CIS 60.0FT FROM LT. SUPT.

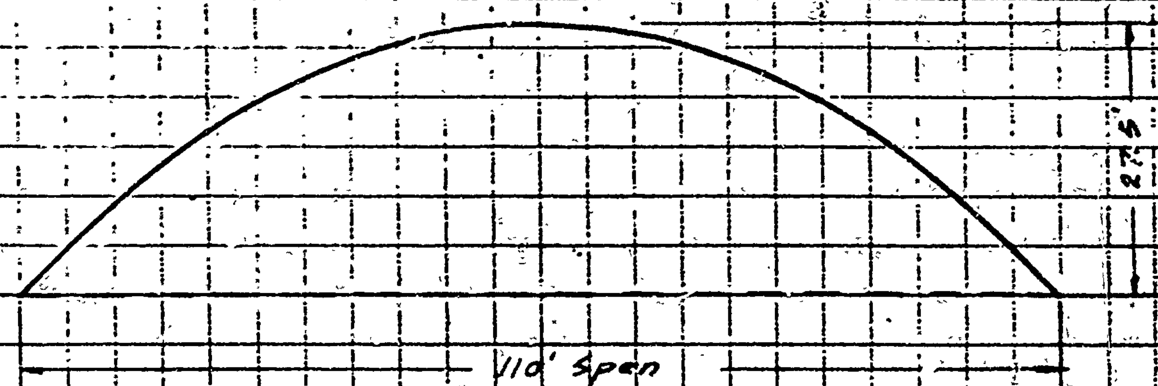
:***

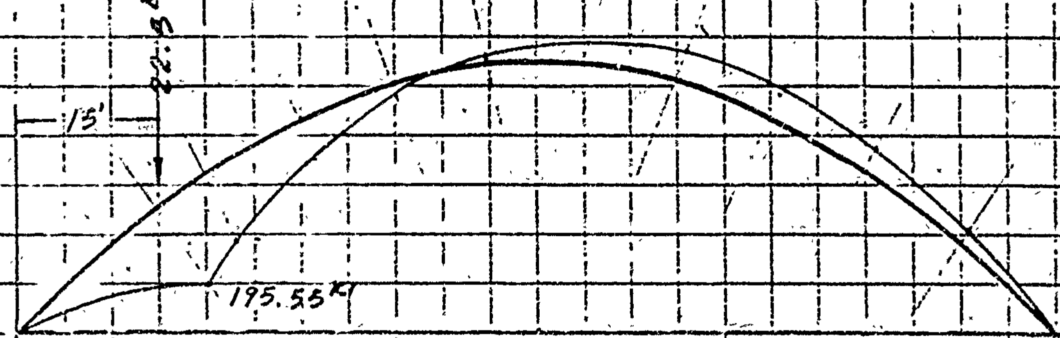
:THE HORIZONTAL REACTION H1=H2= 17.404KIPS

:THE SHEAR AT THE LEFT SUPPORT V1= 10.227KIPS

:THE SHEAR AT THE RIGHT SUPPORT V2= 12.273KIPS

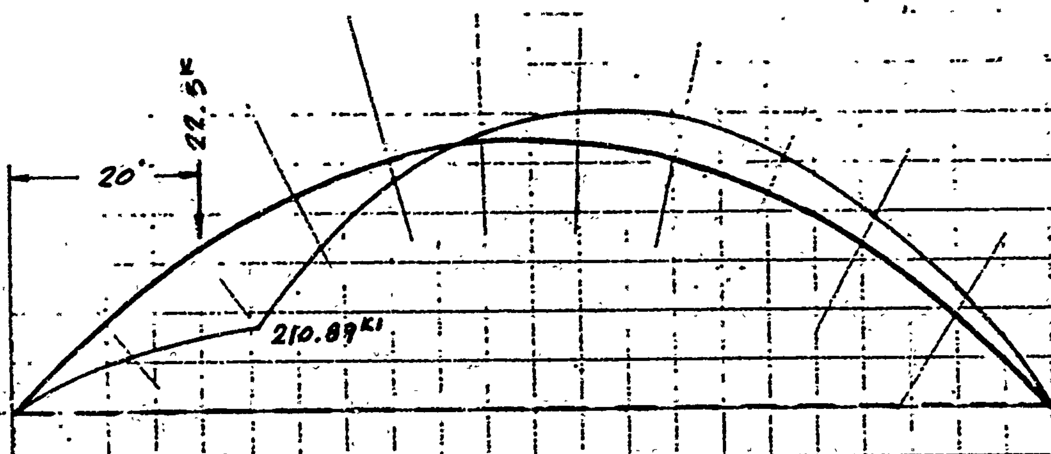
SM	X	M	N	Q
60.0	.0	.00	19.538	-5.075
60.0	10.0	-55.95	19.946	-3.105
60.0	20.0	-80.25	20.174	-.715
60.0	30.0	-72.31	20.076	2.109
60.0	40.0	-33.92	19.482	5.288
60.0	50.0	36.71	18.258	8.610
60.0	60.0	138.98	18.258	8.610
60.0	70.0	47.90	13.562	-16.420
60.0	80.0	-11.54	10.766	-18.374
60.0	90.0	-39.34	8.094	-19.698
60.0	100.0	-35.49	5.698	-20.519
60.0	110.0	.00	3.628	-20.985

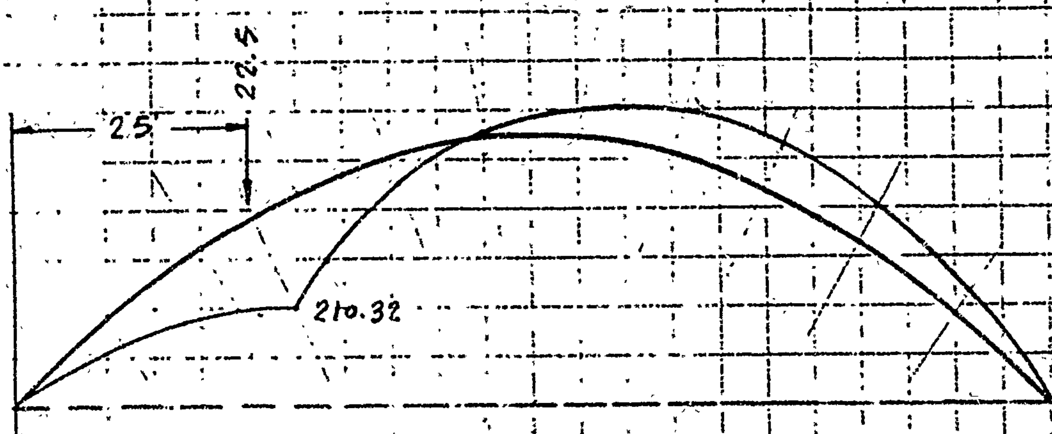




Compute M @ Load $M = \frac{(22.5)(95)(15)}{110} - (7.405)(12.955) = 195.55^{k'}$

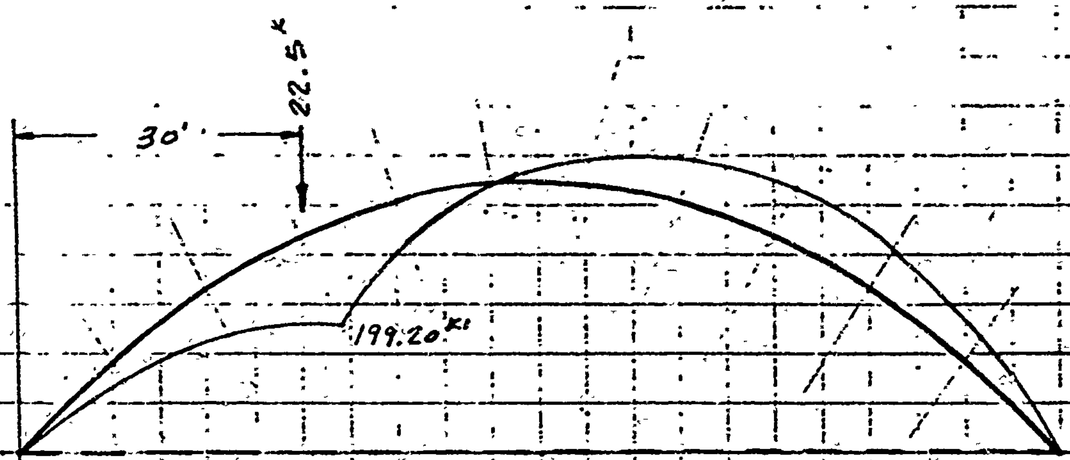
$y = (4)(27.5)\left(1 - \frac{15}{110}\right)\left(\frac{15}{110}\right) = 12.955$

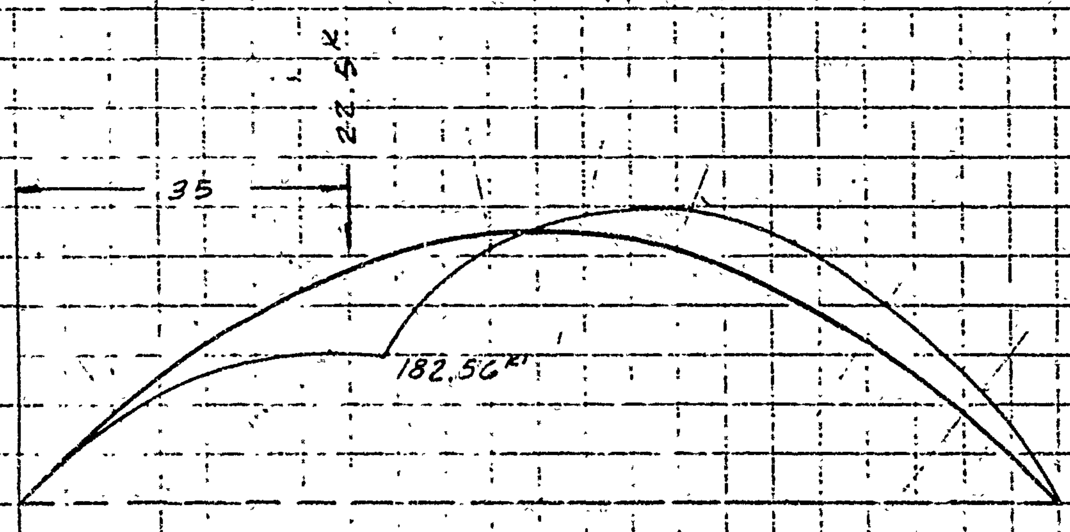




Compute M @ Load $M = \frac{(22.5)(85)(25)}{110} - (11.613)(19.3182) = 210.32^{K'}$

$y = 4(27.5)\left(1 - \frac{25}{110}\right)\frac{25}{110} = 19.3182$





Compute M @ Load $M = \frac{(22.5)(75)(35)}{110} - (14.850)(23.864) = 182.557^{k'}$

$y = 4(27.5)\left(1-\frac{35}{110}\right)\left(\frac{35}{110}\right) = 23.864$

SUMMATION OF MOMENTS FOR CRITICAL LOADING:

x = 10

m = 20	M = 97.70
m = 25	M = 68.29
m = 30	M = 42.09
	208.08

x = 20

M = 210.89
M = 157.69
M = 108.49
477.07

x = 30

M = 117.54
M = 155.71
M = 199.20
472.45

x = 40

m = 20	M = 41.68
m = 25	M = 62.34
m = 30	M = 89.22
	193.24

x = 50

M = -16.71
M = -9.91
M = 3.55
-23.07

x = 60

M = -57.62
M = -61.05
M = -57.82
-176.49

x = 70

m = 20	M = -81.05
m = 30	M = -91.07
m = 40	M = -94.87
	-266.99

x = 80

M = -87.00
M = -99.98
M = -107.62
-294.60 MAX(-)

x = 90

M = -75.48
M = -87.77
M = -96.05
-259.60

x = 100

m = 20	M = -46.48
m = 25	M = -54.44
m = 30	M = -60.18
	-161.10

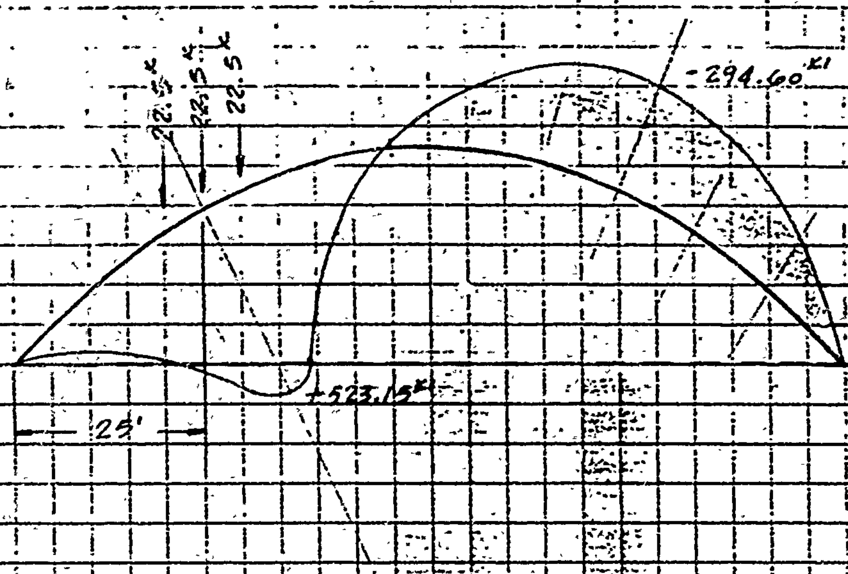
x = 25

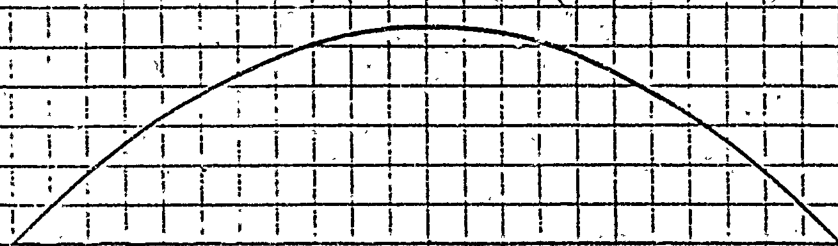
M = 162.02
M = 210.32
M = 150.81
523.15 MAX.(+)

$$M_{25} = (22.5)(20)(1 - {}^{25}/_{110}) - (9.613)(19.3182) = 162.02$$
(m = 20)

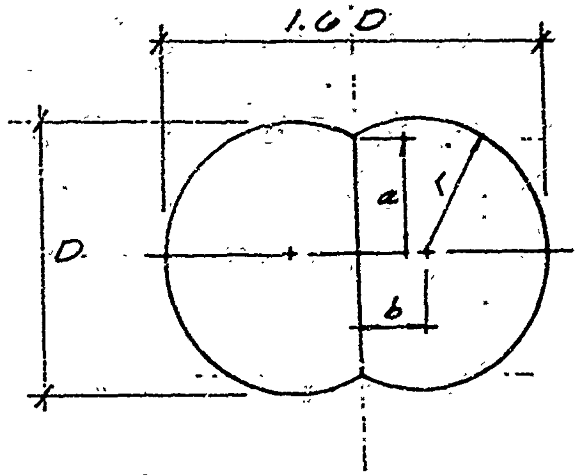
$$M_{25} = {}^{(22.5)(80)(25)}/_{110} - (13.370)(19.3182) = 150.807$$
(m = 30)

Tank Loading Spans Over 15' ; Stressing 3 Cables/Arch
(Max. Moments Occure @ 20, 25, 30 on intervals)





INVESTIGATE INFLATION PRESSURES & FABRIC STRESSES:



MAX. BENDING MOMENT IS
523.15 KIP-FT. = 6.278×10^6 IN.-LBS.

IF $a = .8r$
$b = .6r$

FABRIC STRESS DUE TO BENDING (S_B):

$$S_B = \frac{M}{2N(ab + r^2 \sin^{-1}(b/r))}$$

N = No. OF CELLS
M = MOMENT
(ASSUME WEB CARRIES NO LOAD)

$$S_B = \frac{M}{2N(.48r^2 + r^2 \sin^{-1}(.6))}$$

$$S_B = \frac{M}{2.247\, N r^2}$$

TO PREVENT COMPRESSION FAILURE $S_I = S_B$

FABRIC STRESS DUE TO INFLATION (S_I)

$$S_I = \frac{P(r^2 \sin^{-1}(b/r) + ab)}{2r \sin^{-1}(b/r)}$$ (WEB CARRIES NO LOAD)

OR

$$P = \frac{S_I\, 2r \sin^{-1}(b/r)}{r^2 \sin^{-1}(b/r) + ab}$$ FOR $S_I = S_B$

$$P = \frac{(S_B)(2r)(\sin^{-1}(.6))}{r^2 \sin^{-1}(.6) + .48r^2} = 1.146\, S_B / r$$

$$P = \frac{1.146}{r}\left(\frac{M}{2.247\, N r^2}\right) = .51\, M / N r^3$$

FOR $N = 2$
$M = 6.278 \times 10^6$ IN-LBS.

$$P = 1.600 \times 10^6 / r^3 \quad (\text{LBS./IN}^2)$$

MAX. LONGITUDINAL FABRIC STRESS: (S_L)

$S_{L_{MAX.}} = S_B + S_I$ SINCE $S_B = S_I$

$S_{L_{MAX.}} = 2S_B = (2)\left(\frac{M}{2.247 N r^2}\right)$ FOR $N = 2$

$M = 6.278 \times 10^6$ IN-LBS.

$S_L = 2.794 \times 10^6 / r^2$ (LBS./IN.)

MAX. TRANSVERSE FABRIC STRESS: (S_T)

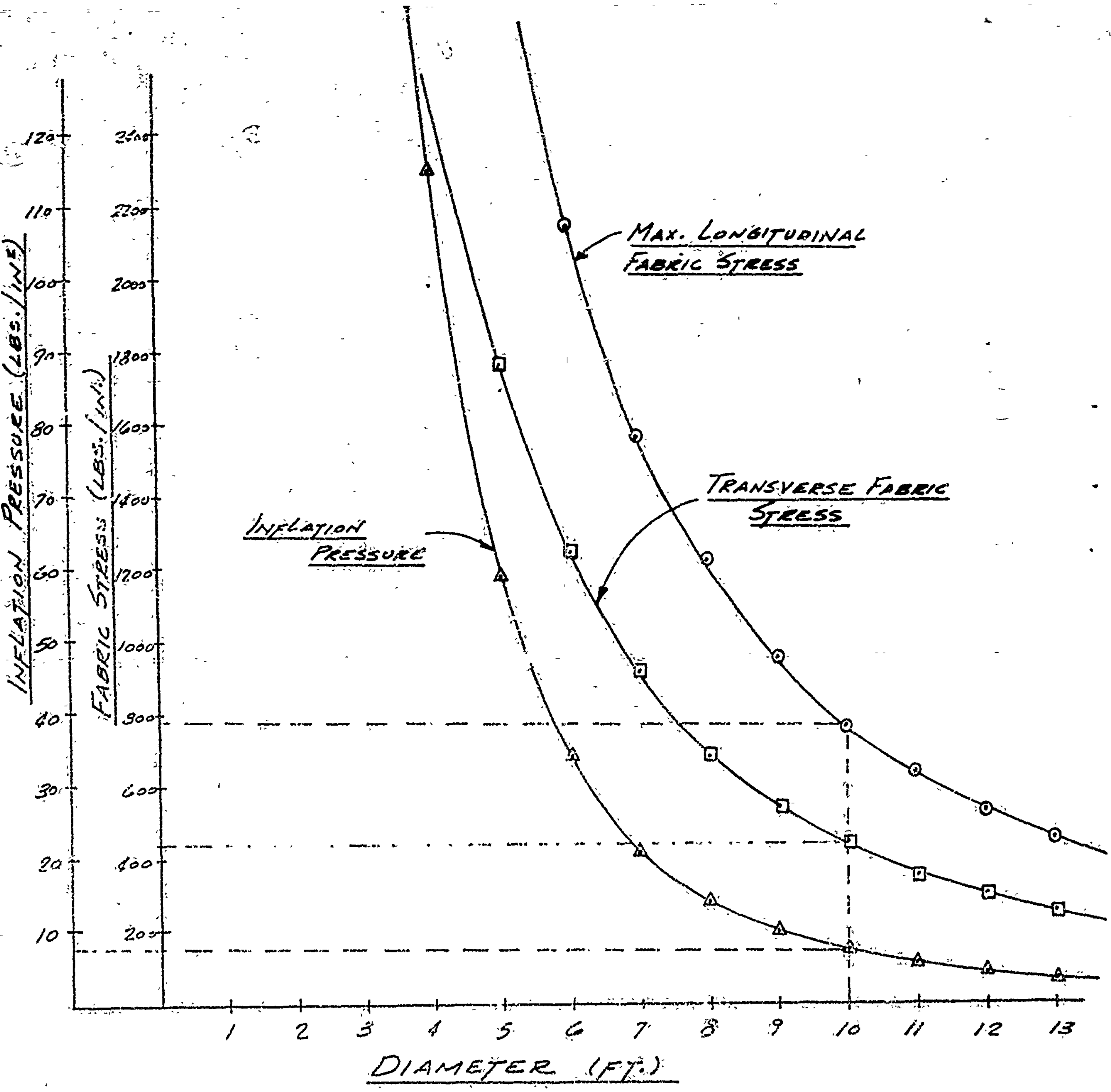
$S_T = Pr$

```
10 FOR D=1 TO 15 STEP 1
>20 F
20 BAD FORMAT
>20 R=6*D
>30 P=1600000/(R*R*R)
>40 S1=2794000/(R*R)
>50 S2=P*R
>60 PRINT D,P,S1,S2
>70 NEXT D
>80 END
>RUN
14:57   12/27
```

DIA. (FT.)	PRESS (LBS./IN²)	LONG. FABRIC STRESS (LBS/IN)	TRANS. FABRIC STRESS (LBS./IN.)
1	7407.41	77611.1	44444.4
2	925.926	19402.8	11111.1
3	274.348	8623.46	4938.27
4	115.741	4850.69	2777.78
5	59.2593	3104.44	1777.78
6	34.2936	2155.86	1234.57
7	21.5959	1583.90	907.029
8	14.4676	1212.67	694.444
9	10.1611	958.162	548.697
10	7.40741	776.111	444.444
11	5.56529	641.414	367.309
12	4.28669	538.966	308.642
13	3.37160	459.237	262.985
14	2.69949	395.975	226.757
15	2.19479	344.938	197.531

```
80 HALT
>SYS

!BYE
12/27/ '72 14:58
CLT 7
CCU 0.020
```

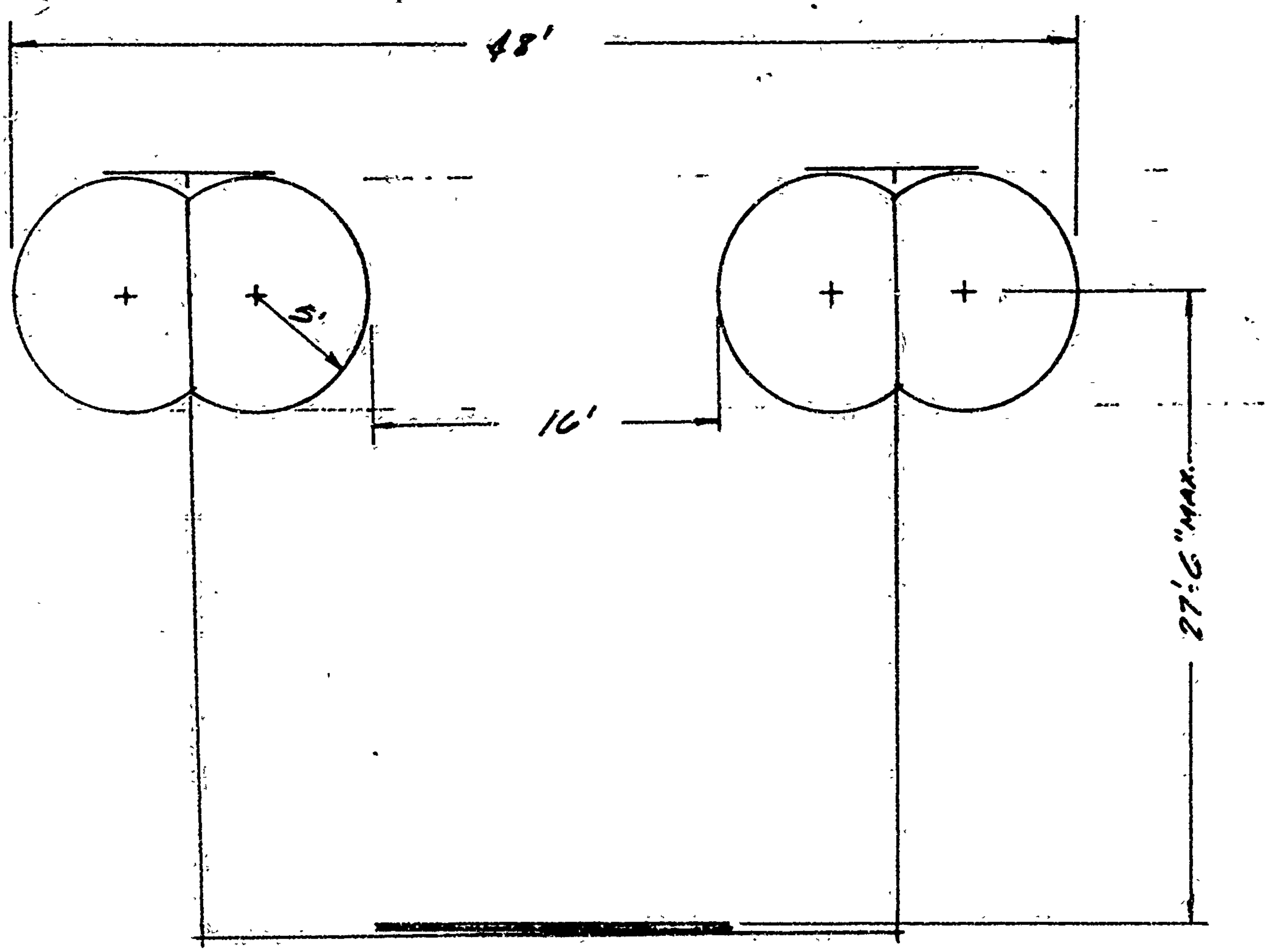


FOR 10FT. DIMETER ARCH

MAX. LONG. FABRIC STRESS = 776 LBS./IN.

TRANS. FABRIC STRESS = 444 LBS./IN.

INFLATION PRESSURE = 7.4 LBS./IN²



OVERALL DIMENSIONS - 48 FT. W X 32'-6 H
FABRIC STRESS - 776 LBS./IN.
INFLATION PRESSURE - 7.4 LBS./IN^2
VOLUME = $(2)[(2)(\pi)(10)^2/4 - (9.27)(5) - (8)(5-2)] \times 126 = 21,856$ FT^3

SURFACE AREA = $(2)[2(\pi)(10) - (2)(9.27)]\, 126 = 11,162$ FT^2

CONCEPT Nº 6

INVERSE SUSPENSION

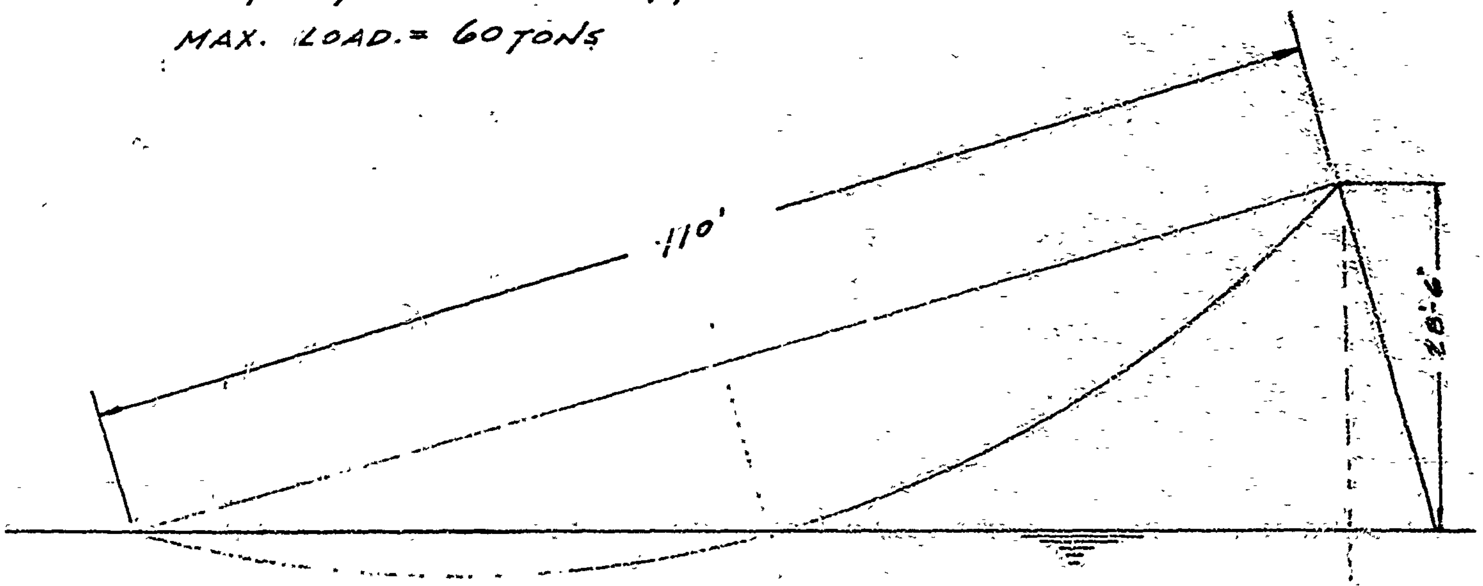
BRIDGE

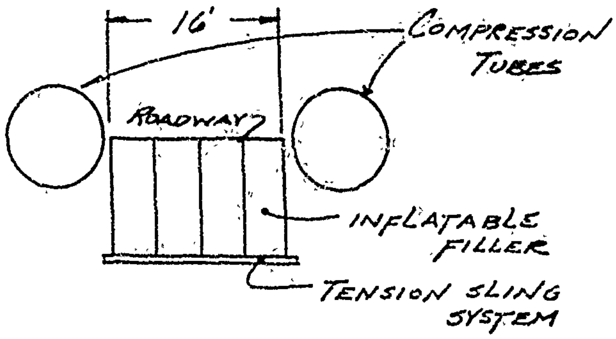
C-59a

INVERSE SUSPENSION BRIDGE CONCEPT:

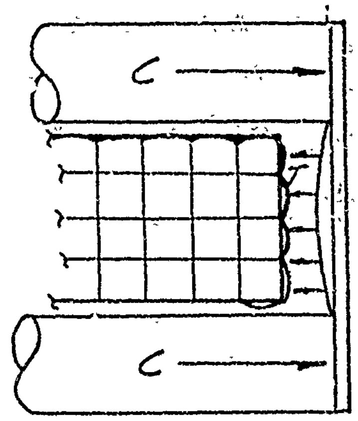
DESIGN DATA:

LENGTH = 110 FT.
WIDTH OF ROADWAY = 16 FT.
MAX. LOAD = 60 TONS





SECTION



PLAN VIEW

FILLER SYSTEM:

$$p = \frac{LOAD}{AREA} = \frac{120{,}000^{\#}}{(16)(15)} = 4 \text{ LBS/IN}^2$$

$$S_s = (p)(r) = (4)(48) = 192 \text{ LBS./IN.}$$

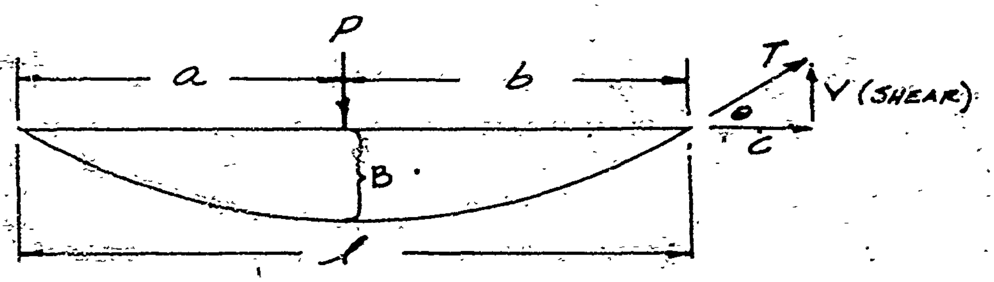
```
5=XISEARCH
12/18/  '72 11:53
!LØGIN: 15073RD,C,
ID= D
!BASIC
>10 FØR B=1 TØ 15
>20 LET R=(((4*B*B)+(110*110))/(8*B))
>30 LET A=ATN(55/(R-B))
>40 LET T=120000/SIN(A)
>50 LET C=T*CØS(A)
>60 PRINT B,R,A,T,C
>70 NEXT B
>80 END
>RUN
11:56    12/18
```

B	R (FT.)	ANGLE (RAD.)	TENSION	COMPRESSION
1	1513	3.63596E-02	3.30109E+06	3.29891E+06
2	757.250	7.26952E-02	1.65218E+06	1.64782E+06
3	505.667	.108983	1.10327E+06	1.09673E+06
4	380.125	.145199	829364.	820636.
5	305	.181320	665455.	654545.
6	255.083	.217322	556545.	543455.
7	219.571	.253184	479065.	463792.
8	193.063	.288883	421227.	403773.
9	172.556	.324398	376485.	356848.
10	156.250	.359707	340909.	319091.
11	143	.394791	312000.	288000.
12	132.042	.429631	288091.	261909.
13	122.846	.464208	268028.	239664.
14	115.036	.498504	250987.	220442.
15	108.333	.532504	236364.	203636.

```
80 HALT
>SYS

!BYE
12/18/  '72 11:58
CLT 5
CCU 0.012
```

INVESTIGATE SUSPENSION CONCEPTS:

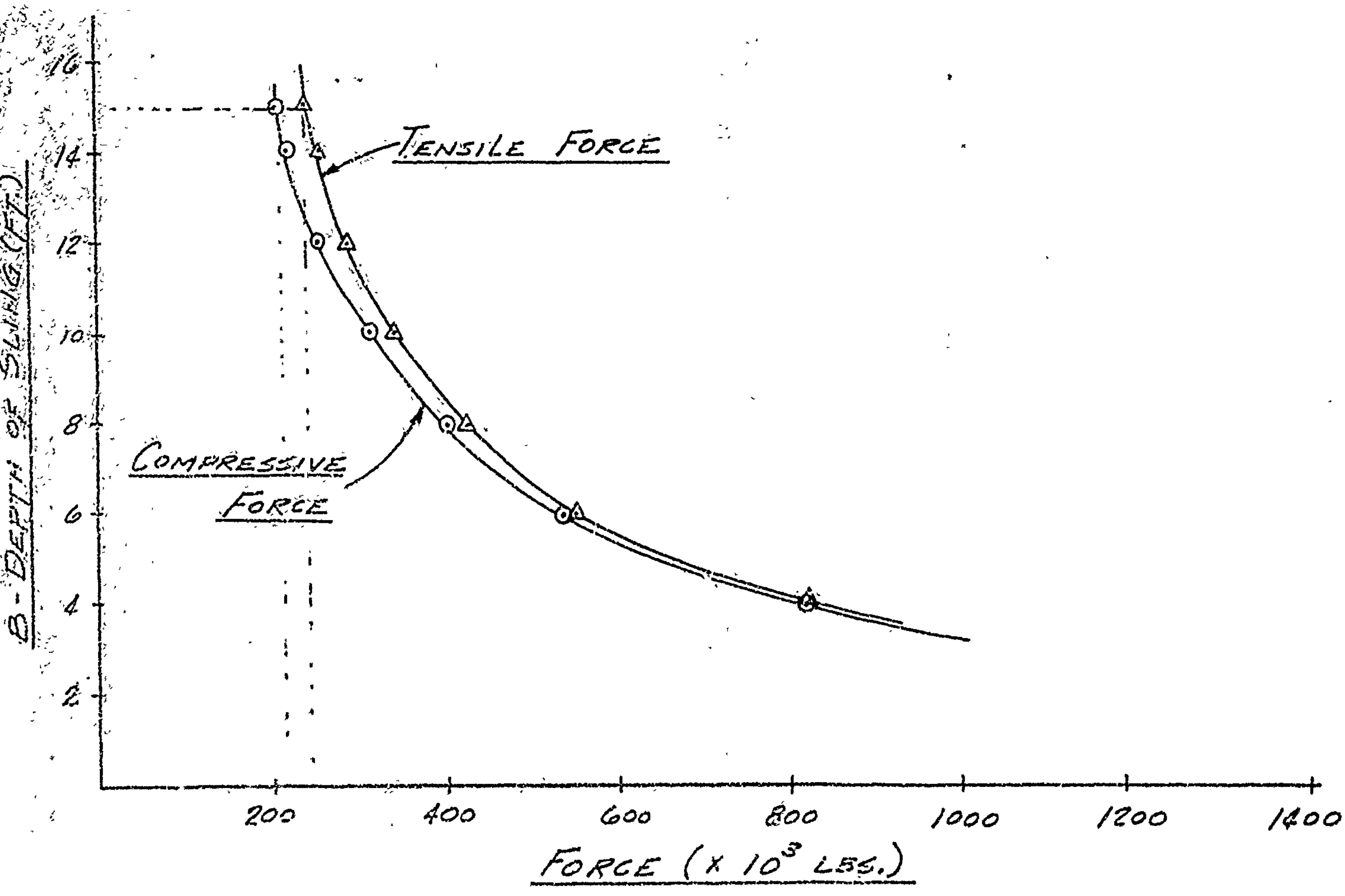


V(MAX.) OCCURES WHEN P IS AT SUPPORT

$T = V / \sin \theta$

$C = T \cos \theta$

FOR $P = 120{,}000$ LBS.
$l = a = 110$ FT



```
AX:5QJERSEARCH
12/18/  '72 14:30
!LØGIN: 1507BRD,C,
ID= A
!BASIC
>10 LET C=101818
>20 FØR P=10 TØ 25
>30 LET D=SQR((4*C)/(P*3.14))
>40 LET S=P*(D/2)
>50 PRINT P,D,S
>60 NEXT P
>70 END
>RUN
14:33    12/18
```

P	DIA.	FABRIC STRESS
10	113.888	569.439
11	108.588	597.233
12	103.965	623.790
13	99.8863	649.261
14	96.2528	673.770
15	92.9891	697.418
16	90.0363	720.290
17	87.3480	742.458
18	84.8870	763.983
19	82.6229	784.918
20	80.5309	805.309
21	78.5901	825.196
22	76.7832	844.615
23	75.0954	863.597
24	73.5143	882.172
25	72.0290	900.363

```
70 HALT
>SYS

!BYE
12/18/  '72 14:34
CLT 3
CCU 0.010
```

FOR $B = 15$ FT.

$T = 236{,}364$ LBS.
$C = 203{,}636$ LBS.

t (PER INCH OF WIDTH) = 236,364 LBS / (16 FT.)(12 IN/FT.)

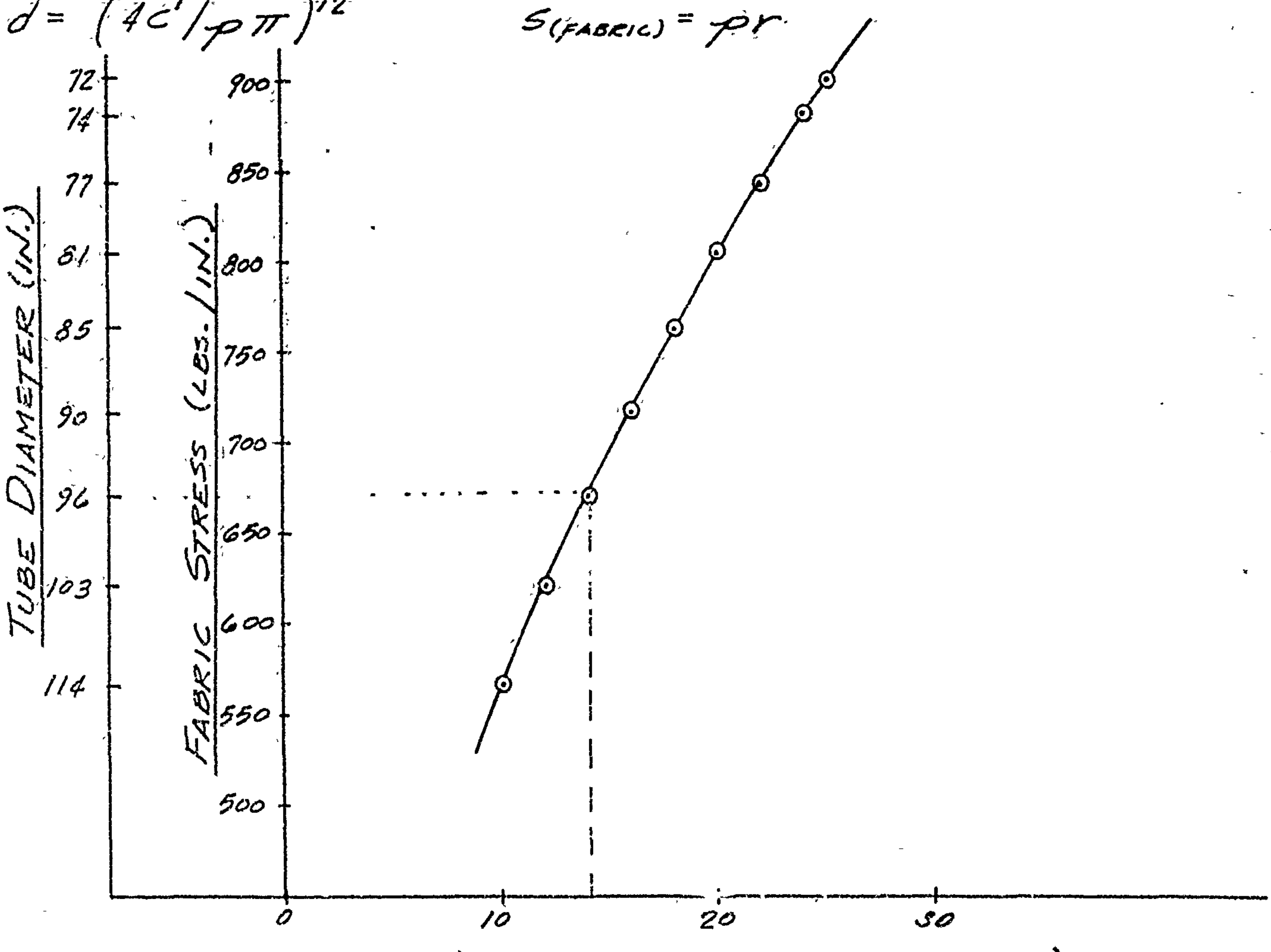
$t = 1231$ LBS/IN.

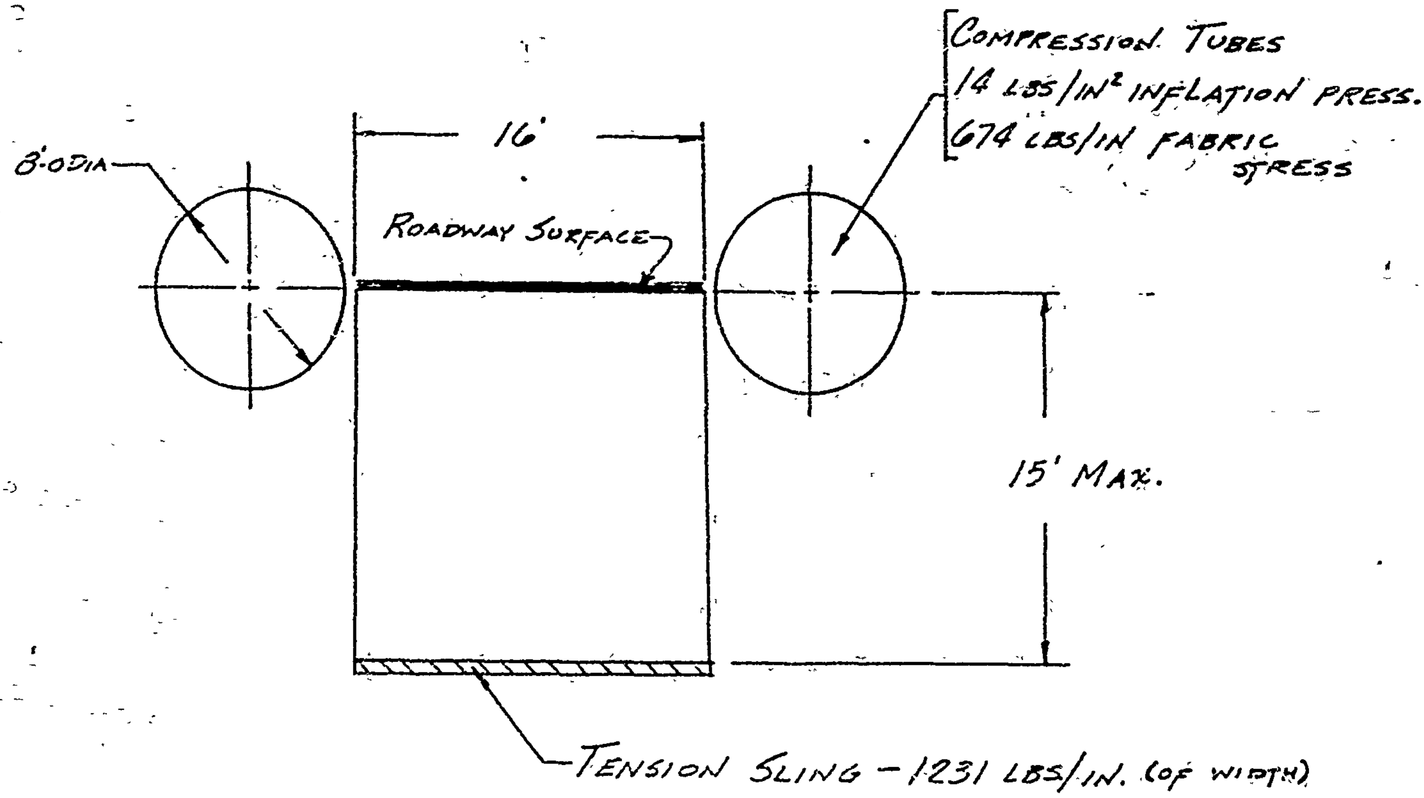
$C/2 = 101{,}818$ LBS. PER TUBE $= C'$

$A = \frac{C/2}{p} = \frac{C'}{p}$ p = INFLATION PRESSURE

$A = \pi d^2/4$

$d = (4C'/p\pi)^{1/2}$





OVERALL DIMENSIONS - 32 FT. W X 19' H
FABRIC STRESS - 674 LBS./IN.
INFLATION PRESSURE - 14 LBS/IN²
VOLUME - TUBES - $(\pi)(8)^2/4 \times 110 \times 2 = 11{,}058$ FT.³
FILLER - $(2/3)(110)(15)(16) = 17{,}600$ FT³
SURFACE AREA - TUBES - $(\pi)(8)(110)(2) = 5529$ FT.²
FILLER - $(2/3)(110)(15)(2) + (110)(16) + (115)(16) = 5800$ FT²

CONCEPT № 7

TUBES

WITH

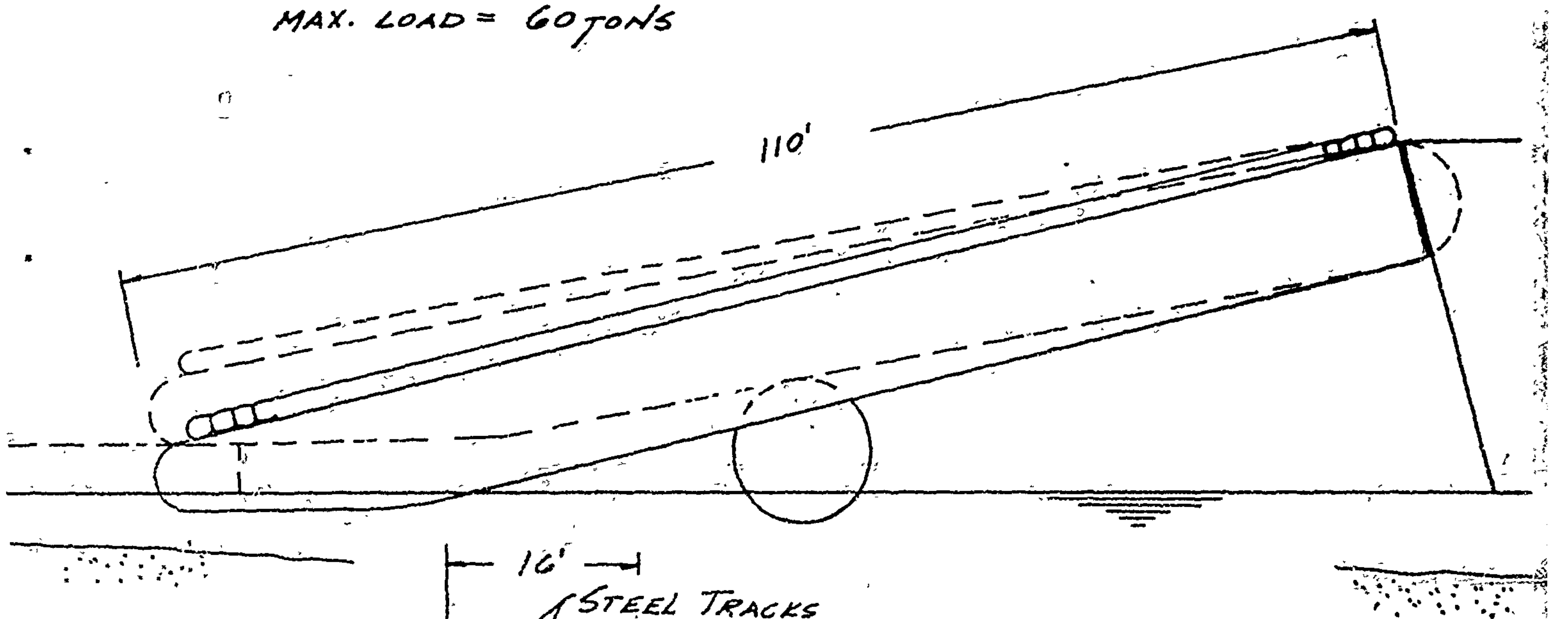
SUPPORT

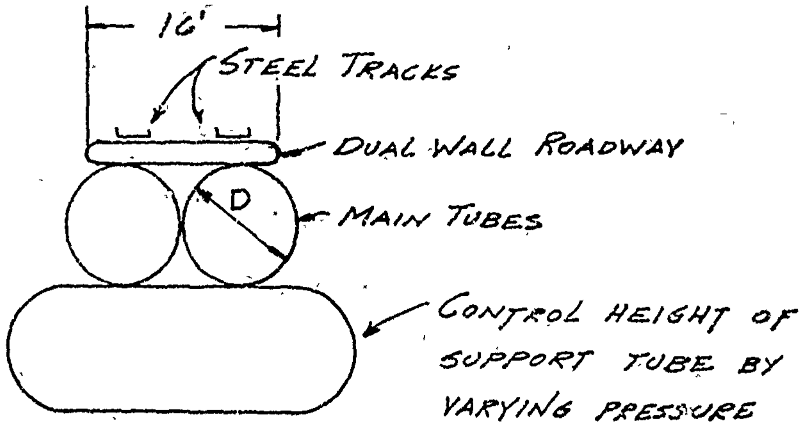
C-65a

CIRCULAR TUBES WITH SUPPORT CONCEPT:

DESIGN DATA:

LENGTH = 110 FT.
WIDTH OF ROADWAY = 16 FT.
MAX. LOAD = 60 TONS





SECTION

(TRANSITION PIECE REQD. AT BEACH OR CAUSEWAY END OF RAMP)

$S_I = S_B$

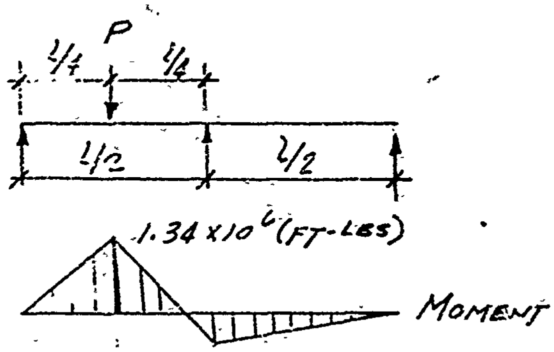
LONGITUDINAL STRESS (INFLATION) $S_I = pd/4$

LONGITUDINAL STRESS (MOMENT) $S_B = M/\text{AREA} = \frac{4M}{\pi d^2}$

INFLATION PRESSURE TO RESIST BENDING $p = \frac{4}{d}\left(\frac{4M}{\pi d^2}\right) = \frac{16M}{\pi d^3}$

MAX. FABRIC STRESS $= (pd/4)(2) = pd/2$

INVESTIGATE VARIOUS BENDING MOMENT CONDITIONS:



$P = 120{,}000$ LBS.

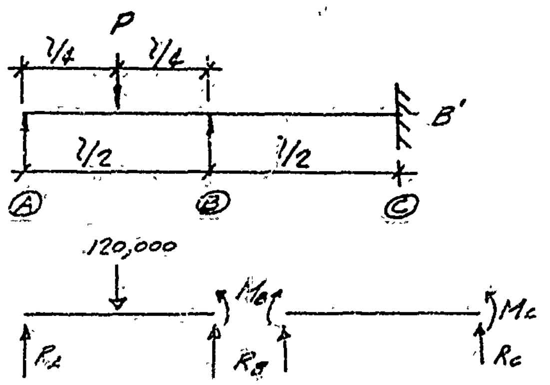
$l = 110$ FT.

$M_{(MAX)} = \frac{13}{64}(P)(l/2)$ (FROM HANDBOOK)

$M_{(MAX.)} = \frac{13}{64}(120{,}000)(55)$

$M_{(MAX)} = 1{,}340{,}625$ FT-LBS.

$= 16.088 \times 10^6$ IN-LBS.



(SOLVE BY THREE MOMENT EQUATION)

$\overset{0}{M_A}(55) + (2)(M_B)(110) + M_C(55) = -(120{,}000)(27.5)(27.5)(1 + 1/2)$

$4M_B + M_C = -2{,}475{,}000$ (FT.-LBS.)

$M_B(55) + 2M_C(55+0) + M_{B'}(0)$

$M_B = -2M_C$

$-8M_C + M_C = -2{,}475{,}000$

$M_C = 353{,}571$ FT.-LBS.

$M_B = -707{,}143$ FT.-LBS.

$\circlearrowleft + \Sigma M_A = 0$

$(120{,}000)(27.5) - (-707{,}143) = 55R_B$

$R_B = 72{,}875$ LBS.

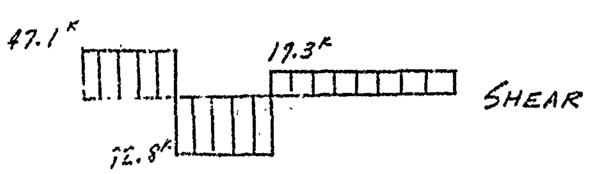
$\uparrow + \Sigma F_V = 0 \quad \therefore R_A = 47{,}143$ LBS.

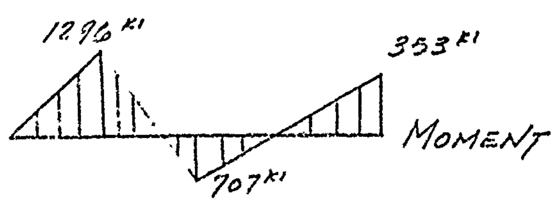
$\circlearrowleft + \Sigma M_C = 0$

$-353{,}571 + (-707{,}143) + 55R_B = 0$

$R_B = 19{,}286$ LBS.

$\Sigma F_V = 0 \quad R_C = -19{,}286$ LBS (ACTING DOWN)





$M_{(MAX)} = 1{,}296{,}000$ FT-LBS.

$= 15.552 \times 10^6$ IN-LBS.

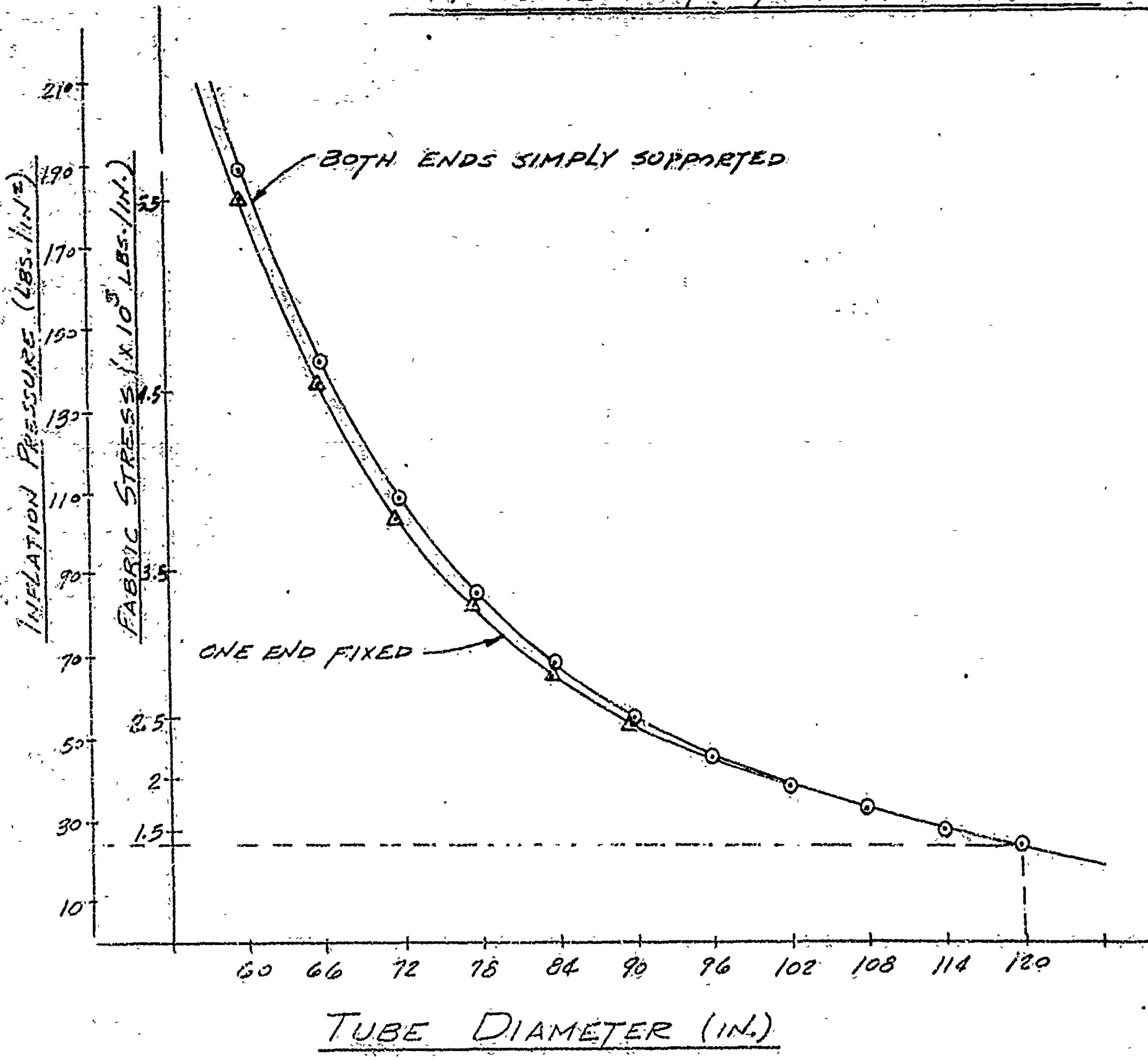
```
XOC
RSEARCH
01/03/  '73 12:54
!LØGIN: 157FFF
 ?
!LØGIN: 1507BRD,C,
ID= B
!BASIC
>10 FØR D=60 TØ 120 STEP 6
>20 M=8044000 (EA. TUBE)
>30 P=(16*M)/(3.14*D*D*D)
>40 S=(P*D)/2
>50 PRINT D,P,S
>60 NEXT D
>70 END
>RUN                    (LBS./IN²)       (LBS./IN.)
12:56    01/03          PRESS.           STRESS
 60  DIA.               189.762          5692.85
 66  (IN.)              142.571          4704.84
 72                     109.816          3953.37
 78                     86.3731          3368.55
 84                     69.1552          2904.52
 90                     56.2257          2530.16
 96                     46.3285          2223.77
 102                    38.6244          1969.85
 108                    32.5380          1757.05
 114                    27.6661          1576.97
 120                    23.7202          1423.21


70 HALT
>10 FØR D=60 TØ 120 STEP 6
>20 M=7776000 (EA. TUBE - FIXED END)
>30 P=(16*M)/(3.14*D*D*D)
>40 S=(P*D)/2
>50 PRINT D,P,S
>60 NEXT D
>70 END
>RUN
12:59    01/03
 60                     183.439          5503.18
 66                     137.821          4548.09
 72                     106.157          3821.66
 78                     83.4954          3256.32
 84                     66.8511          2807.75
 90                     54.3524          2445.86
 96                     44.7850          2149.68
 102                    37.3376          1904.22
 108                    31.4540          1698.51
 114                    26.7443          1524.43
 120                    22.9299          1375.80


70 HALT
>SYS

!BYE
01/03/  '73 12:59
CLT 4
CCU 0.020
```

REQUIREMENTS FOR MAIN TUBES



FOR DIA. = 120 IN. = 10 FT.

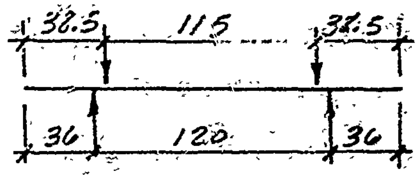
BOTH ENDS SIMPLY SUPPORTED:

$p = 23.7$ LBS./IN² $s = 1423$ LBS./IN.

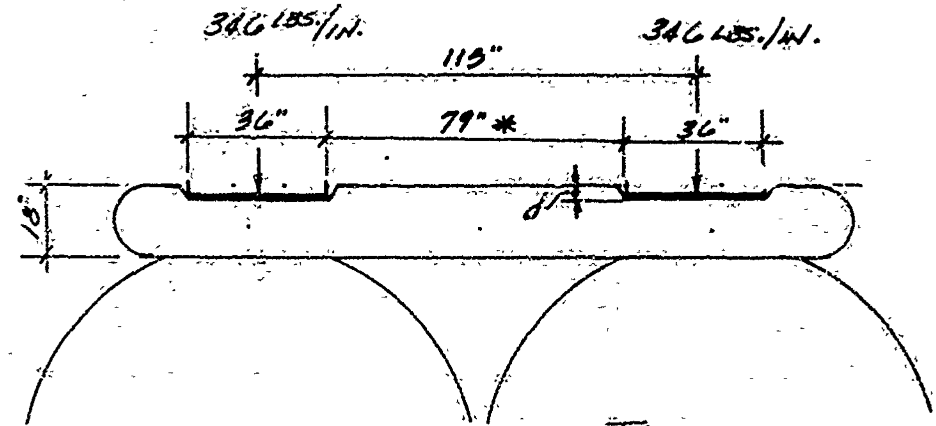
ONE END FIXED:

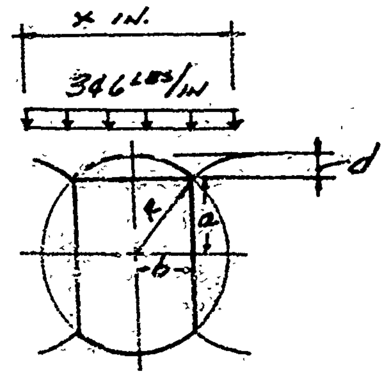
$p = 22.9$ LBS./IN² $s = 1376$ LBS./IN.

DUAL WALL ROADWAY:



TRACK SPACING ON 60 TON TANK = 115 IN.
TRACK WIDTH = 27" USE 36" SUPPORT TRACK





+ (1/4 SCALE) +

TANK LOADING PER INCH = 60,000 LBS / 173 IN. = 346 LBS./IN. (PER TRACK)

FOR PRELIMINARY DESIGN, CONSIDER TANK LOADING CRITICAL. BENDING MOMENT IN DUAL WALL ≈ 0. HIGH INFLATION REQD. TO KEEP LOCAL DEFLECTION TO A MINIMUM.

DUAL WALL DESIGN - $a/b \geq 1.3$ LET $a = 1.3b$

$d = R - a$

$R = (a^2 + b^2)^{1/2} = ((1.3b)^2 + b^2)^{1/2} = (2.69b^2)^{1/2} = 1.64b$

$d = 1.64b - 1.3b = .34b$

IF ALLOWED TO DEFLECT TO WEB LINE, THEN:

AREA OF CONTACT = (2b)(WIDTH OF TRACK) = 72b (IN²) (for $d = .34b$)

LOAD = (346 LBS./IN.)(2b) = 692b (LBS.)

INFLATION PRESSURE = LOAD/AREA = 692b/72b = 9.6 LBS./IN²

FOR R = 9 IN. b = 9/1.64 = 5.48 IN d = (5.48)(.34) = 1.86 IN.

$S = pR = (9.6)(9) = 86.5$ LBS./IN.

* 79" DIMENSION WILL HAVE TO BE REDUCED FOR OTHER VEHICLES UNDER THE P-25 ALLOWANCE. BENDING MOMENT WILL EFFECT THE DUAL WALL BEAM FABRIC STRESSES.

OVERALL DIMENSIONS – 20 FT. W x 12 FT D
FABRIC STRESS – 1423 LBS./IN.
INFLATION PRESSURE – 23.7 LBS./IN^2
VOLUME – TUBES – $2 \times (\pi)(10)^2/4 \times 110' = 17,279$ FT^3
DUALWALL – $(\pi)(1.5)^2/4 \times 18' \times 73 = 2,322$ FT^3
SURFACE AREA – TUBES – $(\pi)(10)(2)(110) = 6911$ FT^2
DUAL WALL – $(18)(1.5)(110) = 2970$ FT^2

TUBE TUNNEL CONCEPT

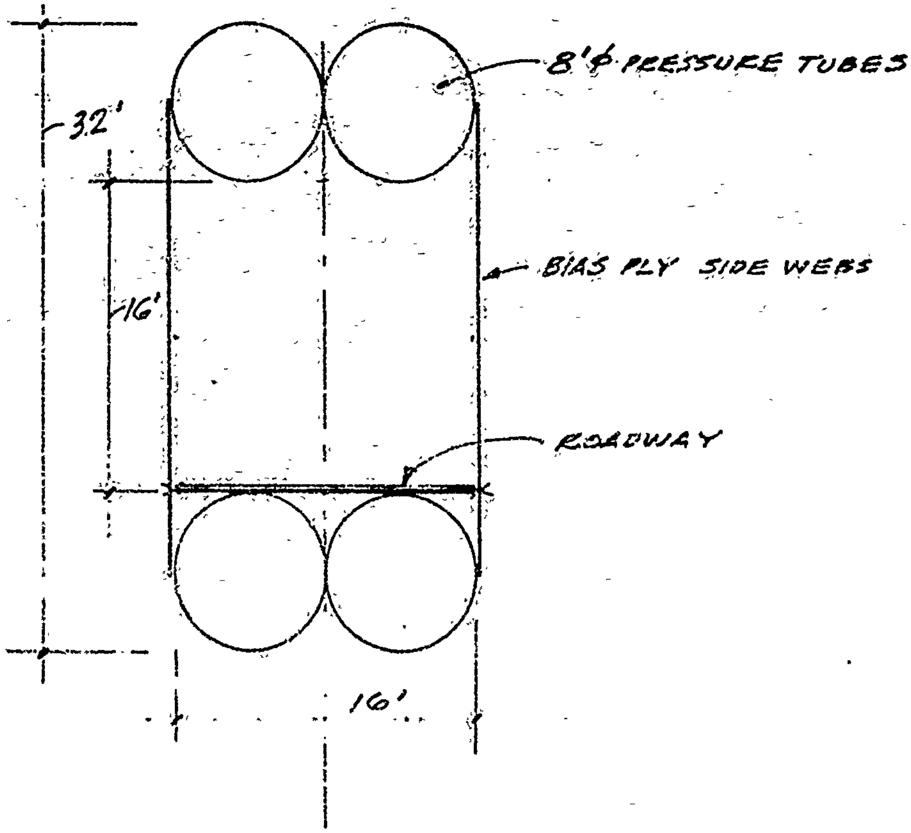
DESIGN DATA:

INSIDE WIDTH - 16 FT.
INSIDE HEIGHT - 16 FT.
LENGTH - 110 FT.
LOAD - 60 TONS

THE MAXIMUM BENDING MOMENT WITH A TANK AT MID SPAN

IS $M = \frac{PL}{4} = \frac{120\,000(110)}{4} = 3{,}300{,}000$ FT. LBS.

RAMP CROSS SECTION IS -



IF SIDE WEBS CARRY NO SHEAR THEN MOMENT PER

TUBE IS $M_T = \frac{M}{4} = \frac{3{,}300{,}000}{4} = 825{,}000$ 1#

THE BENDING STRESS IS

$$S_B = \frac{4M}{\pi d^2} = \frac{4(825{,}000)}{\pi (8)^2} = 16413\ \#/'$$

$$= 1368\ \#/''$$

THE PRESSURE REQ'D. IS

$$P = \frac{4S_2}{d} = \frac{4(1368)}{96} = 57 \text{ psi.}$$

MAX. STRESS IS

$$S_M = \frac{Pd}{2} = \frac{57(96)}{2} = 2736 \text{ \#/"}$$

IF SIDE WEBS CARRY FULL SHEAR THEN THE FOUR TUBES ACT AS ONE BEAM. TAKING MOMENTS ABOUT THE CENTROID OF THE LOWER TUBES

$$PAy - M = 0$$

WHERE $A = 2\pi r^2$
$y = 16 + d$

$$P(2\pi r^2)(16+d) - M = 0$$

$$P = \frac{M}{(2\pi r^2)(16+d)} = \frac{3{,}300{,}000}{(2\pi 4^2)(16+8)} = 1368 \text{ PSF}$$

$$= 9.5 \text{ PSI.}$$

MAX. STRESS IS

$$S_M = \frac{Pd}{2} = \frac{9.5(96)}{2} = 456 \text{ \#/"}$$

OVERALL DIMENSIONS - 16 FT. W x 32 FT. H
FABRIC STRESS - 2736 LBS./IN - NO WEB CONTRIBUTION
456 LBS/IN - W/ WEB CONTRIBUTION
INFLATION - 57 LBS./IN^2 - NO WEB CONTRIBUTION
10 LBS./IN^2 - W/ WEB CONTRIBUTION

VOLUME - $4 \times \frac{(\pi)(8)^2}{4} \times 110' = 22{,}117 \text{ FT}^3$

SURFACE AREA = $4 \times (\pi)(8) \times 110' = 11{,}058 \text{ FT}^2$

CONCEPT № 9

HYBRID

TRUSS AND INFLATED

BLADDER

HYBRID STRUCTURE –

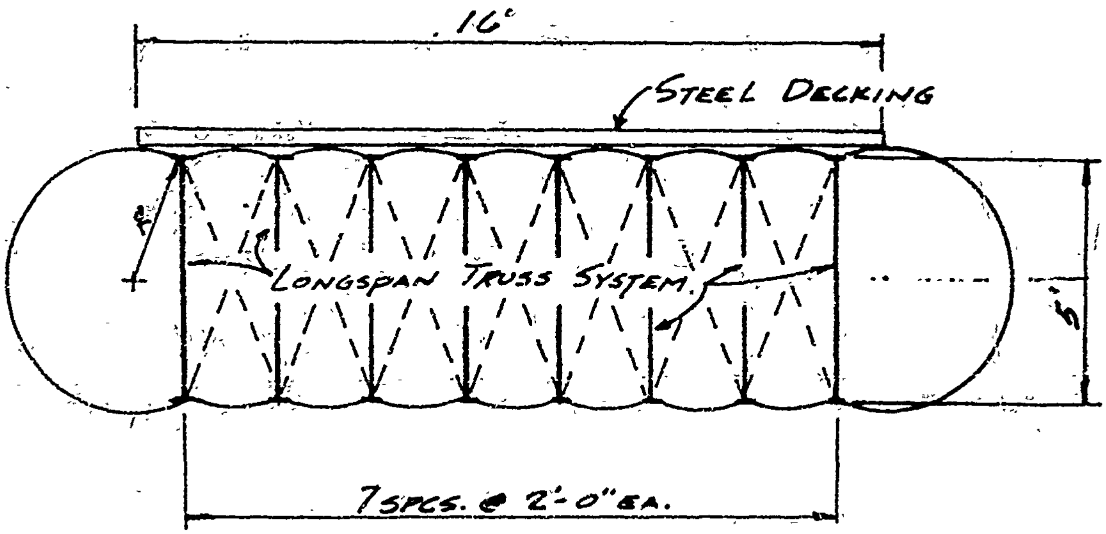
STEEL JOIST WITH INFLATABLE BLADDER

DESIGN CRITERIA:

LENGTH = 110 FT.

MIN. WIDTH = 16 FT.

MAX. LOAD = 60 TONS



LOADING – 60 TON TANK AT MIDSPAN:

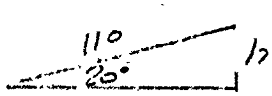
$M = \frac{PL}{4} = (120{,}000 \text{ LBS.})(110 \text{ FT.})/4 = 3.30 \times 10^6$ FT.-LBS.

EQUIVILENT UNIFORM LOADING – $M = \frac{WL^2}{8}$

$W = \frac{8}{(L^2)}(M) = \frac{8}{(110)^2}(3.30 \times 10^6) = 2181$ LBS./FT.

DISTRIBUTED OVER 8 JOISTS = 272 LBS./FT. LIVE LOAD PER JOIST

LOAD DISTRIBUTION AT MAX. INCLINATION OF 20°



$h = (110)(\sin 20°) = 37.62'$

$\text{SLOPE} = \frac{\text{RISE}}{\text{RUN}} = \frac{37.62}{110} = .342$ FT./FT. = 4 IN./FT.

$P = 120{,}000$ LBS.

$F_V = (120{,}000)(\cos 20°) = 112{,}763$ LBS.

$F_H = (120{,}000)(\sin 20°) = 41{,}042$ LBS.

LOAD DISTRIBUTION AT MAX. INCLINATION (CONT.)

$M = \frac{F_V L}{4} = (112,763)(110)/4 = 3.10 \times 10^6$ FT.-LBS.

EQUIVILENT UNIFORM LOADING = $M = \frac{wL^2}{8}$

$w = \frac{8}{(110)^2}(3.10 \times 10^6) = 2000$ LBS./FT.

DISTRIBUTED OVER 8 JOISTS = 256 LBS./FT. LIVE LOAD PER JOIST

$F_H = 41,042\text{ LBS.}/8 = 5130$ LBS. TENSION / JOIST

GENERAL REMARKS CONCERNING TRUSS SYSTEM:

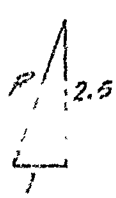
1. FROM STANDARD SPECIFICATIONS AND LOAD TABLES FOR DEEP LONGSPAN STEEL JOISTS, THE FOLLOWING CRITERIA MUST BE FOLLOWED.
   a) TOP COMPRESSION FLANGE LATERALLY SUPPORTED EVERY 36 IN. - CAN BE ACCOMPLISHED WITH DECK.
   b) MAX. SLOPE IN ORDER TO USE LOAD TABLES IS 1/2 IN./FT. - <u>SLOPE TO STEEP. - TABLES VOID</u>!

2. NECESSARY TO DESIGN A TRUSS SYSTEM - APPROX. 60 IN. DEEP TO CARRY HORIZONTAL AND VERTICAL FORCES.

PRESSURIZATION AND FABRIC STRESS:

PRESSURIZATION OF BLADDER REQD. TO SEPARATE JOISTS AND TENSION DIAGONAL CABLE BRIDGING.

ASSUME INFLATION PRESSURE = 5 LBS./IN^2



$R = [(2.5)^2 + (1)^2]^{1/2} = 2.69$ FT.

TRANSVERSE FABRIC STRESS = pR = MAX. STRESS

$S_T = (5\text{ LBS./IN}^2)(2.69)(12) = 161$ LBS./IN.

STANDARD LOAD TABLE FOR

BASED ON

This table was developed using 30 000 psi allowable tensile stress. Steels with allowable tensile stresses from 22,000 psi to 30,000 psi may be used to meet this load table. The following table gives the TOTAL safe uniformly distributed load-carrying capacities in pounds per linear foot of span.

All loads shown are for roof construction only. The weight of DEAD loads, including weight of joists, must in all cases be deducted to determine the LIVE load-carrying capacity of the joists. Approximate weights per linear foot of joist include accessories.

The figures shown in red are the LIVE loads per linear foot of joist which will produce an approximate deflection of 1/360 of the span. Loads which will produce an approximate deflection of 1/240 of the span may be obtained by multiplying the red figures by 1.5. (NOTE: The tabulated loads corresponding to these deflection limitations have been computed on the basis of 30,000 psi allowable stress provisions. For joists designed to a lower working stress, these loads may be increased in the ratio of 30,000 psi to the design stress used, in order to meet the same deflection limitations.) For roofs, LIVE load deflection is limited to 1/360 of the span where a plaster ceiling is attached or suspended; 1/240 of the span for all other cases. In no case shall the TOTAL capacity of the joists be exceeded.*

When holes are required in the top or bottom chords, the carrying capacities must be reduced in proportion to reduction of chord areas.

The top chords are considered as being stayed laterally by the roof deck.

The load table applies to joists with either parallel chords or standard pitched chords. When top chords are pitched, the carrying capacities are determined by the nominal depth of the joist at the center of the span. Standard top chord pitch is ⅛" per foot. If pitch exceeds this standard, the load table does not apply.

The load table may be used for parallel chord joists installed to a maximum slope of ½" per foot.

Joist Designation	Approx. Wt. in Lbs. per Linear Ft.	Depth in Inches	SAFE LOAD** in Lbs. Between	CLEAR OPENING OR NET SPAN IN FEET															
52DLH10	27	52	26700	288	281	285	279	273	267	261	256	251	246	241	236	231	227	223	218
				180	174	168	163	158	153	148	144	139	135	131	127	123	120	116	113
52DLH11	29	52	29300	327	320	313	306	279	293	287	281	275	270	264	259	254	249	244	240
				197	191	184	178	173	167	162	157	152	148	143	139	135	131	127	124
52DLH12	31	52	32700	365	357	349	342	334	327	320	314	307	301	295	289	284	278	273	268
				215	208	202	195	189	183	177	172	167	162	157	152	148	143	139	135
52DLH13	36	52	39700	443	433	424	414	406	397	389	381	373	366	358	351	344	338	331	325
				260	252	244	236	228	221	214	208	201	195	190	184	179	173	168	164
52DLH14	40	52	45400	507	497	486	476	466	457	447	438	430	421	413	405	397	390	382	375
				291	281	272	263	255	247	239	232	225	218	212	205	199	194	188	183
52DLH15	45	52	51000	569	[illegible]	545	533	522	511	500	490	480	470	461	451	443	434	426	418
				328	317	307	297	287	278	270	261	253	246	238	231	225	218	212	206
52DLH16	50	52	55000	614	601	588	575	563	551	540	528	518	507	497	487	478	468	459	451
				365	353	342	331	320	310	301	291	282	274	266	258	250	243	236	229
52DLH17	55	52	63300	706	691	676	661	647	634	620	608	595	583	572	560	549	539	528	518
				416	402	389	376	365	353	342	332	321	312	302	294	285	277	269	261
56DLH11	29	56	28100	288	283	277	272	267	262	257	253	248	244	239	235	231	227	223	219
				178	172	167	162	157	153	148	144	140	136	132	129	125	122	119	116
56DLH12	31	56	32300	331	324	318	312	306	300	295	289	284	278	273	268	263	259	254	249
				194	188	183	177	172	167	162	158	153	149	145	141	137	133	130	126
56DLH13	36	56	39100	401	394	386	379	372	365	358	351	344	338	331	325	319	314	308	303
				235	228	221	215	208	202	196	191	185	180	175	170	166	161	157	153
56DLH14	40	56	44200	453	444	435	427	419	411	403	396	388	381	375	368	361	355	349	343
				263	255	247	240	233	226	220	213	207	201	196	191	185	180	176	171
56DLH15	45	56	50500	518	508	498	488	478	469	460	451	443	434	426	419	411	403	396	389
				296	287	278	270	262	255	247	240	233	227	221	215	209	203	198	192
56DLH16	50	56	54500	559	548	537	526	516	506	496	487	478	469	460	452	444	436	426	[illegible]
				330	320	310	301	292	284	276	268	260	253	246	239	233	226	220	[illegible]
56DLH17	55	56	62800	643	630	618	605	594	582	571	560	549	539	529	520	510	501	492	[illegible]
				375	364	353	343	333	323	314	305	296	288	280	272	265	258	251	244

C-76

DEEP LONGSPAN STEEL JOISTS/DLH SERIES

[M]AXIMUM ALLOWABLE TENSILE [illegible]

Each span cell gives two values (upper / lower) as printed.

Joist Designation	Approx. Wt. in Lbs. per Linear Ft.	Depth in Inches	SAFE LOAD** in Lbs. Between	CLEAR OPENING OR NET SPAN IN FEET															
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	119-120
60DLH12	31	60	31100	295 177	289 172	284 167	279 163	274 158	270 154	265 150	261 146	256 142	252 138	248 135	244 131	240 128	236 125	232 122	228 119
60DLH13	36	60	37800	358 214	351 208	345 202	339 197	333 191	327 186	322 181	316 176	311 172	306 167	301 163	296 159	291 155	286 151	282 147	277 143
60DLH14	39	60	42000	398 228	391 222	383 216	376 210	370 204	363 199	356 193	350 188	344 183	338 179	332 174	327 170	321 165	316 161	310 157	305 153
60DLH15	45	60	49300	487 269	458 262	450 255	442 248	434 241	427 235	419 228	412 222	405 216	398 211	392 205	385 200	379 195	373 190	367 185	381 181
60DLH16	50	60	54200	513 300	504 292	494 284	485 276	476 269	468 261	460 254	451 248	444 241	436 235	428 229	421 223	414 217	407 212	400 207	393 201
60DLH17	55	60	62300	590 342	579 332	569 323	558 314	548 306	538 298	529 290	519 282	510 275	501 268	493 261	484 254	476 248	486 241	460 235	453 229
60DLH18	62	60	71900	681 386	668 376	656 365	644 355	632 345	621 336	610 327	599 319	589 310	578 302	568 294	559 287	549 280	540 273	531 266	522 259
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	127-128
64DLH12	31	64	30000	264 162	259 158	255 154	251 150	247 146	243 143	239 139	235 136	231 132	228 129	224 126	221 123	218 120	214 117	211 115	208 112
64DLH13	36	64	36400	321 196	315 191	310 186	305 181	300 177	295 172	291 168	286 164	281 160	277 156	273 152	269 149	264 145	260 142	257 138	253 135
64DLH14	39	64	41700	367 210	360 204	354 199	349 194	343 189	337 184	332 180	326 175	321 171	316 167	311 163	306 159	301 155	296 151	292 148	287 144
64DLH15	45	64	47800	421 247	414 241	407 235	400 229	394 223	387 217	391 212	375 207	359 202	363 197	358 192	352 187	347 183	341 179	336 174	331 170
64DLH16	50	64	53800	474 276	466 268	458 262	450 255	443 248	435 242	428 236	421 230	414 225	407 219	401 214	394 209	388 204	382 199	376 194	370 190
64DLH17	55	64	62000	546 314	536 306	527 298	518 290	509 283	501 276	492 269	484 262	478 256	458 250	461 244	454 238	446 232	439 227	432 222	426 216
64DLH18	62	64	71600	630 355	619 346	608 337	598 328	587 320	578 312	568 304	559 297	549 289	540 282	532 275	523 269	515 263	507 256	499 250	491 245
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	135-136
68DLH13	36	68	35000	288 181	284 177	279 173	275 168	271 164	267 161	263 157	259 153	255 150	252 146	248 143	244 140	241 137	237 134	234 131	231 128
68DLH14	39	68	40300	332 194	327 189	322 185	317 180	312 176	308 172	303 168	299 164	294 160	290 156	286 153	281 149	277 146	273 143	269 140	266 137
68DLH15	43	68	45200	372 217	365 212	360 207	354 202	348 197	343 192	337 188	332 184	327 179	322 175	317 171	312 167	308 164	303 160	298 156	294 153
68DLH16	50	68	53600	441 255	433 249	427 243	420 237	413 231	407 226	400 220	394 215	388 210	382 206	376 201	371 196	365 192	360 188	354 184	349 180
68DLH17	55	68	60400	497 290	489 283	481 276	474 270	467 263	460 257	453 251	446 245	439 240	433 234	427 229	420 224	414 219	408 214	403 209	397 205
68DLH18	62	68	69900	575 328	566 320	557 313	549 305	540 298	532 291	524 284	516 277	508 271	501 265	493 259	486 253	479 247	472 243	465 237	459 231
68DLH19	70	68	80500	662 372	651 363	641 354	631 346	621 337	611 330	601 322	592 314	583 307	574 300	565 293	557 287	548 280	540 274	532 268	525 262
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	143-144
72DLH14	39	72	39200	303 180	298 176	294 172	290 168	285 164	281 161	277 157	274 154	270 151	266 147	262 144	259 141	255 138	252 135	248 132	245 130
72DLH15	43	72	44900	347 202	342 197	336 193	331 188	326 184	322 180	317 176	312 172	308 169	303 165	299 161	295 158	291 155	286 151	282 148	279 145
72DLH16	50	72	51900	401 237	395 231	390 226	384 221	378 216	373 211	368 207	363 202	358 198	353 193	348 189	343 185	338 181	334 178	329 174	325 170
72DLH17	55	72	58400	451 270	445 264	438 258	432 252	426 246	420 241	414 236	408 230	402 225	397 221	391 216	386 211	381 207	376 202	371 198	366 194
72DLH18	62	72	68400	528 305	520 298	512 291	505 285	497 279	490 272	483 266	479 261	470 255	463 249	457 244	450 239	444 234	438 229	432 224	426 220
72DLH19	70	72	80200	619 346	609 338	600 330	591 323	582 316	573 309	565 302	557 295	549 289	541 283	533 277	526 271	518 265	511 260	504 254	497 249

*Section 204.10 of the "Standard Specifications for Deep Longspan Steel Joists, DLJ and DLH Series" limits the design LIVE load deflection as follows: [1/3]60 of span where a plaster ceiling is attached or suspended; 1/240 of span for all other cases.

**To extrapolate for safe uniform load between spans shown, divide the Safe Load in pounds by net span in feet plus .67 feet (The added .67 feet, eight inches, is necessary to obtain the proper span for which the load tables were developed.)

C-77

PRESSURE STABILIZED LIGHTWEIGHT TRUSSES

DESIGN DATA:

LENGTH 110 FT.
LOAD 60 TONS

MAXIMUM BENDING MOMENT WITH LOAD AT MID SPAN IS

$$M = \frac{PL}{4} = \frac{120000\,(110)}{4} = 3{,}300{,}000 \text{ FT. LBS.}$$

ASSUMING LOAD MUST BE CARRIED BY TWO TRUSSES, THE MOMENT PER TRUSS IS

$$M/_T = 1{,}650{,}000 \text{ FT. LBS.}$$

$$= 19{,}800{,}000 \text{ IN. LBS.}$$

FOR 6061-T6 ALUM. FABRICATION

$$S_{ALL.} = 15 \text{ KSI.}$$

ASSUME DEPTH OF SECTION = 72 IN.

$$I_{REQ'D.} = \frac{Mc}{S} = \frac{19{,}800{,}000\,(36)}{15{,}000}$$

$$= 47520 \text{ IN.}^4$$

I/UNIT AREA FOR PAIR AT 72" SPC. = 2592 IN.^{4}

AREA REQ'D TOP & BOTTOM AT 72" SPC.

$$= \frac{47520}{2592} = 18.333 \text{ IN.}^2$$

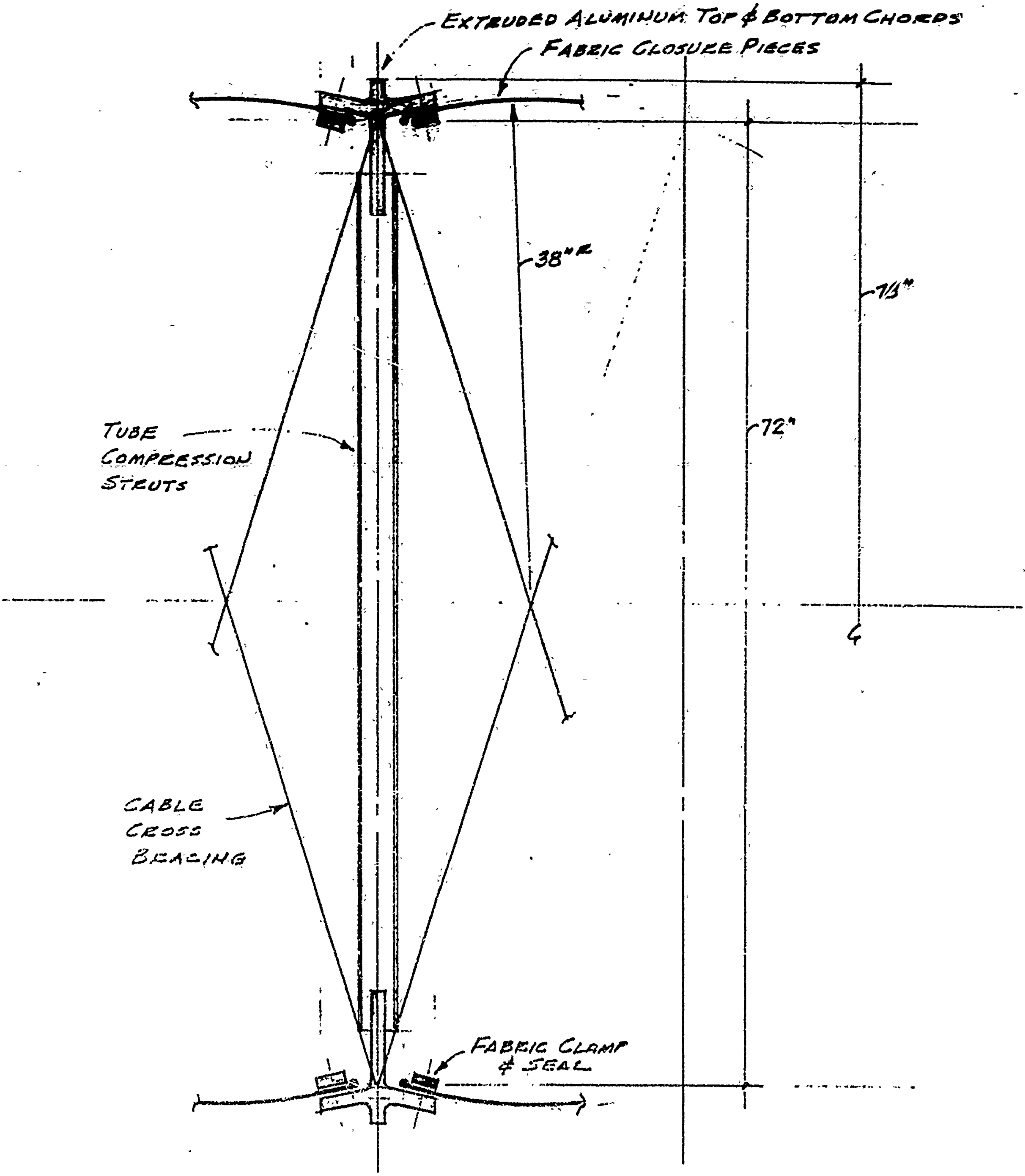
MAXIMUM FABRIC STRESS

$$S = pr = 5(38) = 190 \text{ \#/in}$$

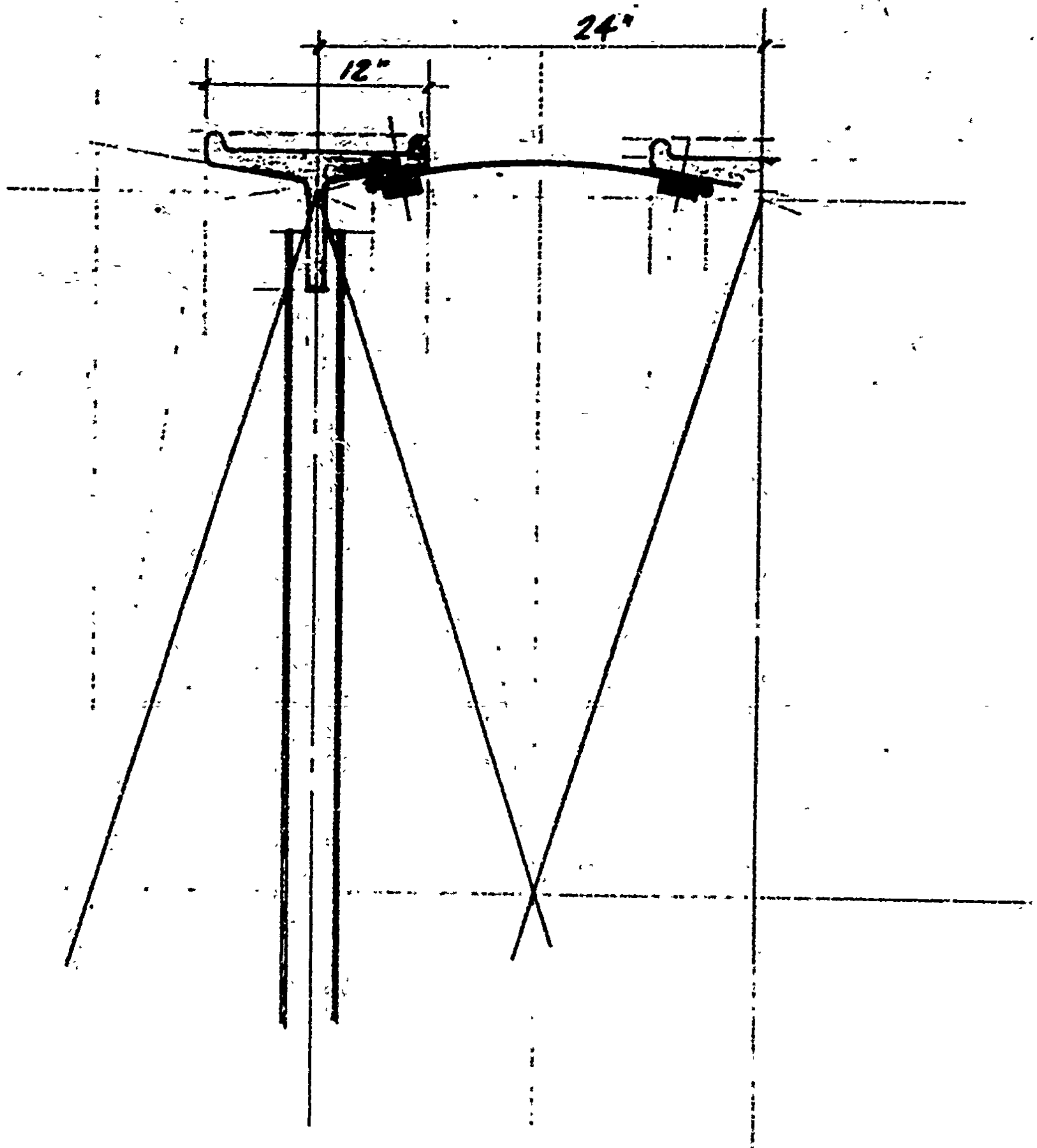
FOR. f.s. = 3

MIN. BREAKING STRENGTH = 3(190) = 570 #/in

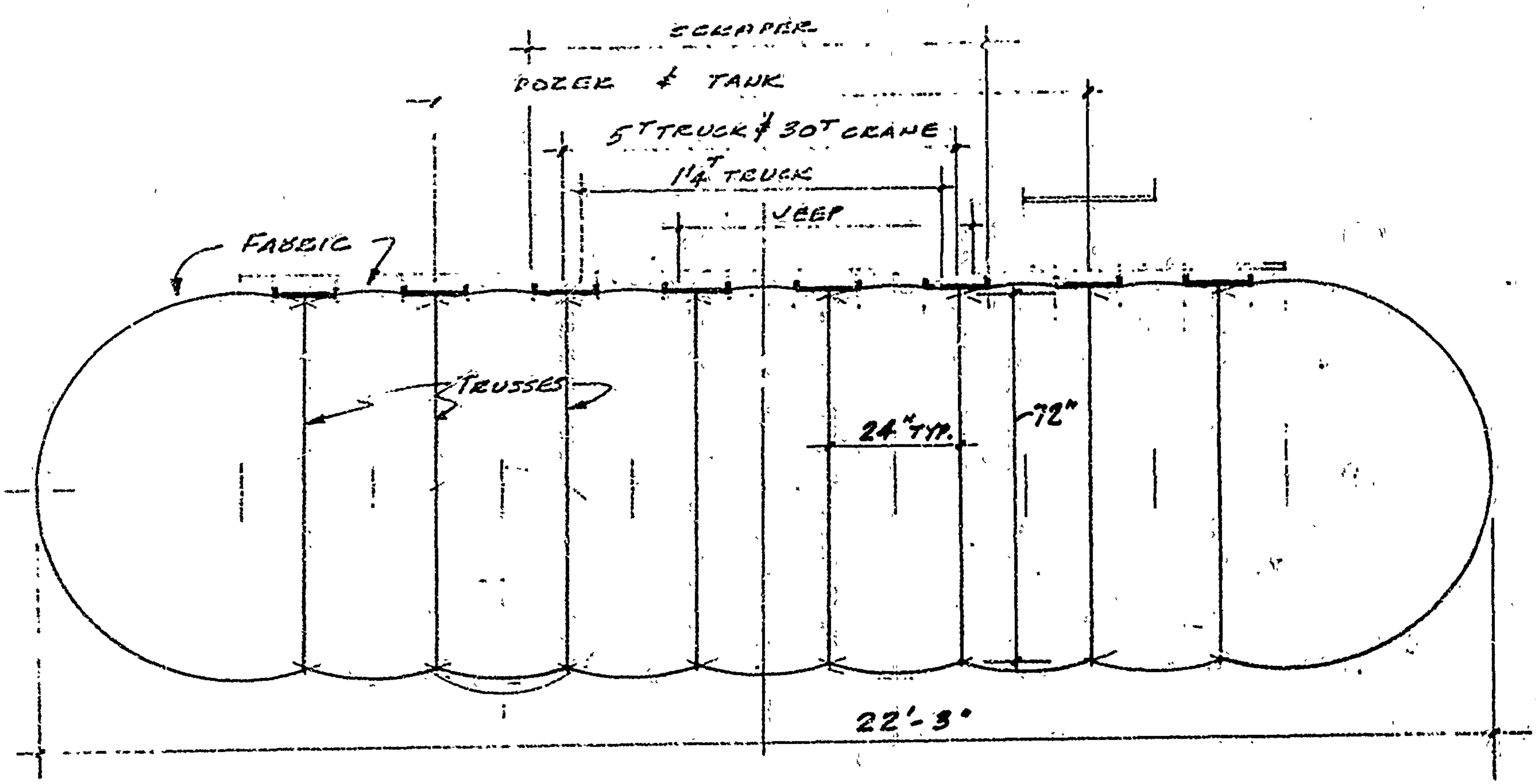
2 PLY 10 oz. POLYESTER IS O.K.



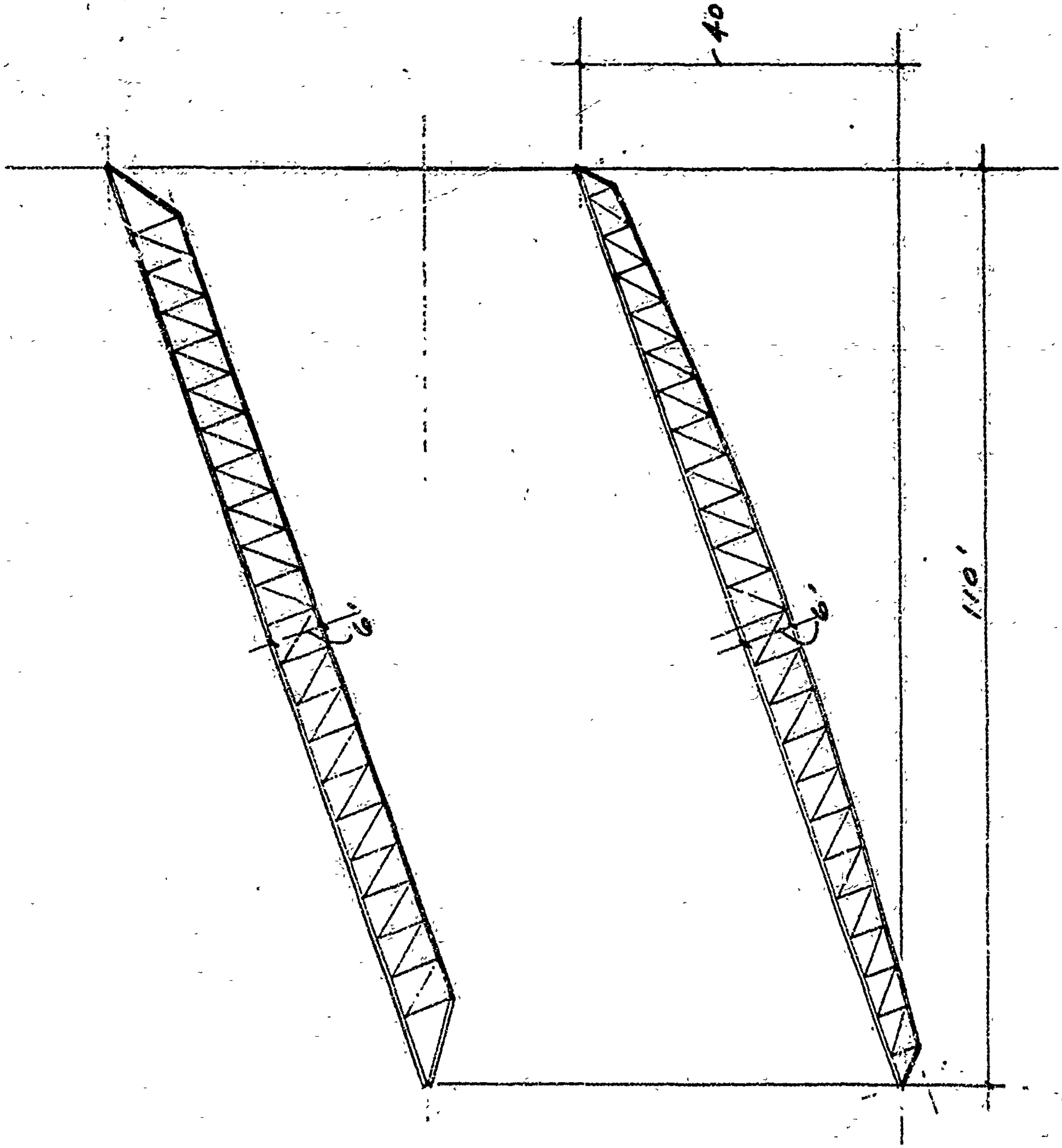
CELLWISE CROSS SECTION



ALTERNATE TOP CHORD EXTRUSION



RAMP CROSS SECTION



40'
110'
6'
6'

OVERALL DIMENSIONS: 22 FT. W x 5 FT. D
FABRIC STRESS - 161 LBS./IN.
INFLATION PRESSURE - 5 LBS./IN^2
VOLUME - $[16 \times 5 + (\pi \times 5)^2/4]\ 110 = 10{,}960\ FT^3$
SURFACE AREA (FABRIC) = $[32 + (\pi)(5)]\ 110 = 5{,}248\ FT^2$
APPROX. WT. OF JOISTS = $8 \times 50 \times 110 = 44{,}000$ LBS.

CONCEPT № 10

HYBRID

COMPRESSION DECK

WITH

BLADDER

C-83a

HYBRID STRUCTURE -

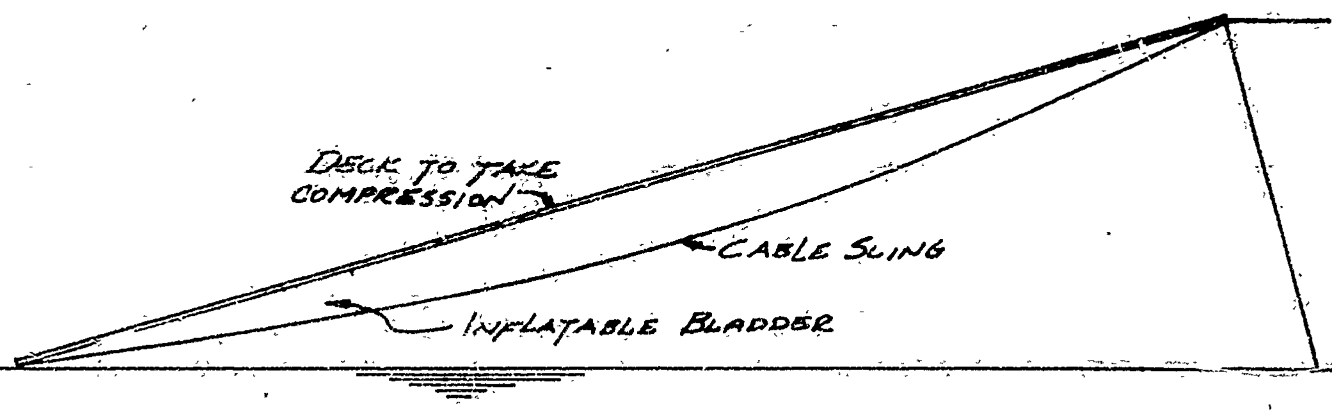
ALUMINUM DECK WITH CABLE BELLY AND BLADDER

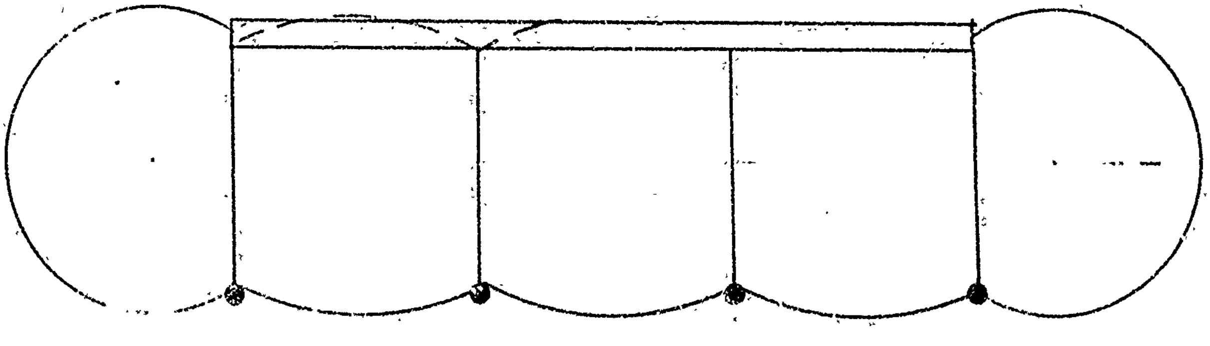
DESIGN CRITERIA:

LENGTH = 110 FT.

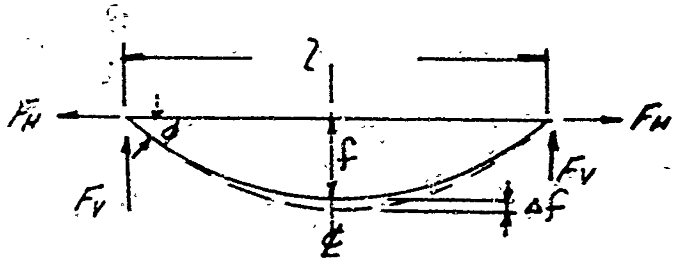
MIN. WIDTH = 16 FT.

MAX. LOAD = 60 TONS





SUSPENSION FORCES –



[FOR STATIC BEHAVIOR IN CABLES, REF. BETHLEHEM BOOKLET 2318–A pg. 15]

FOR CONCENTRATED LOAD OF 60 TONS @ MIDSPAN
MOMENT = 3.30×10^6 FT. LBS.

EQUIVALENT UNIFORM LOADING TO PRODUCE THIS MOMENT IS:

$M = wl^2/8$

$w = \frac{8}{(110)^2}(3.30 \times 10^6) = 2181$ LBS./FT.

L (CABLE LENGTH) $= l[1 + (8/3)(f/l)^2]$ LET $f = 5$ FT.

$L = 110[1 + (8/3)(5/110)^2] = $ 110.6 FT.

T (TENSION) $= \frac{ql^2}{8f}(1 + 16(f/l)^2)$

$T = \frac{(2181)(110)^2}{(8)(5)}[1 + 16(5/110)^2] = $ 681,562 LBS.

4 CABLES = 170,390 LBS./CABLE
(CABLE FACTOR OF SAFETY = 2)
BREAKING STRENGTH = 170 TONS

$1\frac{11}{16}$ Φ CLASS A – BRIDGE STRAND
(PRESTRETCHED – $E = 24 \times 10^6$ LBS./IN²)

AREA EA. CABLE = 1.71 IN.²
WT. EA. CABLE = 5.98 LBS./FT.

$\Delta L = TL/EA$

$\Delta L = (681,562\text{ LBS.})(110.6\text{ FT.})(12\text{ IN./FT.}) / (24 \times 10^6\text{ LBS./IN}^2)(1.71\text{ IN}^2)(4)$

$\Delta L = $ 5.51 IN.

$$\Delta f = \frac{\Delta L}{16/15\,(f/l)\left[5-24(f/l)^2\right]}$$

$$\Delta f = \frac{5.51\ \text{IN.}}{(16/15)(5/110)\left[5-24\,(5/110)^2\right]}$$

$\Delta f = 22.96$ IN. $= 1.91$ FT.

$$\text{TAN}\,\phi = \frac{4(f+\Delta f)}{l}$$

$$\text{TAN}\,\phi = \frac{(4)(5+1.91)}{110}$$

$\phi = 14.10°$

$F_V = T \sin\phi = (681,562) =$ **166,095 LBS.**

$F_H = T \cos\phi = (681,562) =$ **661,014 LBS.**

INFLATION PRESSURE REQD.

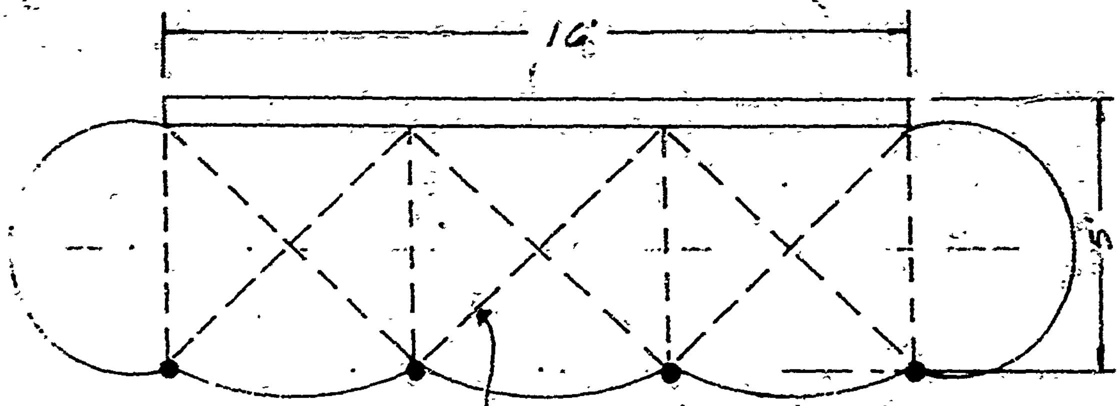
$p = \text{FORCE}/\text{AREA}$ FORCE = 120,000 LBS.
AREA = 16 FT. x 14.5 FT. = 232 FT^2

$p = 120,000/(232)(144) =$ **3.6 LBS./IN^2 MIN. INFLATION REQD.**

FABRIC STRESS = pR (DUE TO INFLATION)

$S = (3.6)(2.5')(12\ \text{IN/FT.}) =$ **108 LBS./IN.**

INVESTIGATE STRUCTURAL REQUIREMENTS:



$STRESS_{(SYSTEM)} = \frac{P}{A} + \frac{MC}{I}$ COMBINED AXIAL & BENDING

STRESS DUE TO BUCKLING WILL GOVERN OVER BENDING STRESS.

COMPRESSION MEMBER (DECK) TO BE CONSTRUCTED OF ALUMINUM. (6061-T6) WT. = 174 LBS./FT^3

P (AXIAL COMPRESSIVE FORCE) = F_H (CABLE) = 661,014 LBS.

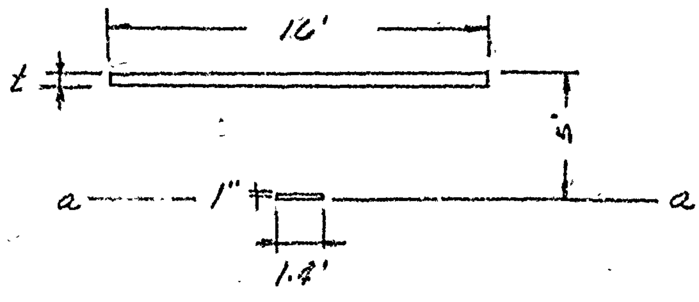
BENDING MOMENT = 3.30×10^6 FT.-LBS. (TANK LOADING AT MIDSPAN)

TRANSFORMED SECTION REQD. TO CALC. INERTIA:

$E_{CABLE} = 24 \times 10^6$ LBS./IN^2
$E_{AL.} = 10 \times 10^6$ LBS./IN^2

TRANSFORM TO ALUMINUM: $\frac{E_C}{E_A} = \frac{24}{10} = 2.4$

AREA CABLES = (4)(1.71) = 6.84 IN^2
EQUIV. AREA OF ALUM. = (2.4)(6.84) = 16.4 IN^2 ⅊ 1" X 16.4"



COMPUTE CENTROID IN TERMS OF t

$\bar{y} = \frac{\Sigma A y}{\Sigma A}$ (TAKE MOMENTS ABOUT a-a)

A (IN.^{2})	y (IN.)	Ay (IN.^{3})
16.4	.5	8.2
$192t$	$60 - .5t$	$11,520t - 96t^2$

$$\bar{y} = \frac{-96t^2 + 11,520t + 8.2}{192t + 16.4}$$

LET $t = 1$ IN.

$$\bar{y} = \frac{(-96)(1) + (11,520)(1) + 8.2}{(192)(1) + 16.4} = 54.86 \text{ IN.}$$

$$I_{TRANSFORMED} = \frac{bh^3}{12} + Ad^2$$

$$\frac{(192)(1)^3}{12} = 16 \qquad + \overset{4133}{(192)(1)(4.64)^2} = 4149$$

$$\frac{(16.4)(1)^3}{12} = 1.3 \qquad + (16.4)(1)(54.36)^2 = 48,463$$

$$I_T = 55,612 \text{ IN}^4$$

$r = \sqrt{I/A}$ $\quad A = 192 + 16.4 = 208.4$ IN^2

$r = (55,612/208.4)^{1/2} = 15.89$ IN (ENTIRE SYSTEM)

$L/r = 200$ OR LESS COMPRESSION MBR.

$r_{COMP} = (4149/192)^{1/2} = 4.65$ IN.

@ 10 FT. LATERAL SUPPORT

$r_{REQD.} = \frac{(10)(12)}{200} = .60$ IN. < 4.65 OK

$$\text{COMBINED STRESS} = P/A + \frac{MC}{I}$$

$$= \frac{661,016}{192} + \frac{(3.30 \times 10^6)(12)(5.14)}{55,612}$$

$$= 3442 + 3660$$

$$= 7102 \text{ LBS./IN}^2$$

ALLOW. COMBINED STRESS = STRESS DUE TO COMPRESSION FOR 6061-T6 ALUMINUM.

FROM TEXT - "STATICS & STRENGTH OF MATERIALS" BY JENSEN & CHENOWETH pg. 304

$$L/r = {}^{K=1}\,120/4.65 = 25.8$$

ALLOW. STRESS = 13,000 LBS./IN² > 7102 LBS./IN² ok

OVERALL DIMENSIONS - 22 FT. W x 5 FT. DEEP

FABRIC STRESS - 108 LBS./IN.

INFLATION PRESSURE - 3.6 LBS./IN²

VOLUME - $[[(16 \times 5) + (\pi)(5)^2/4]\, 110]\; 2/3 = 7306 \text{ FT}^3$

FABRIC SURFACE AREA = $(22)(\pi)(5)(22)(2/3) = 5068 \text{ FT}^2$

WT. OF CABLES = $4 \times 110.6 \times 5.98 = 2646$ LBS.

APPENDIX-D

REFINED

DESIGN

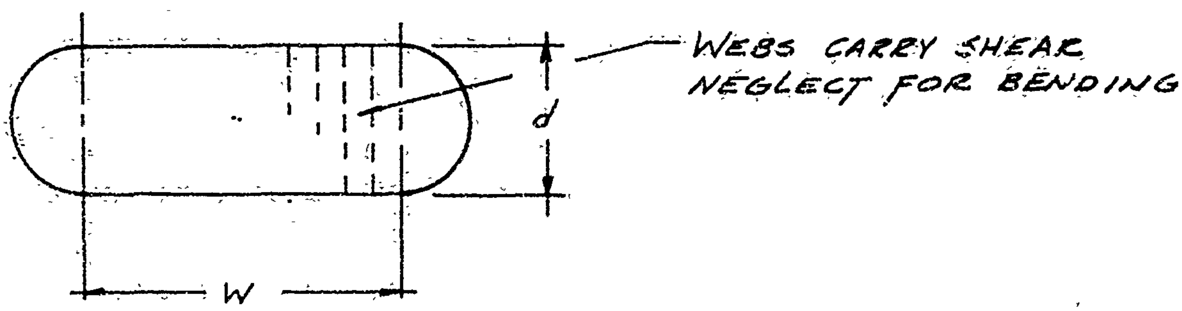
CALCULATIONS

REFINED DESIGN FOR CONCEPT Nº 2

DESIGN DATA:

1. LENGTH = 110 FT.
2. MIN. WIDTH = 16 FT.
3. WT. OF ALUM. DECK = 11.34 TONS } REF. PRELIM. INVESTIGATION
4. APPROX. WT. OF FABRIC = 11 TONS } REF. PRELIM. INVESTIGATION
5. CONSIDER 1 OR 2 INTERMEDIATE SUPPORTS
6. REF. BIRDAIR DWG. 7258-3-1 UNDER CONCEPT Nº 2 FOR CONFIGURATION.

SUMMARY OF STRESS EQUATIONS (FROM PRELIM. DUAL-WALL BEAM INVESTIGATION)



$$S_l = \frac{F}{C} = \frac{pA}{C}$$

$$S_l = \frac{p(Wd + \pi d^2/4)}{2W + \pi d}$$

$$S_t = \frac{pd}{2}$$

TERMS:

S_l = FABRIC STRESS DUE TO INFLATION (LONGITUDINAL DIRECTION)

F = FORCE = pA

p = INFLATION PRESSURE

A = CROSS-SECTIONAL AREA

C = CIRCUMFERENCE

S_t = FABRIC STRESS DUE TO INFLATION (TRANSVERSE DIRECTION)

$$f_s = \frac{M}{A} = \frac{M}{(Wd + \pi d^2/4)}$$

TERMS:

f_s = FABRIC STRESS DUE TO BENDING MOMENT
M = BENDING MOMENT
A = CROSS-SECTIONAL AREA

TO PREVENT WRINKLING-

$$f_s = s_i$$

$$\frac{(Wd + \pi d^2/4)\,p}{2W + \pi d} = \frac{M}{(Wd + \pi d^2/4)}$$

FOR W = 16 FT. = 192 IN.

$$M = \frac{(192d + \pi d^2/4)^2\,p}{384 + \pi d} \qquad \text{EQ. 1}$$

MAX. LONGITUDINAL FABRIC STRESS = $2s_i$

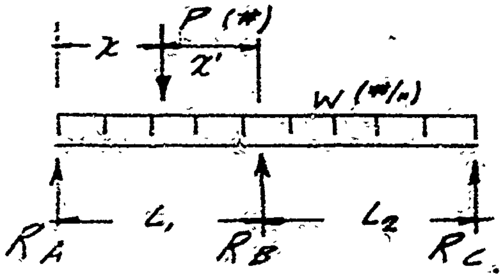
BENDING MOMENT FOR VARIOUS CONDITIONS-

LOAD

LIVE LOAD = 60 TON MOVING CONCENTRATED LOAD.

DEAD LOAD = 11.34 TONS DECK
APPROX 11.0 TONS FABRIC
22.34 TONS = 44,680 LBS ÷ 1320 IN.

DEAD LOAD = 33.8 LBS./IN.



TWO SPAN - CONTINUOUS

(ASSUME R_B IS A RIGID SUPPORT)

SOLVE BY THREE-MOMENT EQUATION:

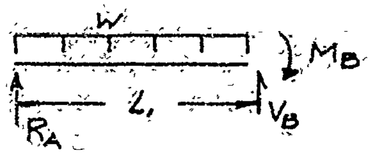
BENDING MOMENT CREATED BY DEAD LOAD

$2M_B(L_1 + L_2) = -\frac{1}{4}(wL_1^3 + wL_2^3)$

FOR $L = 660$ IN $w = 33.8$ LBS./IN.

SOLVE FOR M_B

$M_B = -1,840,410$ IN.-LBS.



$\circlearrowleft + \Sigma M_B = 0 = R_A(L_1) + M_B - (W)(L_1^2/2)$

SOLVE FOR R_A WITH $L_1 = 660$ IN $M_B = 1,840,410$

$R_A = 8365.5$ LBS.

$\uparrow + \Sigma F_V = 0 = R_A + V_B - wL_1$ $V_B = 13,942.5$ LBS.

BECAUSE OF SYMMETRY -

$R_A = R_C = 8365.5$ LBS.

$R_B = 2V_B = 27,885$ LBS.

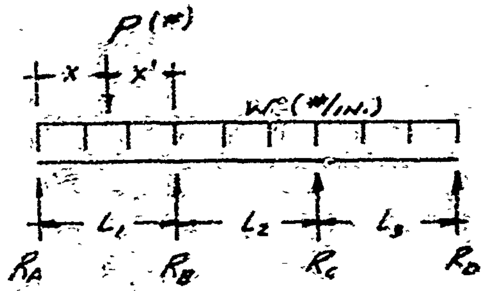
{MOMENT (DEAD LOAD) = $(R_A)(x) - (w)(x^2/2)$
FOR ANY POINT $x \leq 660$ IN. }

BENDING MOMENT CREATED BY MOVING LIVE LOAD

REF. A.I.S.C. STEEL MANUAL

M MAX. (AT POINT OF LOAD) $= \frac{P(x)(x')}{4(L_1)^3}\left(4L_1^2 - x(L_1 + x)\right)$

M_1 (AT SUPPORT R_B) $= -\frac{P(x)(x')}{4(L_1)^2}(L_1 + x)$



3 SPAN CONTINUOUS

(ASSUME R_B AND R_C ARE RIGID SUPPORTS)

BENDING MOMENT FOR DEAD LOAD

REF: AISC STEEL MANUAL-

$R_A = R_D = .400\,wL$

$R_B = R_C = 1.10\,wL$

MOM. (DEAD LOAD) = $(R_A)(x) - (w)(x^2/2)$

FOR ANY POINT $x \leq 440$ IN

MOM. (DEAD LOAD) = $(.5\,wL)(x) - .1\,wL^2 - (w)(x^2/2)$

FOR ANY POINT X WHERE $440 < x \leq 660$

BENDING MOMENT FOR MOVING LIVE LOAD-

SOLVE BY THREE MOMENT EQUATION:

$$2M_B(L_1+L_2) + M_C L_2 = -P(x)(x')\left(1+\frac{x}{L_1}\right)$$

$$M_B(L_2) + 2M_C(L_2+L_3) = 0$$

FOR $L_1 = L_2 = L_3 = 440$ IN AND $x \leq 440$ IN

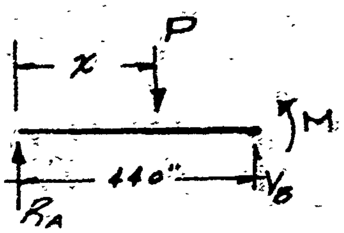
$$M_B = -4M_C$$

$$-8M_C(880) + M_C(440) = -P(x)(440-x)\left(1+\frac{x}{440}\right)$$

$$M_C = \frac{1}{6600}\left[P(x)(440-x)\left(1+\frac{x}{440}\right)\right]$$

$$M_B = -\frac{4}{6600}\left[P(x)(440-x)\left(1+\frac{x}{440}\right)\right]$$

NOTE: ONLY FOR $x \leq 440$ IN.



$\curvearrowleft + \Sigma M_B = 0 = R_A(440) - P(440-x) + M_B = 0$

$$R_A = \frac{1}{440}\left[P(440-x) - \frac{4}{6600}\left(P(x)(440-x)\left(1+\frac{x}{440}\right)\right)\right]$$

MOM. MAX. (AT POINT OF LOAD) $= R_A(x)$
FOR $x \leq 440$ IN.

MOM. (AT SUPPORT R_B) $= R_A(440) - P(440-x)$

NOTE: LOADING OF CONCENTRATED LIVE LOAD IN SPAN NO. 1 CREATES THE MAXIMUM BENDING MOMENTS ON THE BEAM.

Z5=<ZJORCH

02/23/ '73 09:15

PROGRAM LISTING

```
!LØGIN: 1507BRD,C,
ID= F
!BASIC
>LØAD TWØ
>LIST
10 PRINT"THIS IS A PRINT ØUT FØR BENDING MØMENT ØN A TWØ SPAN"
12 PRINT"CØNTINUØUS BEAM WITH A CØNCENTRATED LIVE LØAD MØVING"
13 PRINT"ACRØSS THE BEAM."
15 PRINT
20 PRINT"THE CØNCENTRATED LIVE LØAD (LBS)="
30 INPUT P
40 PRINT"THE DEAD LØAD ØF THE RAMP(LBS/IN)="
50 INPUT W
60 PRINT
70 PRINT"DISTANCE        TØTAL          TØTAL"
80 PRINT"ALØNG           MØMENT          MØMENT"
90 PRINT"THE RAMP        AT LØAD        AT SUPPØRT"
100 PRINT" (IN)          (IN-LBS)       (IN-LBS)"
101 PRINT
105 FØR X=60 TØ 660 STEP 30
110 M1=(8365.5*X)-((W*(X↑2))/2)
120 M2=(8365.5*660)-((W*(660↑2))/2)
130 M3=((P*X*(660-X))/(4*(660↑3)))*((4*(660↑2))-(X*(660+X)))
140 M4=(((P*X*(660-X))/(4*(660↑2)))*(660+X))*-1
150 M5=M1+M3
160 M6=M2+M4
170 PRINT X,M5,M6
180 NEXT X
190 END
>SYS

!BYE
02/23/ '73 09:17
CLT 2
CCU 0.018
```

```
*
!BASIC
>LØAD TWØ
>RUN
14:52    02/22
THIS IS A PRINT ØUT FØR BENDING MØMENT ØN A TWØ SPAN
CØNTINUØUS BEAM WITH A CØNCENTRATED LIVE LØAD MØVING
ACRØSS THE BEAM.

THE CØNCENTRATED LIVE LØAD (LBS)=
?120000
THE DEAD LØAD ØF THE RAMP(LBS/IN)=
?33.8
```

DISTANCE ALØNG THE RAMP (IN)	TØTAL MØMENT AT LØAD (IN-LBS)	TØTAL MØMENT AT SUPPØRT (IN-LBS)
60	6.82426E+06	-3.62553E+06
90	9.58194E+06	-4.49020E+06
120	1.19094E+07	-5.32140E+06
150	1.38138E+07	-6.10797E+06
180	1.53041E+07	-6.83876E+06
210	1.63917E+07	-7.50260E+06
240	1.70896E+07	-8.08834E+06
270	1.74130E+07	-8.58483E+06
300	1.73793E+07	-8.98091E+06
330	1.70077E+07	-9265410
360	1.63195E+07	-9.42719E+06
390	1.53379E+07	-9.45508E+06
420	1.40885E+07	-9.33793E+06
450	1.25985E+07	-9.06458E+06
480	1.08973E+07	-8.62388E+06
510	9.01652E+06	-8.00467E+06
540	6.98948E+06	-7.19578E+06
570	4.85173E+06	-6.18607E+06
600	2.64078E+06	-4.96438E+06
630	396211.	-3.51954E+06
660	-1840410	-1840410

```
190 HALT
>SYS
```

```
COMPUTERSEARCH
02/23/  '73 08:53
!LOGIN: 1507BRD,C,
ID= D
!BASIC
>LOAD CONY

CONY
UNABLE TO OPEN
>LOAD CONT
>LIST
10 PRINT"THIS IS A PRINT OUT FOR BENDING MOMENTS ON A THREE"
12 PRINT"SPAN CONTINUOUS BEAM WITH A CONCENTRATED LIVE LOAD"
13 PRINT"MOVING ACROSS THE BEAM."
15 PRINT
20 PRINT"THE CONCENTRATED LIVE LOAD (LBS)="
30 INPUT P
40 PRINT"THE DEAD LOAD OF THE RAMP (LBS/IN)="
50 INPUT W
60 PRINT
65 PRINT"DISTANCE        TOTAL            TOTAL"
70 PRINT" ALONG          MOMENT           MOMENT"
80 PRINT"THE RAMP       AT LOAD        AT 1ST. SUPPORT"
90 PRINT" (IN)          (IN-LBS)         (IN-LBS)"
100 PRINT
110 FOP X=40 TO 440 STEP 20
120 M1=(.4*W*440*X)-(W*((X↑2)/2))
130 M2=-.1*W*(440↑2)
140 Z=(4/6600)*(P*X*(440-X)*(1+(X/440)))
150 K=(1/440)*(((P*(440-X))-Z))
160 M3=K*X
170 M4=(K*440)-(P*(440-X))
180 M5=M1+M3
190 M6=M2+M4
200 PRINT X,M5,M6
210 NEXT X
220 END
>SYS

!BYE
02/23/  '73 08:55
CLT 2
CCU 0.023
```

PROGRAM LISTING

```
!BASIC
>LOAD CONT
>RUN
14:55   02/22
THIS IS A PRINT OUT FOR BENDING MOMENTS ON A THREE
SPAN CONTINUOUS BEAM WITH A CONCENTRATED LIVE LOAD
MOVING ACROSS THE BEAM.

THE CONCENTRATED LIVE LOAD (LBS)=
?120000
THE DEAD LOAD OF THE RAMP (LBS/IN)=
?33.8
```

DISTANCE ALONG THE RAMP (IN)	TOTAL MOMENT AT LOAD (IN-LBS)	TOTAL MOMENT AT 1ST. SUPPORT (IN-LBS)
40	4.45915E+06	-1.92379E+06
60	6.25732E+06	-2.53867E+06
80	7.77222E+06	-3.12974E+06
100	9.00890E+06	-3.68908E+06
120	9.97385E+06	-4.20875E+06
140	1.06750E+07	-4.68081E+06
160	1.11217E+07	-5.09734E+06
180	1.13248E+07	-5.45040E+06
200	1.12966E+07	-5.73205E+06
220	1.10508E+07	-5934768
240	1.06024E+07	-6.[illegible]941E+06
260	9.96818E+06	-6.06[illegible]4E+06
280	9.16607E+06	-5.9[illegible]594E+06
300	8.21556E+06	-5.79156E+06
320	7.13756E+06	-5.47817E+06
340	5.95445E+06	-5.03784E+06
360	4.69002E+06	-4.[illegible]263E+06
380	3.36952E+06	-3.74462E+06
400	2.01962E+06	-2.87586E+06
420	668470.	-1.84842E+06
440	-654368.	-654368.

```
220 HALT
>SYS

!BYE
02/22/  '73 14:57
CLT 15
RAD SPACE 1
DISC SPACE 1
CCU 0.152
```

```
N:SEJEF EANCH
02/23/  '73 10:35
!LOGIN: 1307BRD.C,
?D= F
!BASIC
>10 PRINT"FØR A GIVEN DEPTH AND INFLATIØN PRESSURE THE RESULTING"
>11 PRINT"BENDING MØMENTS CAN BE SUPPØRTED"
>12 PRINT
>16PRINT"THE INFLATIØN PRESSURE (PSI)="
>17 INPUT P
>20 PRINT" DEPTH            BENDING"
>30 PRINT" ØF RAMP    ..   MØMENT"
>40 PRINT"  (IN)           (IN-LBS)
40 BAD TEXT STRING
>40 PRINT"  (IN)           (IN-LBS)"
>50 FØR D=20 TØ 150 STEP 10
>60 X=(192*D+.7854*D↑2)↑2
>70 Y=384+3.14159*D
>80 M=X*P/Y
>90 PRINT D,M
>100 NEXT D
```

```
*C
!BASIC
>LOAD STRESS
>RUN
16:34   02/22
THE FOLLOWING IS A LISTING OF FABRIC STRESSES AND
INFLATION PRESSURES REQUIRED TO RESIST MAXIMUM BENDING
MOMENTS.

THE MAX.BENDING MOMENT (IN-LBS)=
?17413000
```

DEPTH OF RAMP (IN)	MAXIMUM LONG. STRESS (LBS/IN)	MAXIMUM TRANS. STRESS (LBS/IN)	INFLATION PRESSURE (PSI)
50	3011.98	1761.60	70.4640
100	1287.47	830.546	16.6110
150	749.551	517.244	6.89659
200	498.940	361.696	3.61696
250	358.800	270.082	2.16065
300	271.548	210.569	1.40379

```
110 HALT
>RUN
16:36   02/22
THE FOLLOWING IS A LISTING OF FABRIC STRESSES AND
INFLATION PRESSURES REQUIRED TO RESIST MAXIMUM BENDING
MOMENTS.

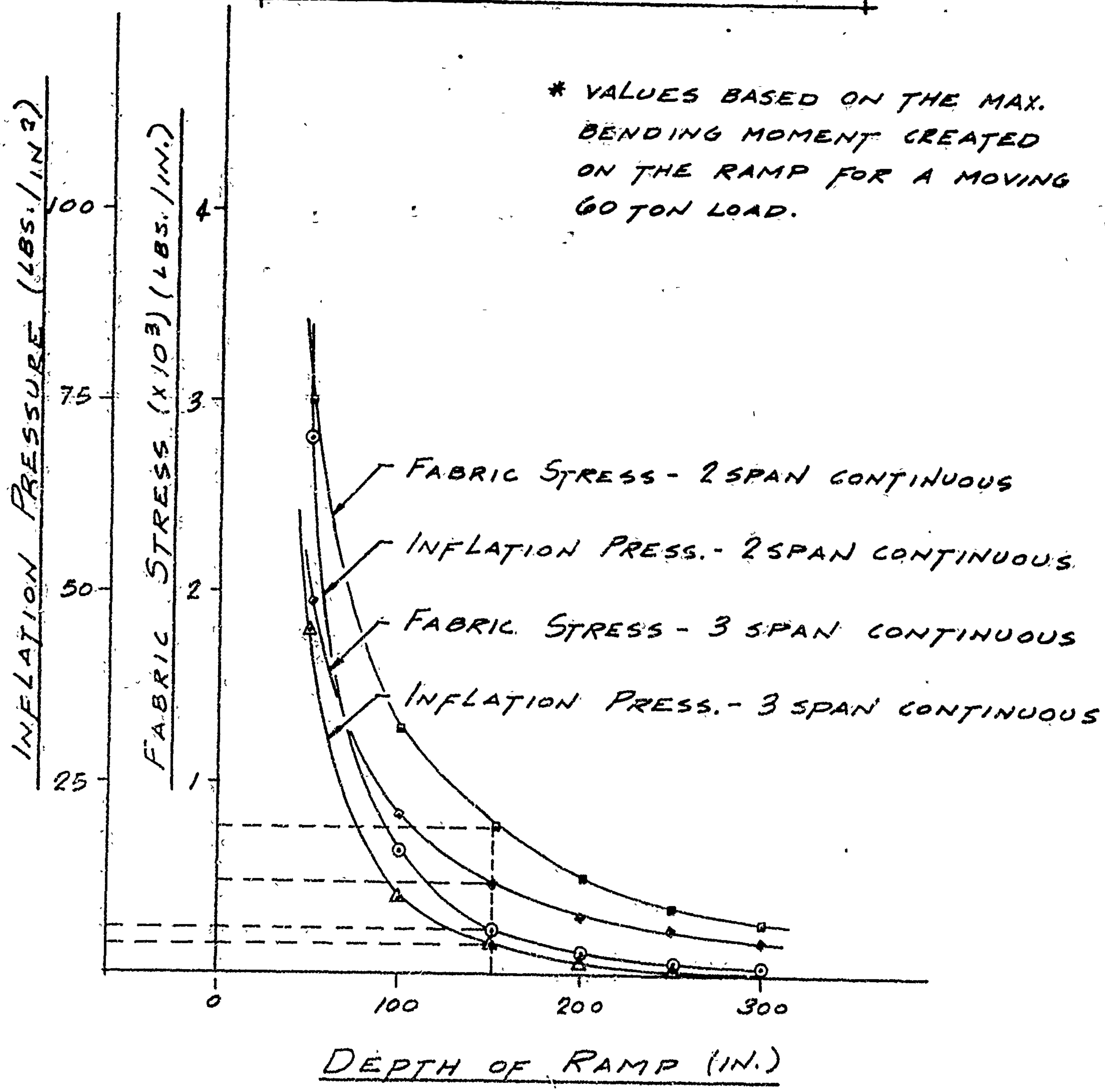
THE MAX.BENDING MOMENT (IN-LBS)=
?11324800
```

DEPTH OF RAMP (IN)	MAXIMUM LONG. STRESS (LBS/IN)	MAXIMUM TRANS. STRESS (LBS/IN)	INFLATION PRESSURE (PSI)
50	1958.88	1145.68	45.8273
100	837.323	540.159	10.8032
150	487.481	336.398	4.48530
200	324.493	235.234	2.35234
250	233.351	175.652	1.40521
300	176.605	136.946	.912976

```
110 HALT
>SYS

!BYE
02/22/ '73 16:37
CLT 13
RAD SPACE 2
DISC SPACE 1
CCU 0.110
```

INFLATION PRESSURE AND MAX. LONGITUDINAL FABRIC STRESS VS. DEPTH *



FOR MAX. DEPTH = 150 IN.

2 SPAN CONT.

MAX. LONG. FABRIC STRESS = 749.6 LBS/IN.

MAX. TRANS. FABRIC STRESS = 517.2 LBS/IN.

INFLATION PRESSURE = 6.90 LBS./IN.²

3 SPAN CONT.

MAX. LONG. FABRIC STRESS = 487.5 LBS/IN.

MAX. TRANS FABRIC STRESS = 336.4 LBS/IN.

INFLATION PRESSURE = 4.5 LBS/IN.²

10:40 . 02/23
FOR A GIVEN DEPTH AND INFLATION PRESSURE THE RESULTING
BENDING MOMENTS CAN BE SUPPORTED

THE INFLATION PRESSURE (PSI)=
?6.9

DEPTH OF RAMP (IN)	BENDING MOMENT (IN-LBS)
20	266484.
30	603369.
40	1.08122E+06
50	1.70517E+06
60	2.48100E+06
70	3.41498E+06
80	4.51377E+06
90	5.78428E+06
100	7.23365E+06
110	8.86920E+06
120	1.06984E+07
130	1.27287E+07
140	1.49678E+07
150	1.74235E+07

110 HALT
>RUN
10:42 02/23
FOR A GIVEN DEPTH AND INFLATION PRESSURE THE RESULTING
BENDING MOMENTS CAN BE SUPPORTED

THE INFLATION PRESSURE (PSI)=
?4.5

DEPTH OF RAMP (IN)	BENDING MOMENT (IN-LBS)
20	173794.
30	393502.
40	705143.
50	1.11206E+06
60	1.61804E+06
70	2.22716E+06
80	2.94376E+06
90	3.77236E+06
100	4.71760E+06
110	5.78426E+06
120	6.97719E+06
130	8.30132E+06
140	9.76163E+06
150	1.13631E+07

110 HALT
!BASIC
>SYS

!BYE
02/23/ '73 10:44
CLT 8
CCU 0.024

*

```
!BASIC
>LØAD TWØ
>RUN
14:52   02/22
THIS IS A PRINT ØUT FØR BENDING MØMENT ØN A TWØ SPAN
CØNTINUØUS BEAM WITH A CØNCENTRATED LIVE LØAD MØVING
ACRØSS THE BEAM.

THE CØNCENTRATED LIVE LØAD (LBS)=
?120000
THE DEAD LØAD ØF THE RAMP(LBS/IN)=
?33.8
```

DISTANCE ALØNG THE RAMP (IN)	TØTAL MØMENT AT LØAD (IN-LBS)	TØTAL MØMENT AT SUPPØRT (IN-LBS)	REQD. DEPTH p = 6.9 PSI
60	6.82426E+06	-3.62553E+06	97
90	9.58194E+06	-4.49020E+06	114
120	1.19094E+07	-5.32140E+06	126
150	1.38138E+07	-6.10797E+06	135
180	1.53041E+07	-6.83876E+06	140
210	1.63917E+07	-7.50260E+06	146
240	1.70896E+07	-8.08834E+06	148
270	1.74130E+07	-8.58483E+06	150
300	1.73793E+07	-8.98091E+06	148
330	1.70077E+07	-9265410	146
360	1.63195E+07	-9.42719E+06	145
390	1.53379E+07	-9.45508E+06 *	140
420	1.40885E+07	-9.33793E+06	136
450	1.25985E+07	-9.06458E+06	128
480	1.08973E+07	-8.62388E+06	122
510	9.01652E+06	-8.00467E+06	114 *
540	6.98948E+06	-7.19578E+06	↑
570	4.85173E+06	-6.18607E+06	
600	2.64078E+06	-4.96438E+06	
630	396211	-3.51954E+06	↓
660	-1840410	-1840410	114

```
190 HALT
>SYS
```

* GOVERNS FOR MIN. DEPTH AT SUPPORT

```
!BASIC
>LOAD CONT
>RUN
14:55    02/22
THIS IS A PRINT OUT FOR BENDING MOMENTS ON A THREE
SPAN CONTINUOUS BEAM WITH A CONCENTRATED LIVE LOAD
MOVING ACROSS THE BEAM.

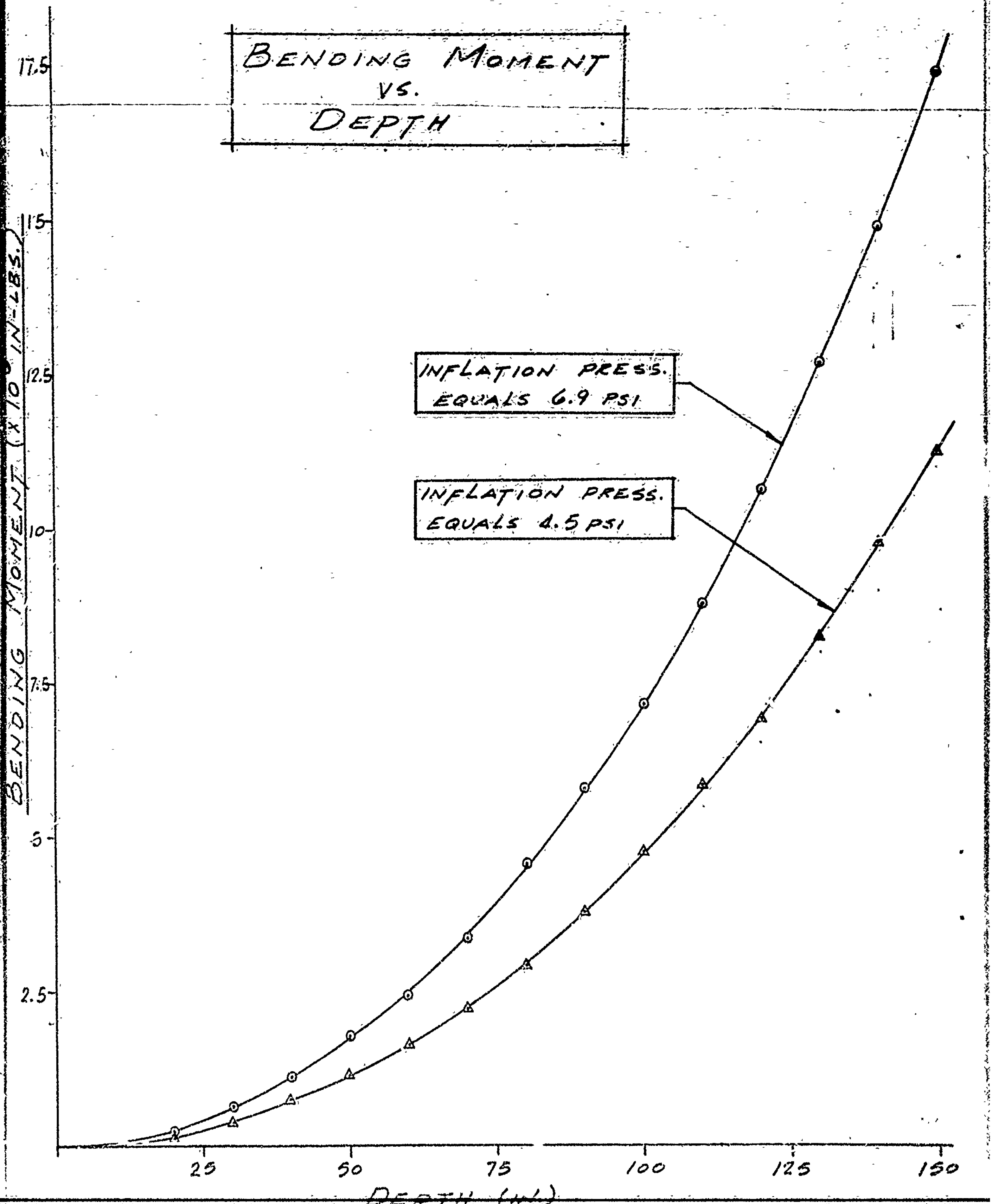
THE CONCENTRATED LIVE LOAD (LBS)=
?120000
THE DEAD LOAD OF THE RAMP (LBS/IN)=
?33.8
```

DISTANCE ALONG THE RAMP (IN)	TOTAL MOMENT AT LOAD (IN-LBS)	TOTAL MOMENT AT 1ST. SUPPORT (IN-LBS)	REQD. DEPTH P=4.5 PSI
40	4.45915E+06	-1.92379E+06	97
60	6.25732E+06	-2.53867E+06	114
80	7.77222E+06	-3.12974E+06	126
100	9.00890E+06	-3.68908E+06	135
120	9.97385E+06	-4.20875E+06	140
140	1.06750E+07	-4.68081E+06	146
160	1.11217E+07	-5.09734E+06	148
180	1.13248E+07	-5.45040E+06	150
200	1.12966E+07	-5.73205E+06	148
220	1.10508E+07	-5934368	146
240	1.06024E+07	-6.04941E+06	145
260	9.96818E+06	-6.06924E+06 *	140
280	9.16607E+06	-5.98594E+06	136
300	8.21556E+06	-5.79156E+06	128
320	7.13756E+06	-5.47817E+06	122
340	5.95445E+06	-5.03784E+06	114 *
360	4.69002E+06	-4.46263E+06	↑
380	3.36952E+06	-3.74462E+06	│
400	2.01962E+06	-2.87586E+06	│
420	668470.	-1.84842E+06	↓
440	-654368.	-654368.	114

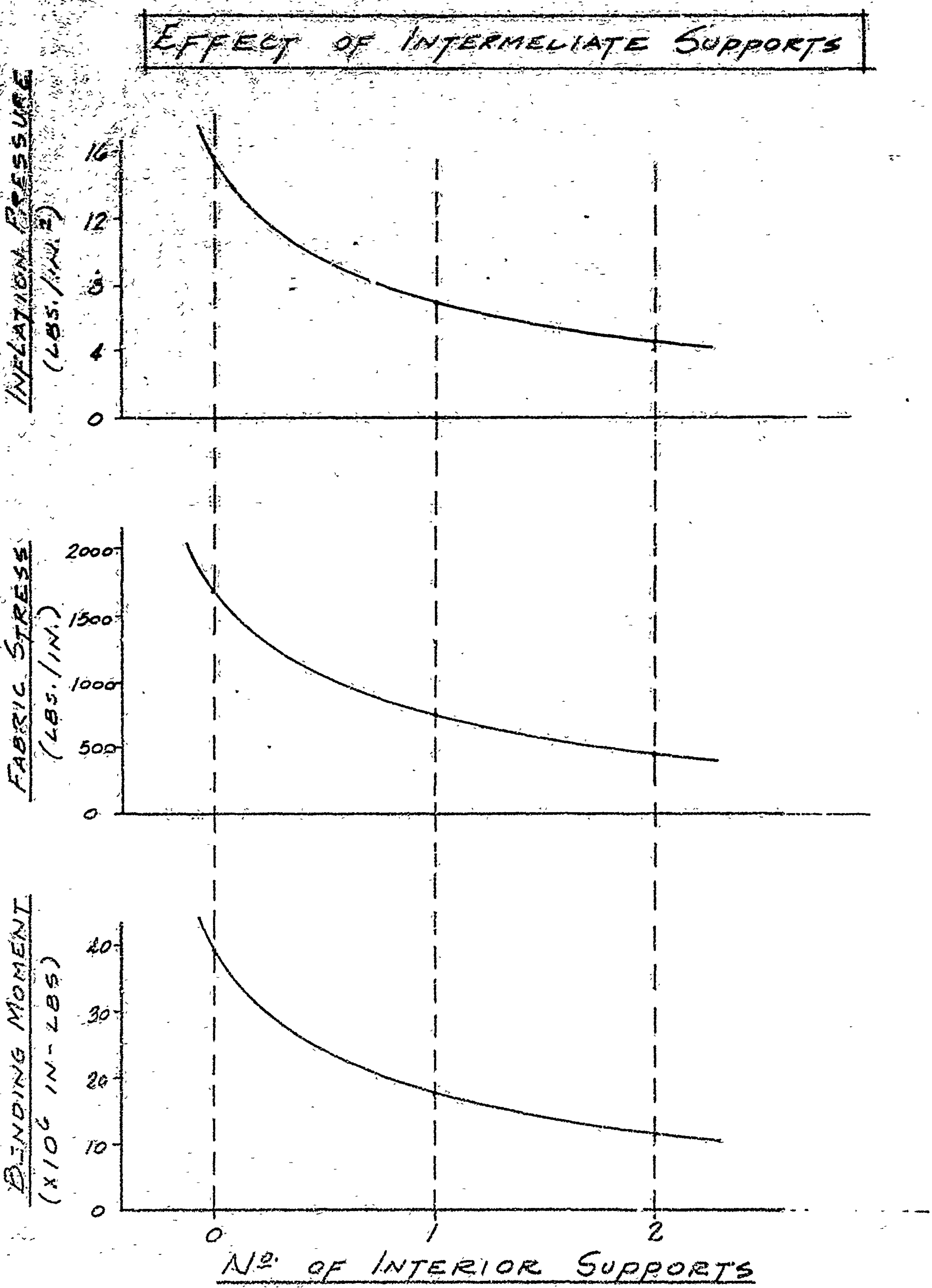
```
220 HALT
>SYS
```

* GOVERNS FOR MIN. DEPTH AT SUPPORT

```
!BYE
02/22/  '73 14:57
CLT 15
RAD SPACE 1
DISC SPACE 1
CCU 0.152
```



BENDING MOMENT
VS.
DEPTH
INFLATION PRESS. EQUALS 6.9 PSI
INFLATION PRESS. EQUALS 4.5 PSI
BENDING MOMENT (X 10 IN-LBS.)
17.5
15
12.5
10
7.5
5
2.5
25
50
75
100
125
150



EFFECT OF INTERMELIATE SUPPORTS
INFLATION PRESSURE
(LBS./IN.2)
16
12
8
4
0
FABRIC STRESS
(LBS./IN.)
2000
1500
1000
500
0
BINDING MOMENT
(X10^6 IN-LBS)
40
30
20
10
0
0
1
2
No. OF INTERIOR SUPPORTS

DEFLECTION OF RAMP UNDER MOVING LOAD

GENERAL DEFLECTION EQUATION:

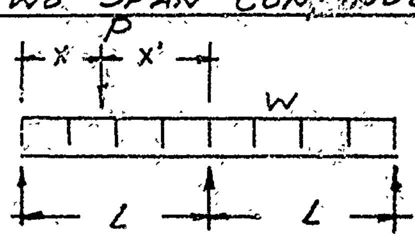
$$\delta = \frac{(V)(x)}{p A}$$

WHERE:

δ = DEFLECTION (DUE TO SHEAR, NOT FLEXURE)
V = SHEAR AT POINT IN QUESTION
x = DISTANCE FROM POINT IN QUESTION TO SUPPORT.
p = INFLATION PRESSURE
A = CROSS-SECTIONAL AREA AT POINT IN QUESTION.

DETERMINE SHEAR (V) AT ANY POINT ALONG RAMP:

TWO SPAN CONTINUOUS:

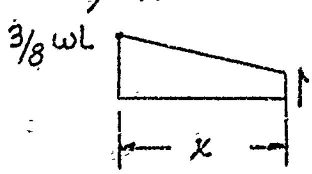


FOR LIVE LOAD

$$V_{L.L.} = \frac{P X'}{4 L^3}\left(4L^2 - x(L+x)\right)$$

REF: AISC STEEL MANUAL

FOR DEAD LOAD



$$V_{D.L.} = 3/8\, w L - w x$$

TOTAL SHEAR (V) (AT ANY POINT x) $= V_{L.L.} + V_{D.L.}$

09:00 02/26

THIS PRINT OUT IS A LISTING OF THE SHEAR VALUE (V) AS A CONCENTRATED LIVE LOAD MOVES ACROSS THE BEAM

THE CONCENTRATED LIVE LOAD (LBS)=
?120000
THE DEAD LOAD OF THE RAMP (LBS/IN)=
?33.8
THE SPAN (IN)=
?660

DISTANCE ALONG RAMP (IN)	SHEAR (V) (LBS)	CONSTANT (V*X)/PRESS. (CU-IN)	DEPTH (IN) *	DEFLECTION (IN)
60	112724.	980206.	97	[illegible].7
90	104945.	1.36885E+06	114	42.6
120	97217.1	1.69073E+06	126	46.1
150	89556.8	1.94689E+06	135	48.4
180	81981.0	2.13863E+06	140	50.6
210	74506.6	2.26759E+06	146	50.6
240	67150.6	2.33567E+06	148	51.2
270	61450.8	2.40460E+06	150	51.7
300	56410.1	2.45261E+06	148	53.8
330	51538.5	2.46488E+06	146	53.1
360	46852.8	2.44450E+06	145	55.1
390	42370.0	2.39483E+06	140	56.7
420	38107.0	2.31956E+06	136	57.1
450	34080.6	2.22265E+06	128	59.4
480	30307.8	2.10837E+06	122	60.0
510	26805.4	1.98127E+06	114	61.7
540	23590.5	1.84621E+06	114	57.5
570	20679.8	1.70833E+06	114	53.2
600	18090.3	1.57307E+06	114	47.0
630	15838.9	1.44616E+06	114	55.1
660	13942.5	1.33363E+06	114	

200 HALT *
>SYS

!BYE
02/26/ '73 09:02
CLT 4
CCU 0.074

CROSS-SECTIONAL AREA (A) = $WD + \frac{\pi D^2}{4}$
FOR W = 192 IN.

FINAL CONFIGURATION FOR CONCEPT Nº 2

3 SPAN CONTINUOUS BEAM MOST DESIRABLE

INFLATION PRESS. REQD. = 4.5 LBS./IN.^{2}

MAX. FABRIC STRESS = 487.5 LBS/IN (OUTER SKIN)

FOR FACTOR OF SAFETY = 3

FABRIC STRENGTH REQUIRED = (487.5)(3) = **1463 LBS./IN.**
(FOR OUTER SKIN)

BEARING LENGTH REQD. EA. END:

DECK DISTRIBUTES LOAD OVER FULL WIDTH = 192"

$L_{REQD} = 120{,}000\ LBS / (4.5\ \#/IN^2)(192\ IN.) = 139\ IN.$

SHEAR FORCE ON WEBS:

MAX. SHEAR OCCURS AT 1ST. INTERIOR SUPPORT

DEPTH AT SUPPORT - 114 IN

SHEAR VALUE WITH LOAD AT SUPPORT

L.L. = 120,000 LBS
D.L. = 1.10 wL = (1.10)(33.8)(440) = 14,359 LBS
(CONSERVATIVE SINCE THE BEARING ON EACH END REDUCES THE D.L. SHEAR VALUE)

TOTAL SHEAR = 134,359 LBS.

SHEAR FORCE ON WEBS:

FOR WEB SPACING = 12 IN.

No. OF WEBS = 16/1 = 16+1 = 17 WEBS REQD.

SHEAR FORCE PER WEB = 136,359/17 = 8021 LBS.

STRESS PER WEB (BIAS PLY) = 8021/(114)(1.414) = 50 LBS./IN

STRESS PER WEB (ST. PLY) = (12)(4.5) = 54 LBS./IN.

FACTOR OF SAFETY = 3

FABRIC STRENGTH REQD. (BIAS PLY) = 150 LBS./IN

FABRIC STRENGTH REQD. (ST. PLY) = 162 LBS./IN

INTERIOR SUPPORT MECHANISM -

NOTE: FOR CONSERVATIVE DESIGN APPROACH, CONSIDER THE SPAN EQUAL TO 440 IN. DO NOT CONSIDER THE EFFECTS OF THE 130 IN. BEARING LENGTH ON THE ENDS.

TO CONTROL DEFLECTION OF THE SUPPORT DUE TO BUOYANCY, AND STILL BE FLEXIBLE ENOUGH TO ACCOMODATE VARYING RAMP ANGLES, A CIRCULAR HORIZONTAL TUBE SEEMS MOST PRACTICAL.

MAX. LOAD AT SUPPORT

L.L. = 120,000 LBS.
D.L. = (1.10)(33.8)(440) = 16,359 LBS

TOTAL LOAD = 136,359 LBS.

INTERIOR SUPPORT MECHANISM

FOR BUOYANCY

$F = \gamma V$

V = VOLUME DISPLACED
γ = 62.4 LBS./FT^3
F = LOAD

$$V = F/\gamma = 136,359/62.4 = 2185\ FT^3$$

IF WHOLE TUBE SUBMERGED

$$D_{(MIN.)} = \sqrt{V/4\pi} = \sqrt{2185/4\pi} = 13.2\ FT$$

∴ FOR 1/4 OF TUBE SUBMERGED, 50 FT ± DIA. REQD.

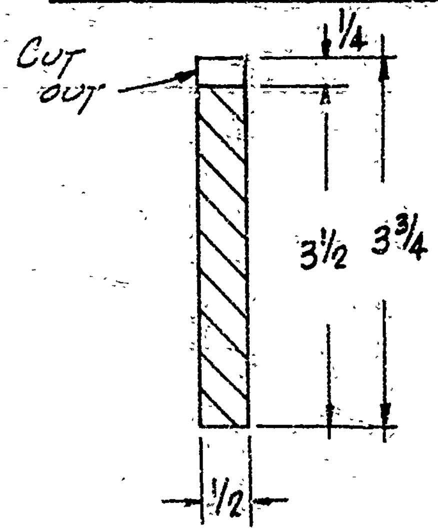
<u>NOTE:</u> HORIZONTAL SUPPORT TUBE INFEASIBLE

REFINED DESIGN FOR CONCEPT Nº 10

DESIGN DATA:

1. LENGTH = 110 FT. = 1320 IN.
2. MIN. WIDTH = 16 FT. = 192 IN.
3. ALUMINUM DECK TO TAKE COMPRESSION
4. CABLES TO CARRY TENSION
5. REFERENCE BIRDAIR DWG. FIGURE 3, CONCEPT Nº 10 FOR GENERAL CONFIGURATION

DESIGN PROPERTIES OF EXISTING ALUMINUM DECK (TO BE USED AS COMP. MBR.)



TYPICAL BAR

CNTR. TO CNTR. SPACING
- 6" LONG. DIR.
- 3" TRANS. DIR.

ASSUME 6061-T6 ALUMINUM FOR FULLY SUPPORTED, ALLOW. COMPRESSIVE STRESS = 14 KSI

FOR WIDTH = 16 FT. = 192 IN.

Nº OF BARS = $^{192}/_{3}$ = 64 + 1 = 65 BARS

TOTAL COMPRESSIVE FORCE = (STRESS)(AREA)

ALLOW. COMP. FORCE = (14,000)(.5)(3.5)(65)

ALLOW. COMP. FORCE = 1.5925×10^6 LBS.

SECTION MODULUS = $bd^2/6$ (PER BAR)

$S = (.5)(3.5)^2/6 = 1.028$ IN^3 PER BAR

DESIGN PROPERTIES OF EXISTING ALUMINUM DECK

WEIGHT PER SQ. FT. =

6 BARS X 12" LONG X .5 X 3.75 = 135 IN^3

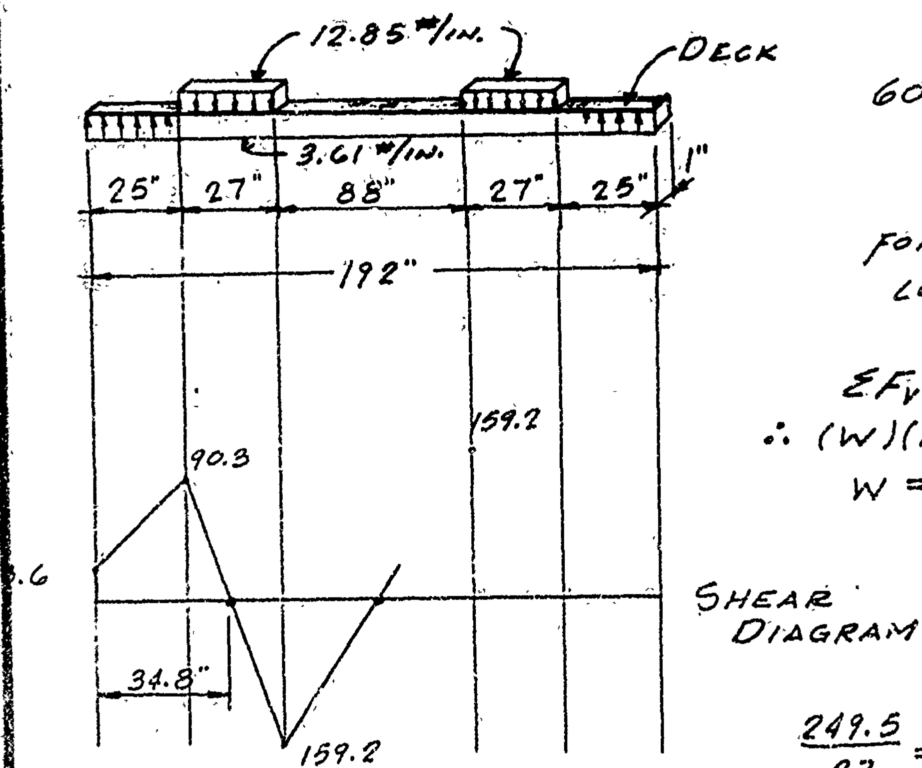
ALUM. = 165 LBS./C.F. = .0955 LBS./IN^3

WT. PER. SQ. FT. = (135)(.0955) = 12.89 LBS./S.F.

TOTAL WT. OF DECK = (16)(110)(12.89)/2000 = 11.34 TONS

CHECK CAPACITY OF DECK TO DISTRIBUTE VARIOUS LOADS:

1. TANK LOADING (TRANS. DIRECTION)



60 TON TANK = 12.85 PSI TRACK PRESS.

FOR 1" WIDE STRIP LOAD = 12.85 LBS./IN.

$\Sigma F_V = 0$

$\therefore (W)(192) = (2)(12.85)(27)$

W = 3.61 LBS./IN.

$\frac{249.5}{27} = \frac{90.3}{x}$

x = 9.8 IN.

BENDING MOM. @ 34.8" = (3.61)(34.8)(34.8/2) − (12.85)(9.8)(9.8/2)
= 556.7 IN-LBS

BENDING MOM. @ CNTR. = (3.61)(96)(96/2) − (12.85)(27)(44 + 13.5)
= 3314.8 IN.-LBS GOVERNS

CHECK CAPACITY OF DECK TO DISTRIBUTE VARIOUS LOADS:

TANK LOADING (CONT.)

ALLOW. BENDING STRESS (6061-T6) ALUMINUM
= 15 KSI

SECTION MODULUS REQD. PER IN. = M/σ

S (PER IN. OF LENGTH) = 3315 IN-LBS / 15,000 PSI
= .2210 IN³

6" BAR SPACING IN LONG. DIR.

$S_{REQD.}$ = 6 x .2210 = 1.326 IN³

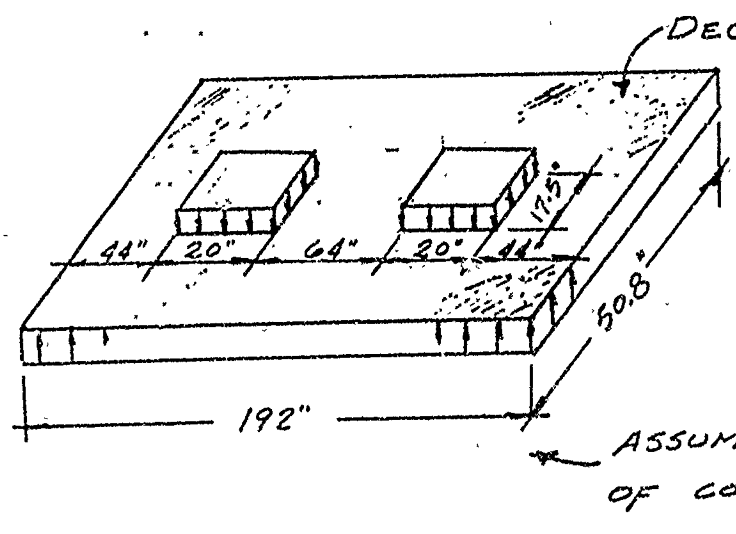
S_{ACTUAL} = 1.028 IN³

CLOSE - PROBABLY SATISFACTORY IF FULL DEPTH IS USED.

2. WHEEL LOADING (TRANS. & LONG. DIR.)

14 C.Y. SCRAPER TOTAL WT. = 63,500 LBS.
FRONT AXLE = 17,600 LBS./WHEEL
TIRE INFLATION PRESS. ≈ 50 PSI

AREA OF CONTACT PER WHEEL = 17,600/50 = 350 IN.²
IF WIDTH OF TIRE = 20 IN.
LENGTH OF CONTACT = 17.5 IN. = 3 BARS LOADED AT ONE TIME



ASSUME TANK INFLATION PRESS. GOVERNS = 3.61 PSI

$\Sigma F_V = 0$

(2)(17,600) = (3.61)(192)(L)

L = 50.8 IN.

CHECK CAPACITY OF DECK TO DISTRIBUTE VARIOUS LOADS:

CANTILEVER CONDITION
CREATES MAX. MOMENT

MAX. BENDING MOM. TRANS. DIR. (M_T) =

$M_T = WL^2/2 = \frac{(21.7)(44)^2}{2} = 21,005$ IN.-LBS.   W (PER BAR) = (3.61)(6) = 21.7 LBS./IN.

$S_{REQD.} = M/\sigma = 21,005/15,000 = 1.40$ IN.^{3}

$S_{ACTUAL} = 1.028$ IN.^{3}

SINCE THE BARS ARE A LITTLE OVERSTRESSED, THE AREA OF CONTACT ADJUSTS ITSELF

∴ FULL WIDTH OF DECK IS NOT STRESSED WHILE LENGTH OF CONTACT INCREASES.

CONCLUSION: EXISTING DECK MATERIAL SEEMS STRONG ENOUGH TO DISTRIBUTE LOCAL LOADS.

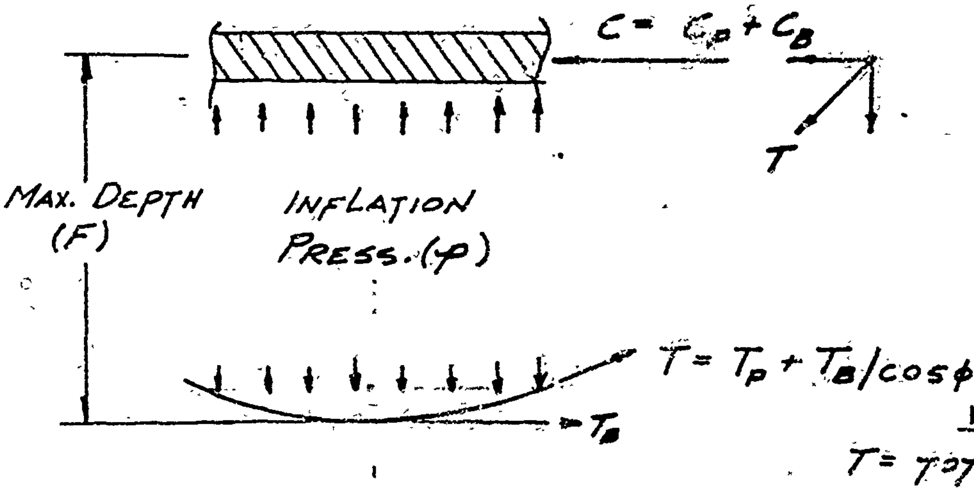
INFLATION PRESSURE TO CARRY 60 TON LOAD

THE MAXIMUM INFLATION PRESSURE EQUALS THE PRESSURE REQUIRED TO RESIST LOCAL DEFLECTION.

∴ INFLATION PRESSURE = 3.6 PSI

NOTE: THIS VALUE IS CONSERVATIVE SINCE THE AREA OF CONTACT IS 192 IN. WIDE X 174 IN. TRACK LENGTH. THE ACTUAL LONGITUDINAL LENGTH IS SOMETHING GREATER THAN 174 IN.

STRESS EQUATIONS:



WHERE:

T = TOTAL TENSION LOAD IN CABLE

T_p = TENSION DUE TO INFLATION PRESSURE

T_B = TENSION DUE TO BENDING MOMENT

C = TOTAL COMPRESSION LOAD IN DECK

C_p = COMPRESSION DUE TO INFLATION PRESSURE

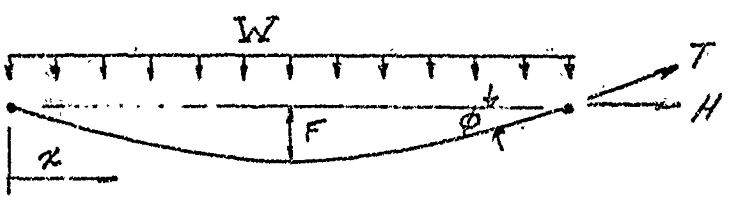
C_B = COMPRESSION DUE TO BENDING MOMENT

NOTE: 1. WEBS TO CARRY VERTICAL STRESS DUE TO INFLATION AND DIAGONAL STRESS DUE TO SHEAR.

2. SHAPE OF CABLE SLING IS TO BE PARABOLIC

STRESS DUE TO INFLATION PRESSURE

CONSIDER UNIFORM LOAD OVER PARABOLIC SHAPED CABLE



REF. TEXT "FRAMES & ARCHES"

$$H_p = \frac{WL}{8F}$$

$$T_p = H\cos\phi + W\left(\tfrac{1}{2} - \tfrac{x}{L}\right)\sin\phi$$

WHERE:

H = HORIZONTAL FORCE

T = CABLE TENSION FORCE

W = TOTAL PRESS. LOAD

L = SPAN LENGTH

F = MAX. DEPTH

x = ANY POINT ALONG SPAN.

STRESS DUE TO INFLATION PRESSURE

TO DETERMINE THE ANGLE ϕ AT ANY POINT ALONG THE PARABOLA

$$\tan\phi = \frac{4F}{L}\left(1 - \frac{2x}{L}\right)$$

(NEGLECT EFFECT OF PRESSURE ON ENDS)

STRESS DUE TO BENDING MOMENT

BENDING MOMENT $(M) = T_B y = C_B y$

WHERE:

y = DEPTH AT ANY POINT x

$$y = 4F\left(1 - \frac{x}{L}\right)\frac{x}{L}$$

COMP. FORCE $= M/y = C_B$

TENSION FORCE $= M/y = T_B$

TOTAL STRESS

$$C = C_p + C_B$$

$C_p = H_p$ (REACTING FORCE)

$$C = \frac{WL}{8F} + \frac{M}{y}$$

$$T = T_p + T_B/\cos\phi$$

$$T = \frac{WL}{8F}\cos\phi + W\left(\frac{1}{2} - \frac{x}{L}\right)\sin\phi + \frac{M}{y}\cos\phi$$

BENDING MOMENT ALONG RAMP

LOAD CONDITIONS:

LIVE LOAD – MOVING CONCENTRATED LOAD (P)

DEAD LOAD –

DECK = 11.34 TONS
FABRIC = 5 "
CABLES = 5 TONS
21.34 TONS

FOR WIDTH = 192 IN
DEAD LOAD = 32.3 LBS./IN. = w

REF. A.I.S.C. STEEL MANUAL FOR EQUATIONS:

$$\text{Mom. (D.L.)} = \frac{wx}{2}(L - x)$$

L = SPAN (IN.)
X = ANY POINT ALONG SPAN (IN.)
w = DEAD LOAD (LBS/IN.)

$$\text{Mom. (L.L.)} = \frac{Pab}{L} = \frac{Px(L-x)}{L}$$

(AT POINT OF LOAD)

P = CONC. LIVE LOAD (LBS.)

DETERMINE MIN. DEPTH (F) REQD.

TOTAL APPLIED COMP. FORCE = ALLOW. COMP. FORCE DECK CAN SUPPORT

MAX. MOM. $x = L/2$
$y = F$

$$W = (\rho)(\text{WIDTH})(L) = (3.61)(192)(1320) = 9.149 \times 10^5 \text{ LBS.}$$

$$\frac{WL^2}{8F} + \frac{M_T}{F} = 1.5925 \times 10^6$$

$$F = \frac{WL^2 + 8M_T}{(8)(1.5925 \times 10^6)}$$

$$M_D = \frac{wL^2}{8} = \frac{(32.3)(1320)^2}{8} = 7.034 \times 10^6 \text{ IN-LBS}$$

$$= \frac{(9.149 \times 10^5)(1320)^2 + (8)(46.63 \times 10^6)}{(8)(1.5925 \times 10^6)}$$

$$M_L = \frac{PL}{4} = \frac{(120{,}000)(1320)}{4} = 39.6 \times 10^6 \text{ IN-LBS}$$

$F_{(MIN.)} = 124$ IN.

$M_T = 46.63 \times 10^6$

```
!LØGIN: 15Q7BRD,C,
ID= D
!BASIC
>LOAD CONCEPT10
>LIST
10 PRINT"THIS PRØGRAM CØMPUTES THE CØMPRESSIVE LØAD ØN THE DECK"
11 PRINT"AND THE TENSILE LØAD ØN THE CABLES AS A CONCENTRATED"
12 PRINT"LØAD MØVES ACRØSS THE RAMP."
15 PRINT
20 PRINT"THE CØNCENTRATED LIVE LØAD (LBS)="
30 INPUT P
40 PRINT"THE DEAD LØAD (LBS/IN)="
50 INPUT W
60PRINT"THE REQUIRED INFLATIØN PRESSURE (PSI)="
70 INPUT Z
72 PRINT"THE MAX. DEPTH AT MIDSPAN (IN)="
73 INPUT F
75 PRINT
80 PRINT"DISTANCE        BENDING        DEPTH ØF        TØTAL        TØTAL"
90 PRINT" ALØNG          MØMENT           RAMP        CØMPRESSIVE TENSILE"
100PRINT" RAMP           (IN-LBS)         (IN)          FØRCE        FØRCE"
110PRINT" (IN)                                           (LBS)        (LBS)"
120 PRINT
130 FØR X=30TØ 660 STEP 30
140 Y=4*F*(1-(X/1320))*(X/1320)
150 A1=ATN(((4*F/1320)*(1-((2*X)/1320))))
160 M1=(W*X/2)*(1320-X)
170 M2=(P*X*(1320-X))/1320
180 M=M1+M2
190 T1=M/Y
200 T=T1/CØS(A1)
210 Z1=Z*192
220 H1=(Z1*(1320↑2))/(8*F)
230 H=H1*CØS(A1)
240 T3=T+H+(Z1*1320*(.5-(X/1320)))
250 C=T1+H1
260 PRINT X,M,Y,C,T3
270 NEXT X
280 END
>SYS

!BYE
02/28/  '73 09:29
CLT 2
CCU 0.024
```

```
B5520$SEARCH
02/28/  '73 09:36
!LOGIN: 1507BRD,C,
ID= D
!BASIC
>LOAD CONCEPTIO
>RUN
09:36   02/28
THIS PROGRAM COMPUTES THE COMPRESSIVE LOAD ON THE DECK
AND THE TENSILE LOAD ON THE CABLES AS A CONCENTRATED
LOAD MOVES ACROSS THE RAMP.

THE CONCENTRATED LIVE LOAD (LBS)=
?120000
THE DEAD LOAD (LBS/IN)=
?22.3
THE REQUIRED INFLATION PRESSURE (PSI)=
?3.61
THE MAX. DEPTH AT MIDSPAN (IN)=
?130
```

DISTANCE ALONG RAMP (IN)	BENDING MOMENT (IN-LBS)	DEPTH OF RAMP (IN)	TOTAL COMPRESSIVE FORCE (LBS)	TOTAL TENSILE FORCE (LBS)
30	4.14319E+06	11.5496	1.51997E+06	1.9068[illegible]E+06
60	8.09367E+06	22.5620	1.51997E+06	1.89016E+06
90	1.18514E+07	33.0372	1.51997E+06	1.87336E+06
120	1.54165E+07	42.9752	1.51997E+06	1.85644E+06
150	1.87889E+07	52.3760	1.51997E+06	1.83939E+06
180	2.19685E+07	61.2397	1.51997E+06	1.82219E+06
210	2.49553E+07	69.5651	1.51997E+06	1.80484E+06
240	2.77497E+07	77.3554	1.51997E+06	1.78733E+06
270	3.03513E+07	84.6074	1.51997E+06	1.76964E+06
300	3.27601E+07	91.3223	1.51997E+06	1.75177E+06
330	34976205	97.5000	1.51997E+06	1.73370E+06
360	3.69996E+07	103.140	1.51997E+06	1.71543E+06
390	3.88303E+07	108.244	1.51997E+06	1.69695E+06
420	4.04683E+07	112.810	1.51997E+06	1.67825E+06
450	4.19136E+07	116.839	1.51997E+06	1.65932E+06
480	4.31662E+07	120.331	1.51997E+06	1.64015E+06
510	4.42261E+07	123.285	1.51997E+06	1.62075E+06
540	4.50933E+07	125.702	1.51997E+06	1.60110E+06
570	4.57670E+07	127.583	1.51997E+06	1.58120E+06
600	4.62495E+07	128.926	1.51997E+06	1.56105E+06
630	4.65386E+07	129.731	1.51997E+06	1.54064E+06
660	46634940	130	1.51997E+06	1.51997E+06

```
280 HALT
>SYS

!BYE
02/28/  '73 09:40
CLT 4
CCU 0.026
```

RESULTS FROM COMPUTER RUN:

FOR INFLATION PRESS. = 3.61 P.S.I.

FOR MAX. DEPTH (F) = 130 IN.

COMPRESSIVE FORCE IN DECK = 1.519×10^6 LBS.

ALLOW. COMP. FORCE = 1.592×10^6 LBS. ok

TENSION FORCE IN CABLES = 1.9×10^6 LBS.
SAY 2.0×10^6 AS $X \rightarrow 0$

FOR S.F. = 2
∴ BREAKING STRENGTH REQD = 4×10^6 LBS.

FOR WEBS AND CABLES @ 12 IN. SPACING

16 CABLES REQD.

BREAKING STRENGTH PER CABLE = 125 TONS

1 7/16 φ CLASS A BRIDGE STRAND

AREA = 1.24 IN^2 WT. = 4.34 LBS/FT.
PRESTRETCHED E = 24,000,000 PSI

DEFLECTIONS:

ASSUMPTION: DEFLECTION CONTROLLED BY COMPRESSION OF ALUMINUM DECK AND ELONGATION OF STEEL CABLES. FABRIC DOES NOT CONTRIBUTE TO FLEXURAL STIFFNESS.

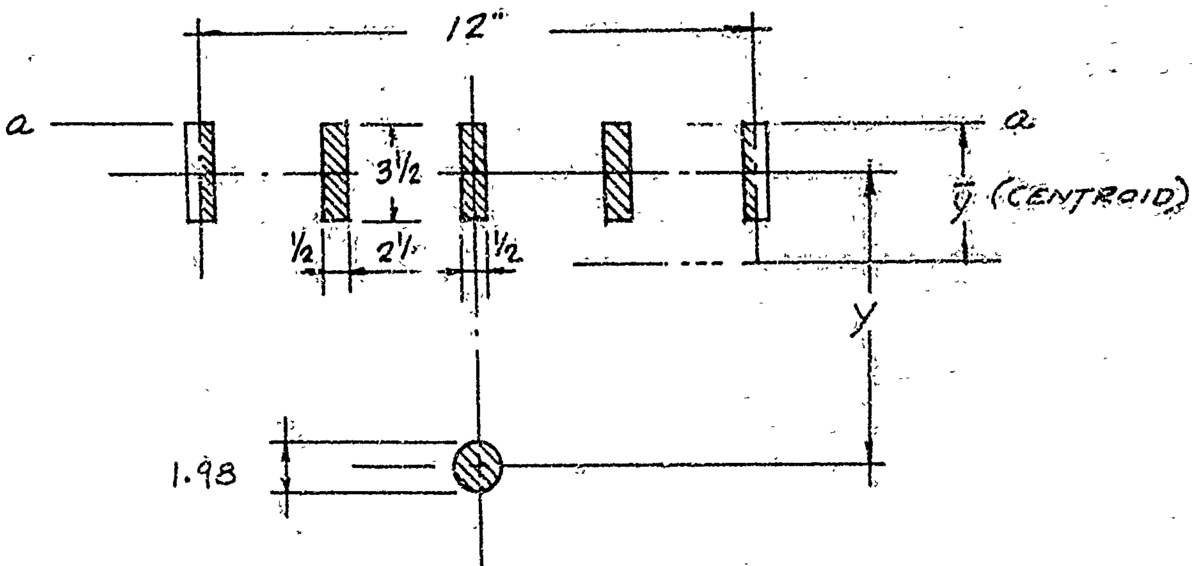
TRANSFORMED SECTION REQD.

$E_{ALUM} = 10 \times 10^6$ PSI

$E_{CABLE} = 24 \times 10^6$ PSI (PRESTRETCHED)

$E_C / E_A = 2.4$ (TRANSFORMED TO ALUMINUM)

AREA STEEL CABLE = 1.24 IN^2
EQUIV. AREA ALUM. CABLE = (1.24)(2.4) = 3.07 IN^2
DIA. = 1.98 IN.



$I_T = I_o + Ad^2$

$I_o \text{ (DECK)} = \left(\frac{bd^3}{12}\right)4 = 4\left[\frac{(.5)(3.5)^3}{12}\right] = 7.146 \text{ IN}^4$

$I_o \text{ (CABLE)} = .0491\,(D)^4 = (.0491)(1.98)^4 = .755 \text{ IN}^4$

DEFLECTIONS:

COMPUTE CENTROID ABOUT a-a

AREA	LEVER ARM	MOM.
(4)(.5)(3.5) = 7.00	1.75	12.25
3.07	y+1.75	5.37 + 3.07y
10.07 IN²		17.62 + 3.07y IN³

$\bar{y} = M/A = 1.75 + .305y$

TOTAL MOMENT OF INERTIA

$I_T = I_o + Ad^2$

$I_T = 7.146 + (7.00)(\bar{y} - 1.75)^2 + .755 + (3.07)(y + 1.75 - \bar{y})^2$

DEFLECTION EQUATIONS:

REF. A.I.S.C. STEEL MANUAL

Δ (AT POINT x) $= \frac{wx}{24EI}(L^3 - 2Lx^2 + x^3)$
DEAD LOAD

Δ (AT POINT OF LOAD) $= \frac{Pa^2b^2}{3EIL}$
LIVE LOAD

$= \frac{P(x)^2(L-x)^2}{3EIL}$

```
0+5IJERSEARCH
03/22/  '73 09:26
!LOGIN: 1507BRD,C,
ID= B
!BASIC
>LOAD DEFLECTION
>LIST
10 PRINT"THIS PRINT OUT IS A LISTING OF THE DEFLECTION AS A "
11 PRINT"CONCENTRATED LIVE LOAD MOVES ALONG THE RAMP:"
15 PRINT
20 PRINT"THE CONCENTRATED LIVE LOAD (LBS)="
30 INPUT P
40 PRINT"THE DEAD LOAD (LBS/IN)="
50 INPUT W
60 PRINT"THE SPAN LENGTH (IN)="
70 INPUT L
80 PRINT"THE MAXIMUM DEPTH (F) IN INCHES ="
90 INPUT F
100 PRINT
110 PRINT"DISTANCE        MOM. OF         DEFL.           DEFL.           TOTAL"
120 PRINT" ALONG          INERTIA         UNDER           UNDER           DEFL."
130 PRINT" RAMP           AT POINT        D.L.             L.L.           (IN)"
140 PRINT" (IN)           (IN4)           (IN)            (IN)"
150 PRINT
160 FOR X=30 TO 660 STEP 30
170 Y=(4*F*(1-(X/L))*(X/L))
180 Y1=1.75+(.305*Y)
190 I=7.146+(7*((Y1-1.75)↑2))+.755+(3.07*((Y+1.75-Y1)↑2))
195I=I*16
200 D1=((W*X)/(24*10000000*I))*(L↑3-(2*L*X*X)+X↑3)
210 D2=(P*(X↑2)*((L-X)↑2))/(3*10000000*I*L)
220 D3=D1+D2
230 PRINT X;I;D1,D2;D3
240 NEXT X
250 END
>SYS

!BYE
03/22/  '73 09:28
CLT 1
CCU 0.026
```

```
COMPUTERSEARCH
03/13/  '73 10:00
!LOGIN: 1507BRD,C,
ID= F
!BASIC
>LOAD DEFLECTION
>195 I=I*16
>RUN
10:01   03/13
```

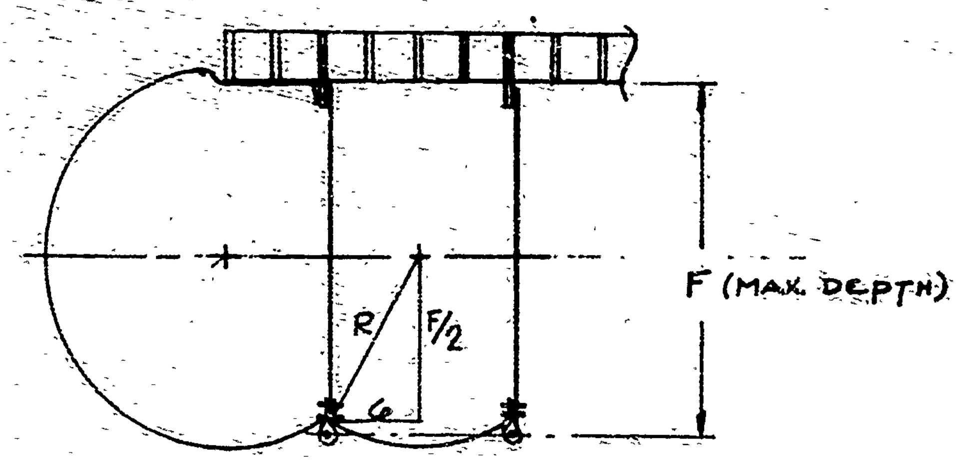
THIS PRINT OUT IS A LISTING OF THE DEFLECTION AS A CONCENTRATED LIVE LOAD MOVES ALONG THE RAMP.

```
THE CONCENTRATED LIVE LOAD (LBS)=
?120000
THE DEAD LOAD (LBS/IN)=
?32.3
THE SPAN LENGTH (IN)=
?1320
THE MAXIMUM DEPTH (F) IN INCHES =
?130
```

DISTANCE ALONG RAMP (IN)	MOM. OF INERTIA AT POINT (IN4)	DEFL. UNDER D.L. (IN)	DEFL. UNDER L.L. (IN)	TOTAL DEFL. (IN)
30	4681.12	1.98171	.969524	2.95124
60	17507.7	1.05652	.989238	2.04576
90	37394.2	.738302	.993064	1.73137
120	63187.7	.578569	.994440	1.57301
150	93794.6	.482966	.995090	1.478[illegible]
180	128180.	.419611	.995450	1.41506
210	165369.	.374762	.995671	1.37043
240	204445.	.341529	.995817	1.33735
270	244551.	.316078	.9959[illegible]8	1.31200
300	284888.	.296111	.995991	1.29210
330	324717.	.280167	.996045	1.27621
360	363359.	.267275	.996086	1.26336
390	400194.	.256768	.996118	1.25289
420	434658.	.248172	.996143	1.24432
450	466250.	.241145	.996165	1.23731
480	494527.	.235435	.996178	1.23161
510	519104.	.230856	.996190	1.22705
540	539655.	.227269	.996200	1.22347
570	555916.	.224573	.996206	1.22078
600	567678.	.222696	.996211	1.21891
630	574795.	.221588	.996214	1.21780
660	577177.	.221222	.996215	1.21744

FABRIC STRESSES:

TRANSVERSE FABRIC STRESS = pR } OUTER SKIN
LONGITUDINAL FABRIC STRESS = $pR/2$ } OUTER SKIN



FOR $F = 130$ IN.
$F/2 = 65$ IN.
$R = [36 + (65)^2]^{1/2}$

$R = 65.3$ IN.
(MAXIMUM)
$p = 3.61$ PSI

MAX. FABRIC STRESS (OUTER SKIN) = (65.3 IN)(3.61 psi) = 235.7 LBS./IN.

FACTOR OF SAFETY = 3

REQUIRED FABRIC STRENGTH = 707 LBS./IN.
(2N14N58)

WEB STRESSES:

2 PLY WEB
- 1 STRAIGHT PLY
- 1 BIAS PLY

STRESS IN STRAIGHT PLY -
(DUE TO INFLATION PRESSURE)

FABRIC STRESS = (p)(WEB SPACING)
= (3.61)(12)
= 43.3 LBS./IN.

FACTOR OF SAFETY = 3

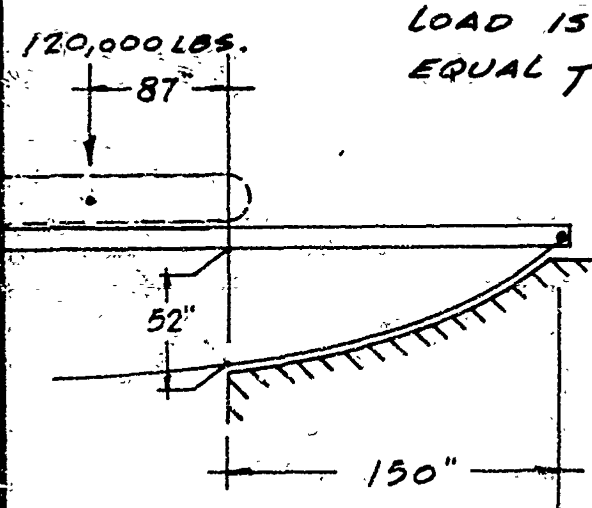
REQUIRED FABRIC STRENGTH ST. PLY = 130 LBS./IN.

FABRIC STRESSES:

WEB STRESS - BIAS PLY

BIAS PLY CARRIES SHEAR STRESS ALONG THE RAMP.

ASSUMPTION: BECAUSE OF GEOMETRY, CONSIDER THE BEARING LENGTH ON EACH END EQUAL TO 150 IN., THEREFORE, ASSUME MIN. DEPTH OF RAMP TO CARRY SHEAR LOAD IS AT 150 IN. OR A DEPTH EQUAL TO 52 IN.



SHEAR FORCE AT SUPPORT

$$V_{D.L.} = \frac{wL'}{2} = \frac{(32.3)(1170)}{2} = 18,895 \text{ LBS.}$$

$L' = 1320 - 300 = 1170$ IN.

$$V_{L.L.} = \frac{Pa'}{L''} = \frac{(120,000)(1083)}{(1170)} = 111,077 \text{ LBS.}$$

$a' = 1170 - 87 = 1083$
$L'' = 1170$

TOTAL MAX. SHEAR FORCE = 129,972 LBS.

SHEAR FORCE ALUM. DECK WILL CARRY:

CROSS-SECTIONAL AREA = (65 BARS)(.5)(3.5) = 113.75 IN^2
ALLOW. SHEAR STRESS (6061-T6 ALUM.) = 10 KSI
SHEAR LOAD = (113.75)(10,000) = 1,137,500 LBS. OK

FABRIC STRESS

WEB STRESS

IF WEB IS TO TRANSFER SHEAR LOAD -

FORCE PER WEB = $129,972/16$ = 8123 LBS./WEB

@ 45° BIAS, LENGTH = (1.414)(52) = 73.5 IN.

STRESS IN BIAS PLY = 110.5 LBS./IN.

FACTOR OF SAFETY = 3

REQUIRED FABRIC STRENGTH BIAS PLY = 332 LBS/IN.

(2N5N42)

WEIGHT CALCULATIONS:

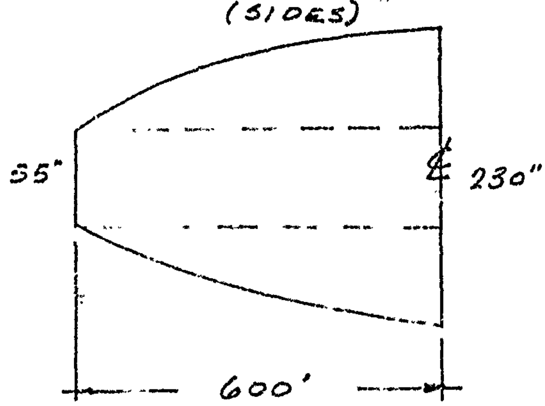
TOTAL WEIGHT OF ALUMINUM DECK = 11.34 TONS

TOTAL WEIGHT OF STAINLESS STEEL CABLES =

16 CABLES x 4.34 LBS./FT. x 120 FT. =	8333 LBS.
HARDWARE 10%	833 LBS.
	9166 LBS.

FABRIC WEIGHT =

OUTER SKIN (SIDES) - 2N14N58 - 58 OZ/S.Y.



$IN^2 = (55)(600) + (2)\left[2/3\,(87.5)(600)\right]$

$IN^2 = 103,000$

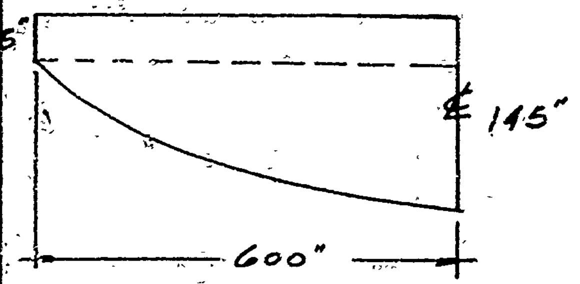
$YD^2 = 79.5$

TOTAL S.Y. = 79.5 X 4 = 318 YD^2

WEIGHT = $(318)\dfrac{(58\ OZ/YD^2)}{16\ OZ/LB}$ = 1153 LBS.

FABRIC WEIGHT CALCULATIONS CONT.

WEBS - 2N5N42 - 42 OZ/YD²



$IN^2 = (22.5)(600) + (2/3)(122.5)(600)$

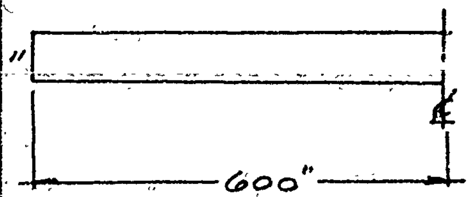
$IN^2 = 62,500$

$YD^2 = 48.2$

TOTAL $YD^2 = 48.2 \times 2 \times 16$ WEBS $= 1542.4$

WEIGHT $= (1542.4)\left(\frac{42\ OZ/YD^2}{16\ OZ/LB.}\right) = 4048.8$ LBS.

BOTTOM CLOSURES



$IN^2 = (20)(600)$

$IN^2 = 12,000\ IN^2$

$YD^2 = 9.3$

TOTAL $YD^2 = 9.3 \times 2 \times 15$ REQD. $= 279$

WEIGHT $= (279)\left(\frac{48\ OZ/YD^2}{(16\ OZ/LB)}\right) = 837$ LBS.

TOTAL FABRIC WEIGHT	=	6039 LBS
10% FOR SEAMS	=	604
		6643 LBS.

ALUMINUM MEMBRANE ON DECK -

1/8" TK × 1320 IN. × 192 IN. = 31,680 IN.³

@ .0955 LBS./CU. IN. = 3025 LBS.

ESTIMATED TOTAL WEIGHT OF CONCEPT No. 10 = 20.76 TONS

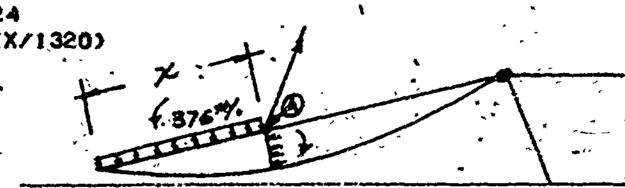
```
[illegible] 654 STEP 12
>20 Y=4*130*(1-(X/1320))*(X/1320)
>30 V1=((192*Y)+((3.14*Y*Y)/4))*12
>40 V1=V1/1728
>50 PRINT V1
>60 NEXT X
>70 END
>RUN
08:48    04/09
 36.2592
 43.1055
 49.9995
 56.9298
 63.8849
 70.8537
 77.8254
 84.7892
 91.7349
 98.6523
 105.531
 112.363
 11[illegible].137
 125.844
 132.476
 139.024
 145.479
 151.833
 158.079
 164.208
 170.213
 176.087
 181.822
 187.413
 192.852
 198.133
 203.250
 208.197
 212.970
 217.561
 221.968
 226.183
 230.204
 234.025
 237.643
 241.053
 244.252
 247.237
 250.004
 252.551
 254.875
 256.974
 258.844
 260.485
 261.895
 263.072
 264.015
 264.723
 265.196
 265.432
```

VOLUME CALCULATIONS

8977.13 x 2 = **17,954.3 FT.^{3}**

```
70 HALT
>SYS
```

```
+F/ZJWRUR
04/09/  '73 11:02
!LOGIN: 1507BRD,C,
ID= C
!BASIC
>5 PRINT"  X                    MOMENT           MOMENT"
>6 PRINT"                       CLOCKWISE        COUNTERCLOCKWISE"
>7 PRINT
>15 FOR X=12 TO 660 STEP 24
>20 Y=4*130*(1-(X/1320))*(X/1320)
>30 Y1=Y/12
>40 A1=1.6*Y1
>50 A2=3.14*Y1*Y1/4
>60 A3=A1+A2
>70 F1=3.6*144*A3
>80M1=F1*(Y1/2)
>90 X1=X/12
>100 M2=375*X1*(X1/2)
>110 PRINT
>110 PRINT X1,M1,M2
>120 NEXT X
>130 END
>RUN
11:08    04/09
```



$\Sigma M_A = 0$

MOM. (CLOCKWISE) = (PRESS.)(AREA)(LEVER ARM)

MOM. (COUNTER-CLOCKWISE) = (LOAD)(LEVER ARM)

LOAD = $\frac{20.6\ \text{TON}}{110'}$ = 375 LBS/FT. (CONSERVATIVE)

X	MOMENT CLOCKWISE (DUE TO PRESS.)	MOMENT COUNTERCLOCKWISE (DUE TO WT. OF RAMP)
1	644.051	187.500
3	5789.85	1687.50
5	16012.8	4687.50
7	31153.1	9187.50
9	50969.2	15187.5
11	75148.7	22687.5
13	103318.	31687.5
15	135052.	42187.5
17	169884.	54187.5
19	207314.	67687.5
21	246816.	82687.5
23	287850.	99187.5
25	329864.	117188.
27	372305.	136688.
29	414624.	157688.
31	456283.	180188.
33	496760.	204188.
35	535556.	229688.
37	572198.	256688.
39	606245.	285188.
41	637290.	315188.
43	664967.	346688.
45	688952.	379688.
47	708965.	414188.
49	724774.	450188.
51	736198.	487688.
53	743106.	526688.
55	745417.	567188.

NOTE:

SINCE THE CLOCKWISE MOMENT EXCEEDS THE COUNTERCLOCKWISE MOM. AT ALL POINTS ALONG THE RAMP, IT IS POSSIBLE TO HOIST THE RAMP AT ANY POINT WITHOUT BUCKLING THE DECK.

```
130 HALT
>SYS

!BYE
04/09/  '73 11:10
CLT 6
CCU 0.014
```

MODEL ANALYSIS

DIMENSIONAL SIMILITUDE REQD. FOR SCALE MODEL OF CONCEPT Nº. 10

BASIC ASSUMPTION: FOR 1/10 SCALE.

DEFLECTION OF MODEL = 1/10 DEFLECTION OF ACTUAL FULL SIZE RAMP

$$\Delta(D.L.) = \frac{WX}{24EI}\left(L^3 - 2LX^2 + X^3\right)$$

(AT POINT X)

$$\Delta(L.L.) = \frac{Pa^2b^2}{3EIL}$$

(AT POINT OF LOAD)

FROM AISC STEEL MANUAL REF. PG. D-34

NOTATION: SUBSCRIPT M = MODEL
SUBSCRIPT A = ACTUAL FULL SIZE RAMP

$$\Delta_M = \frac{1}{10}\Delta_A$$

$$\Delta_{M\,(D.L.)} = \frac{W_M L_M}{24 E_M I_M}\overbrace{\left(L_M^3 - 2L_M^3 + L_M^3\right)}^{L^3} = \frac{1\, W_A L_A}{(10)(24) E_A I_A}\overbrace{\left(L_A^3 - 2L_A^3 + L_A^3\right)}^{L^3}$$

$$L_M = \frac{1}{10} L_A$$

$$I_M = \left(\frac{1}{10}\right)^4 I_A$$

$$\Delta_M = \frac{W_M \left(\frac{1}{10}L_A\right)\left(\frac{1}{10}L_A\right)^3}{24\ E_M \left(\frac{1}{10}\right)^4 I_A} = \frac{W_A L_A\, L_A^3}{(10)(24)\, E_A I_A}$$

$$\frac{W_M}{E_M} = \frac{W_A}{10\, E_A} \qquad \text{EQ. 1}$$

$$\Delta_{M\,(L.L.)} = \frac{P_M L_M^2 L_M^2}{3 E_M I_M L_M} = \frac{1}{10}\left[\frac{P_A L_A^2 L_A^2}{3 E_A I_A L_A}\right]$$

$$L_M = \frac{1}{10} L_A$$

$$I_M = \left(\frac{1}{10}\right)^4 I_A$$

$$\Delta_M = \frac{P_M \left(\frac{1}{10}L_A\right)^2 \left(\frac{1}{10}L_A\right)^2}{3\, E_M \left(\frac{1}{10}\right)^4 I_A \left(\frac{1}{10}\right) L_A} = \frac{P_A L_A^2}{(10)(3)(E_A)(I_A)(L_A)}$$

$$\frac{P_M}{E_M} = \frac{P_A}{100\, E_A}$$ EQ. 2

FROM EQ. 1

$$E_A = \frac{W_A E_M}{10\, W_M}$$ EQ. 3

FROM EQ. 2

$$E_A = \frac{E_M P_A}{100\, P_M}$$ EQ. 4

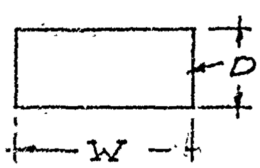
$$\frac{E_M P_A}{100\, P_M} = \frac{W_A E_M}{10\, W_M}$$

$$\frac{P_A}{10\, P_M} = \frac{W_A}{W_M}$$ EQ. 5

$$W = f\left(\frac{L\,(2W + 2D)\,t\,\delta}{L}\right)$$

W = LBS./IN. = FORCE/LENGTH

$\therefore\ W_M = \left(\frac{1}{10}\right)^2 W_A$



ANY RECTANGULAR SHAPE

t = MTL. THICKNESS EQ. 6

$$\frac{P_A}{10 P_M} = \frac{W_A}{W_M}$$ EQ. 5

$$= \frac{W_A}{\left(\frac{1}{10}\right)^2 W_A}$$

$$\therefore\ P_M = \left(\frac{1}{1000}\right) P_A$$ EQ. 7

$$E_A = \frac{P_A E_M}{100 P_M}$$ EQ. 4

$$E_M = \frac{100 P_M}{P_A} E_A$$

$$P_M = \frac{P_A}{1000}$$

$$E_M = 100 \left(\frac{P_A}{1000 P_A}\right) E_A$$

$$E_M = \left(\frac{1}{10}\right) E_A$$ EQ. 8

INFLATION PRESS. (p) = P/L^2

$$p_M = f(p_A)$$

$$p_M = \frac{P_A}{1000 \left(\frac{1}{10} L_A\right)\left(\frac{1}{10} L_A\right)} = \frac{P_A}{L_A L_A}$$

$$p_M = \left(\frac{1}{10}\right) p_A$$ EQ. 9

FOR COMPRESSION DECK

$S = \frac{bh^2}{6} = L^3$ (S = SECTION MODULUS)

$S_M = \left(\frac{1}{10}\right)^3 S_A$ EQ. 10

FOR TENSION CABLES

DIA. = L

$DIA._M = \left(\frac{1}{10}\right) DIA._A$ EQ. 11

FOR FABRIC

A FUNCTION OF WEIGHT OR THICKNESS

WT. PER SQ. YD. IS A FUNCTION OF MTL. THICKNESS (t)

$OZ/YD^2{}_M = \left(\frac{1}{10}\right) OZ/YD^2{}_A$ EQ. 12

SUMMARY OF PARAMETERS REQUIRED TO SIMULATE CONCEPT 10 AT 1/10 SCALE:

$LENGTH_M = \frac{1}{10} LENGTH_A = \frac{1320 \text{ IN}}{10} = 132 \text{ IN.}$

$WIDTH_M = \frac{1}{10} WIDTH_A = \frac{192 \text{ IN.}}{10} = 19.2 \text{ IN.}$

$MAX.\ DEPTH_M = \frac{1}{10} MAX.\ DEPTH_A = \frac{130 \text{ IN.}}{10} = 13 \text{ IN.}$

$INFLATION\ PRESSURE = \frac{1}{10} P_A = \left(\frac{1}{10}\right)(3.6) = .36 \text{ PSI}$

$MAX.\ POINT\ LOAD = \frac{P_A}{1000} = \frac{120,000}{1000} = 120 \text{ LBS.}$

SUMMARY OF PARAMETERS REQD. TO SIMULATE CONCEPT № 10 AT 1/10 SCALE: (CONT.)

COMPRESSION DECK

$E_M = \frac{1}{10} E_A$ (EQ. 8)

$E_M = (\frac{1}{10})(10{,}000{,}000) =$ **1 X 10^6 PSI**
(6061-T6 ALUM.)

$S_M = (\frac{1}{10})^3 S_A$ (EQ. 10)

$S_M = (\frac{1}{10})^3 (1.028)(65) =$ **.0668 IN³**

$S_M = \frac{bh^2}{6}$ $\quad h^2 = \frac{6S_M}{b}$ $\quad b = 19.2$ IN.

h = THICKNESS = .1445 IN. (9 GAGE)

TENSION CABLES

$E_M = \frac{1}{10} E_A = \frac{1}{10}(24{,}000{,}000) =$ **2.4 X 10^6 PSI**

$DIA._M = \frac{1}{10} DIA._A$ (EQ. 11)

$DIA._M = (\frac{1}{10})(1\frac{7}{16}) = 1.4375/10 =$ **.14375 IN.** (1/8 IN.)

FABRIC

$OZ/YD^2_M = (\frac{1}{10})\, OZ/YD^2_A$ (EQ. 12)

OUTER SKIN – $OZ/YD^2_M = (\frac{1}{10})(2N14N48) =$ **4.8 OZ/YD² (2 PLY)**

WEBS – $OZ/YD^2_M = (\frac{1}{10})(2N5N31) =$ **3.1 OZ/YD² (2 PLY-BIAS)**

REFINED ANALYSIS FOR PRACTICAL APPROACH IN DEVELOPING 1/10 SCALE MODEL

ON PAGE E-5, NOTE THE SMALL MODULII OF ELASTICITIES THAT ARE REQD. TO SATISFY THE VARIOUS OTHER PARAMETERS.

FOR PRACTICAL PURPOSES ASSUME $E_M = E_A$

THEREFORE FROM EQ. 2

$$\frac{P_M}{E_M} = \frac{P_A}{100 E_A} \qquad E_M = E_A$$

$$P_M = \frac{P_A}{100}$$

CONVERSLY, FROM EQ. 9

$$\rho_M = \rho_A$$

ON PAGE E-4, NOTE REQD. SECTION MODULUS FOR COMPRESSION DECK. SINCE ACTUAL MODEL DECK WILL BE CONSTRUCTED FROM SHEET ALUMINUM, AND SINCE WE REQUIRE TO STRESS THE DECK TO IT'S ALLOWABLE LOAD, A SCALE DOWN OF CROSS-SECTIONAL AREA SHOULD BE THE DETERMINING FACTOR.

$$AREA_M = \left(\tfrac{1}{10}\right)^2 AREA_A$$

$$= \left(\tfrac{1}{100}\right)(65\,BARS)(3.5\,IN.)(.5\,IN) = 1.14\,IN^2$$

FOR WIDTH = 19.2 IN

THICKNESS = $1.14/19.2$ = .0592 IN. ≈ 1/16 IN.

TO SATISFY SECTION MODULUS - 1/8 IN. THICKNESS REQUIRED - NEGLECT THIS SINCE IT ONLY EFFECTS DEFLECTION

ON PAGE E-4, FABRIC TYPE REQD. WAS BASED ON A WEIGHT COMPARISON. FOR THE MODEL, A MORE PRACTICAL APPROACH WILL BE TO USE THE REDUCED GEOMETRIC DIMENSIONS ALONG WITH THE REQD. INFLATION PRESSURE, AND CALCULATE FABRIC STRENGTH REQD.

BASIC GEOMETRIC REQUIREMENTS FOR 1/10 SCALE MODEL OF CONCEPT No 10

OVERALL LENGTH = 132 IN.
DECK WIDTH = 19.2 IN.
MAX. DEPTH = 13 IN.
MAX. LOAD = 1200 LBS.
INFLATION PRESS. = 3.6 PSI

DECK - 6061-T6 ALUM. 19.2 x 132 x 1/16" TK.

CABLES - 16 REQD. 1/8 ϕ 7X16 NEOPRENE COATED
(BREAKING STRENGTH = 1900 LBS.)

APPROXIMATION OF MODEL WT.

DECK - $(19.2)(132)(.0625)\left(\frac{165}{1728}\right) = 15.1$ LBS.

CABLES - 1/8" ϕ - NEOPRENE COATED
24.5 GMS./FT.
$(16)(136)(1/12)(24.5)(.002) = 9.8$ LBS.

FABRIC - EST. 5.1 LBS.

APPROX. TOTAL WEIGHT = 30 LBS
$W = 30/132 = \underline{.23 \text{ LBS/IN.}}$

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<15TJERSEARCH
03/08/  '73 13:12
!LØGIN: 1507BRD,C,
 ?
!LØGIN: 1507BRD,C,
ID= D
!BASIC
>LØAD MØDEL10
>RUN
13:13   03/08
THIS PRØGRAM CØMPUTES THE CØMPRESSIVE LØAD ØN THE DECK
AND THE TENSILE LØAD ØN THE CABLES AS A CØNCENTRATED
LØAD MØVES ACRØSS THE RAMP.

THE CØNCENTRATED LIVE LØAD (LBS)=
?1200
THE DEAD LØAD (LBS/IN)=
?.23
THE REQUIRED INFLATIØN PRESSURE (PSI)=
?3.6
THE MAX. DEPTH AT MIDSPAN (IN)=
?13
```

DISTANCE ALØNG RAMP (IN)	BENDING MØMENT (IN-LBS)	DEPTH ØF RAMP (IN)	TØTAL CØMPRESSIVE FØRCE (LBS)	TØTAL TENSILE FØRCE (LBS)
3	3562.69	1.15496	14664.9	18489.4
9	10190.9	3.30372	14664.9	18161.3
15	16156.4	5.23760	14664.9	17827.9
21	21459.0	6.95661	14664.9	17488.3
27	26098.8	8.46074	14664.9	17141.5
33	30075.7	9.75000	14664.9	16786.9
39	33389.8	10.8244	14664.9	16423.5
45	36041.1	11.6839	14664.9	16050.7
51	38029.6	12.3285	14664.9	15667.9
57	39355.3	12.7583	14664.9	15274.8
63	40018.1	12.9731	14664.9	14870.9

```
280 HALT
>SYS

!BYE
03/08/  '73 13:16
CLT 3
CCU 0.030
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FROM COMPUTER RUN:

TOTAL TENSILE LOAD = 19,000 LBS

LOAD PER CABLE = $19{,}000/16$ = 1190 LBS

SAFETY FACTOR = $1900/1190$ = 1.6

TOTAL COMPRESSIVE FORCE = 14,665 LBS.
ALLOW. COMPRESSIVE FORCE =
(19.2)(.0625)(14,000) = 16,800 LBS.
ACTUAL LOAD APPROACHES ALLOWABLE LOAD - o/k

FABRIC STRENGTH REQUIREMENTS

OUTER SKIN - $R = ((1.6)^2 + (6.5)^2)^{1/2} = 6.53$

$S = \varphi R = (3.6)(6.53) = 23.5$ LBS./IN.
SAFETY FACTOR = 3
FABRIC STRENGTH = 70.5 LBS./IN.

WEBS - (REFER TO PGS. D-37 → D-39)

STRAIGHT PLY - $S = (3.6)(1.2) = 4.3$
FACTOR OF SAFETY = 3
FABRIC STRENGTH = 13 LBS./IN.

BIAS PLY -
SHEAR FORCE $V_{(D.L.)} = \frac{(.23)(117)}{2}$ = 13.5 LBS.
$L' = 132 - 15 = 117$
$V_{(L.L.)} = \frac{(1200)(108.3)}{117}$ = 1110.8 LBS.
$L'' = 117 - 8.7 = 108.3$
TOTAL SHEAR FORCE = 1124.3 LBS
PER WEB = 70.3 LBS.

$S = 70.3 \text{ LBS} / (5.2)(1.414) = 9.56$
SAFETY FACTOR = 3
FABRIC STRENGTH = 28.7 LBS./IN.

APPENDIX F

DEFLECTION OF AIR-INFLATED RAMP

A critical factor in evaluating the feasibility of an air-inflated ramp is the amount of deflection which might be incurred. Unlike a conventional structure where member stresses are typically the controlling design factor, the normally more flexible air-inflated structure may have perfectly acceptable stress levels and yet deflect to an intolerable degree. In many instances this feature may be used to advantage, allowing the design to flex under high loads (i.e., "give with the punches") and then spring back to its normal shape. Although no critical deflection values have been established for the bow ramp, it is obvious that a great amount of deflection while a heavy vehicle is embarking would not be desirable.

Several efforts have been made to analytically predict the deflection of air-inflated, dual-wall type structures. References 5 thru 10 and 20 all propose analytical means, varying from rather straightforward, linear, small deflection analysis to very complicated, multi-term expressions. The work done by NASA (reference 5, 6, 7, and 8) is mathematically extensive, but has apparently only been used with small (18" x 18" x 1 1/8"), flat plate samples of air mat. It is exceedingly difficult to apply to the subject design. The analysis by Webb (reference 20) is more applicable, but questionable when it attempts to optimize the beam stiffness. Probably the most useful is the work done by Dr. Bulson and Tutt in England (reference 2 and 3); however, it leans upon experimental measurements to establish stiffness coefficients. As will be discussed, even further difficulty arises due to the composite nature of the feasibility configuration.

Deflection of a simple beam structure is typically broken down into two basic mechanisms: that due to bending (i.e., elongation and compression of the upper and lower f[illegible]s) and that due to shear (i.e., a vertical shift between adjacent sections). In most long rigid beams, the bending deflection is so predominate that the shear effect may reasonably be ignored.*

This is not necessarily the case with an air-inflated beam. In fact, both the NASA studies on the air mat construction and the English reports on the unreinforced, parallel web, dual-wall bridge indicate that shear distortion is the major factor. As will be shown, shear stiffness is a function of pressure, but typically NASA reports 82-97% of the air mat deflection is due to shear while the bridge studies indicate up to 97% is calculated as shear.**

Beam bending moment, assuming the upper and lower surfaces remain in tension, is resisted by normal stresses in the surface membranes. Transverse (vertical) shear is resisted by the inflation pressure and any shear capacity of the webs and side closures. This is thus somewhat analogous to sandwich plate theory.

* For a simple rectangular beam with load at mid-point:

$$\frac{\Delta_s}{\Delta_b} = \frac{5}{6}\,\frac{E}{E_s}\left(\frac{d}{L}\right)^2$$

where

E = modulus of elasticity
E_s = shear modulus
d = depth of beam
L = length of beam

ref.: Laurson and Cox "Mechanics of Materials"

**In actual testing, the calculated shear values exceeded total measured deflection at low pressure.

The capacity of the ramp or beam to carry load in bending may be analyzed by simple beam theory. As the webs typically have the high strength warp running vertically between the skins (direction of maximum load), the high elongation fill is lengthwise. Conversely, the low stretch warp runs lengthwise on the skin (maximum load direction in that member). Thus the webs may be conservatively assumed to have a negligible contribution as they have a high elasticity in the bending direction. (Frequently, this may not be the case in special constructions. In such cases the section may be treated as a composite beam with the webs having a different modulus than the skins.) The effective moment of inertia is then expressed by:

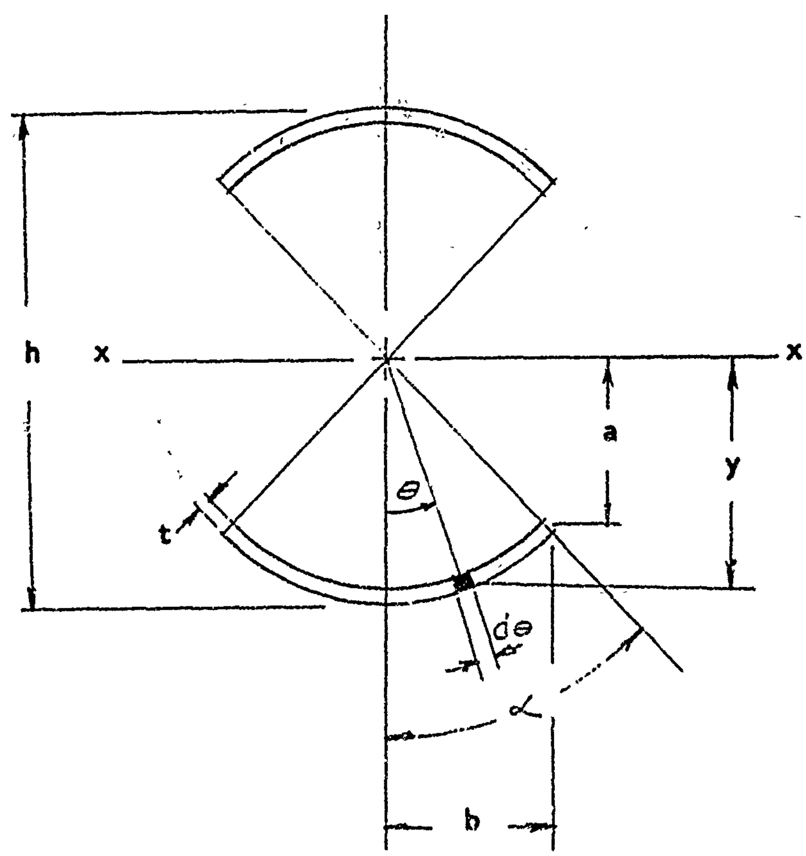


FIG. F1

$$I_{xx} = \int y^2 \, da$$

$$y = r \cos \theta$$

$$dA = tr \, d\theta$$

$$I_{xx} = 4 \int_0^{\alpha} r^2 \cos^2 \theta \, tr \, d\theta$$

$$= 4r^3t \int_0^{\alpha} \cos^2 \theta \, d\theta$$

$$= 4r^3t \left[1/2 \, \theta + 1/4 \sin 2\theta \right]_0^{\alpha}$$

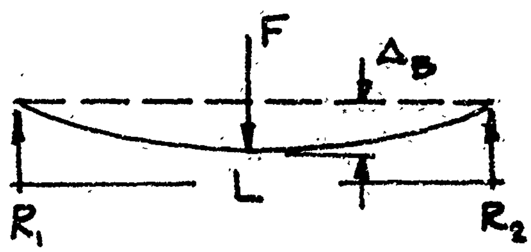
$$= 4r^3t \left[1/2 \alpha + 1/4 \sin 2\alpha \right]$$

$$= r^3t \left[2\alpha + \sin 2\alpha \right]$$

or

$$I_{xx} = \frac{h^3}{8} t \left[\sin 2\alpha + 2\alpha \right]$$

with a simple supported beam, load at center,



@ F

$$\Delta_B = \frac{FL^3}{48 \, EI}$$

where Δ_B = bending deflection

or alternately

Bending stiffness $= S_B = \frac{\text{LOAD}}{\text{DEFL.}}$

$$S_B = \frac{F}{\Delta_B} = \frac{F(48EI)}{FL^3}$$

$$= \frac{48EI}{L^3}$$

Note that this assumes equal material for upper and lower surfaces. The basic equation, which is not derived here, also is for small deflections where $\theta = \tan\theta = \sin\theta$

It is interesting to observe that, theoretically, bending stiffness is not a function of inflation pressure. (However, the pressure must be sufficient to prevent compressive wrinkling and maintain a linear modulus of elasticity.)

The capacity of the air-inflated beam to resist shear may be simply* analyzed. Looking at a free body or small portion of the beam:

*Several references develop the same equation by more rigorous means.

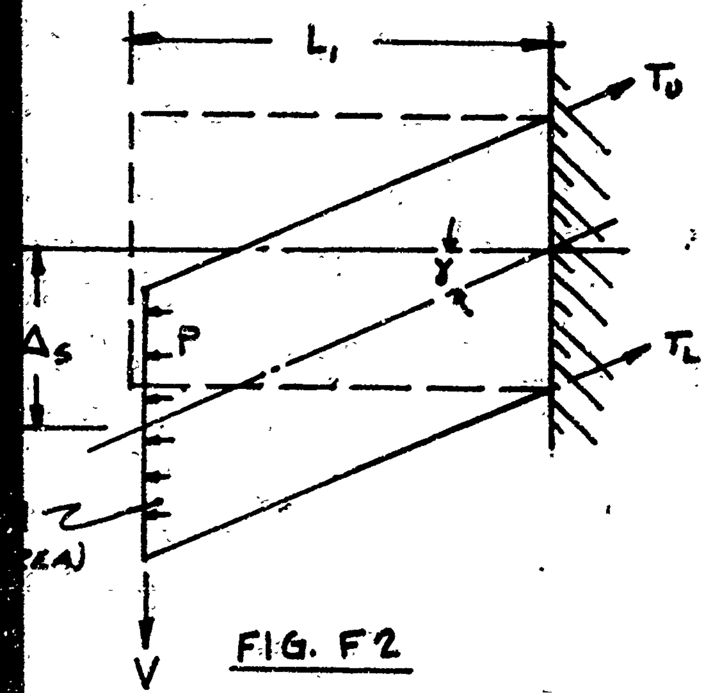


FIG. F2

Δ_S = shear deflection

where P = internal pressure

V = shear force

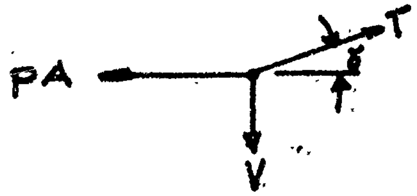
A = cross section area

T = sum of upper + lower skin tensions

L_1 = distance from load to point of reaction

assuming the webs carry no load lengthwise*

Force balance:



$$\tan \gamma = \frac{V}{pA}$$

$$V = pA \tan \gamma$$

for small angles, $\gamma \approx \tan \gamma \approx \sin \gamma$

$$V \approx pA\,\gamma$$

or

$$\gamma = \frac{V}{pA}$$

*a reasonable assumption in this case as the webs normally are not attached to the skin at ends.

Deflection

$\tan \gamma = \frac{\Delta_s}{L_1}$ or $\sin \gamma = \frac{\Delta_s}{L_1}$

$\Delta_s = L_1 \tan \gamma$

$\therefore \Delta_s = L_1 \gamma$ for small angles

$\Delta s = \frac{L_1 V}{pA}$

or deflection per unit length

$\frac{\Delta_s}{L_1} = \frac{V}{pA}$

incidentally $\frac{\Delta_s}{L_1} = \delta$

where δ is the common term for angular shear deflection for small angles

The shear stiffness is $S = \frac{\text{LOAD}}{\text{DEFL.}}$

$S = \frac{V}{\Delta s}$

$= \frac{V}{L_1 V/pA}$

$S = \frac{pA}{L_1}$

again, for a unit length, the stiffness is:

$$S_s = \frac{S}{L_1}$$

$$= \frac{\frac{pA}{L_1}}{L_1}$$

$$\therefore S_s = pA$$

Thus shear stiffness is a direct function of pressure. It is this deflection mode then that result in the beam becoming stiffer with increasing pressure (an intuitive observation which is easily verified experimentally).

As this value may be of frequent use, it may be further developed for a dual-wall cross section. The area for one cell is:

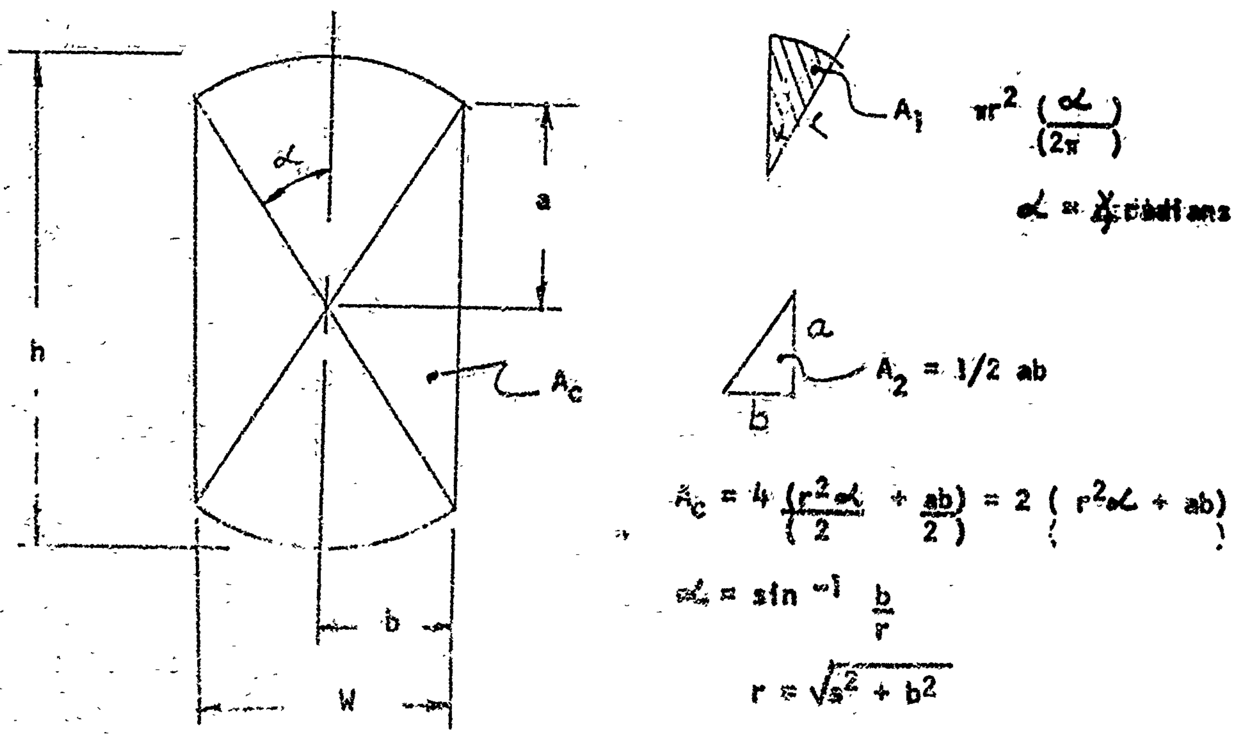


FIG. F3

$a = r \cos \alpha$

$$A_c = 2\left(r^2\alpha + b\,(r \cos\alpha)\right)$$

$$= 2r\,(r\alpha + b \cos\alpha)$$

or

$$A_c = h\left(\frac{h}{2}\alpha + \frac{W}{2}\cos\alpha\right)$$

$$= \frac{h}{2}\,(h\alpha + W \cos\alpha)$$

Substituting in S = PA

For one cell

$$S_c = p\,\frac{h}{2}\,(h\alpha + W \cos\alpha)$$

$$\frac{W}{h} = \frac{b}{r} = \sin\alpha$$

$$S_c = \frac{ph^2}{2}\,(\alpha + \sin\alpha \cos\alpha)$$

where S_c = shear stiffness per unit length per cell

It is significant to note that the contribution to shear stiffness by the web members has been ignored in this analysis and in most reported studies. Tutt and Perkins in Ref. 3 analyze stresses in the web diaphragm, but do not enter the effect into theoretical deflection calculation. The web effect is naturally included when they made experimental measurements of shear resistance. Likewise, Birdair has experimentally observed significant differences in deflection with relatively small changes in web construction. The problem presently is not only to develop a reasonable mathematical model of the detail construction, but also to establish suitable property values (modulus of elasticity, rigidity, etc.) for the non-isotropic fabrics. As a result, in actual practice it is common to take a very pessimistic, conservative approach and use the shear stiffness as a function of pressure (which is only true for the most basic designs) and then experimentally measure true values.

Webb, in Ref. 20, develops an optimum relationship of web/cell geometry for maximum stiffness, for minimum weight, based upon the pressure shear stiffness. Unfortunately, there are several questionable means used (principally in arriving at non-dimensional parameters) in reaching the optimum geometry. Consequently, the web layout, shown in Configuration 10, does not agree with Webb's optimum arrangement, but instead has webs at a considerably closer spacing. This should result in a stiffer beam, but at a possible sacrifice in weight.

It may be apparent that Eirdair is not fully convinced of the practical usefulness of the theoretical derivations. In this regard it may be of interest to look at some comparative results with two experimental beams or panels. A typical beam is shown in Fig. F4. Each beam was 9' x 3' x 6" thick with seven cells. The beams were identical except #1 had a straight single ply flange at the web/skin joint, and #2 had a bias single ply flange at this joint. The results of testing of these panels as simple beam members with various loads at the mid-point are shown in Figures F5 and F6. Assuming the total deflection is that due to bending and shear:

$$\Delta_T = \Delta_B + \Delta_S$$

where Δ_T = total deflection

Δ_B = deflection due to bending

Δ_S = deflection due to shear

F = load

p = pressure

Based upon the previously developed equations:

$$\Delta_B = f\,(F, L^3, E, I)$$

$$\Delta_S = f\,(F, 1/p, L, A)$$

For a given beam, L, E, I, A are constant.

Therefore, at a given F, but varying p:

Δ_B = constant

Δ_S varies as $1/p$

Thus, if we plot deflection as a function of 1/p for various loads, as in Figures F6 and F11, it should be possible to extrapolate the test to obtain a deflection at 1/p = 0. Unfortunately, the experimental points do not lend themselves to a very reliable extrapolation; however, as shown in the upper corner, it is possible to estimate a most probable point where the loads cross the vertical Y axis. Somewhat questionably for both panels, this forces us to ignore the results at 5 psi (as these would indicate an upward deflection). Figures F7 and F12 are detail plots of deflection vs. loads at the various pressure and deflection due to bending, using the stiffness rate derived from the previous figures.

Using these results and using the relationship $\Delta_S = \Delta_T - \Delta_B$ it is possible to arrive at a value for Δ_S at various loads and pressures. This is plotted for 20 lbs. and 40 lbs. in Figures F8 and F13. The value of F/Δ_S for various pressures may then be plotted as in Figures F9 and F14 to give a line representing shear stiffness as a function of pressure. The previously derived bending stiffness is also shown on these figures. The results indicate a stiffness/pressure relationship much higher than the equation $\frac{pA}{L}$. Even more surprising, the bending stiffness of both panels is apparently the same $\left(80 \frac{\text{lb.}}{\text{in.}}\right)$.

The stiffness/pressure ratio is different; at 6 psi panel 1 has a rate of 105 lb./in. while panel 2 has a rate of 135 lb./in. This is quite contradictory to what the simple theory would say. We might then question the correctness of the theoretical pressure or shear stiffness. From the previous equation, $\Delta_S = \frac{LV}{pA}$, it is possible to calculate deflection.

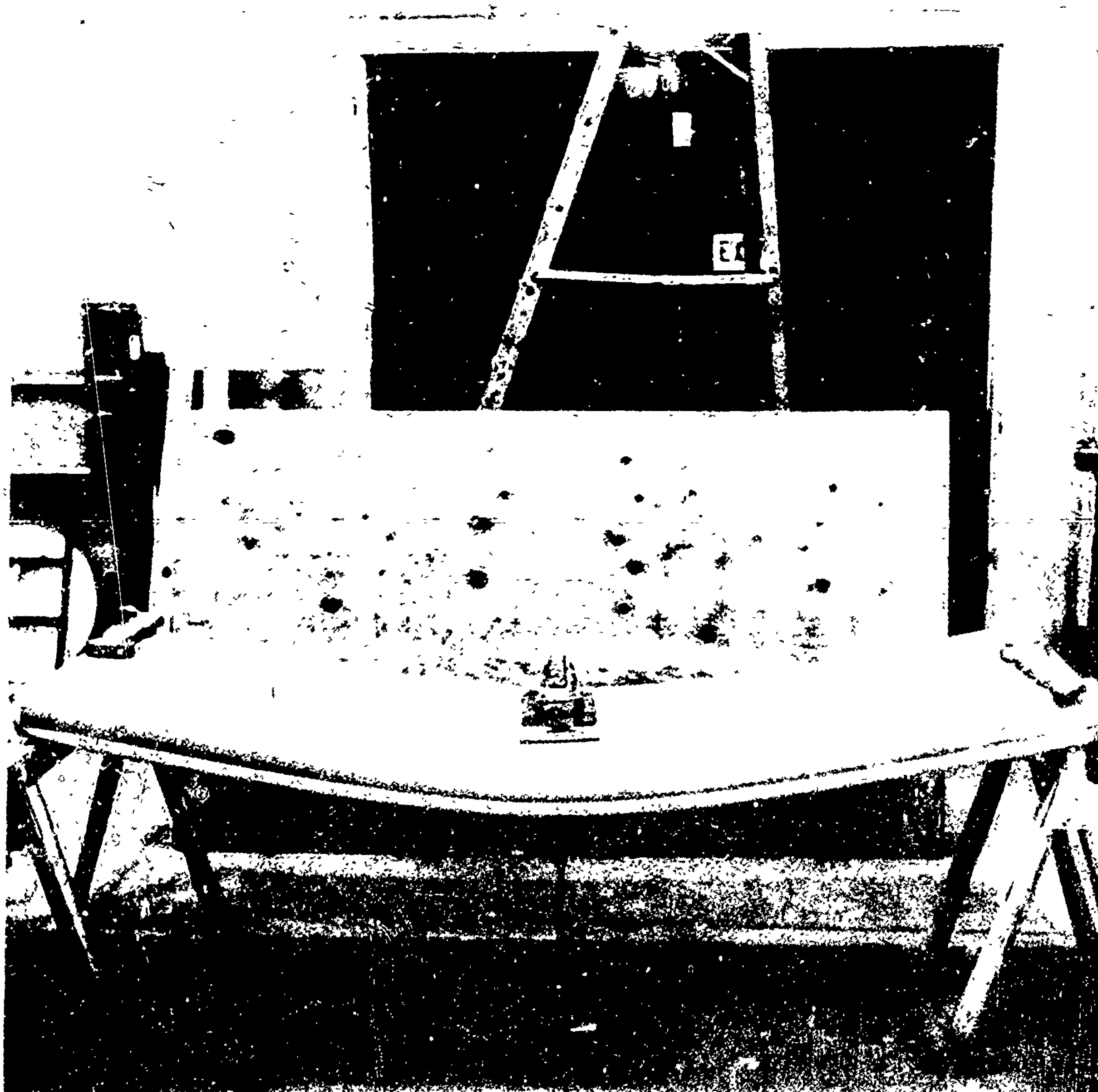
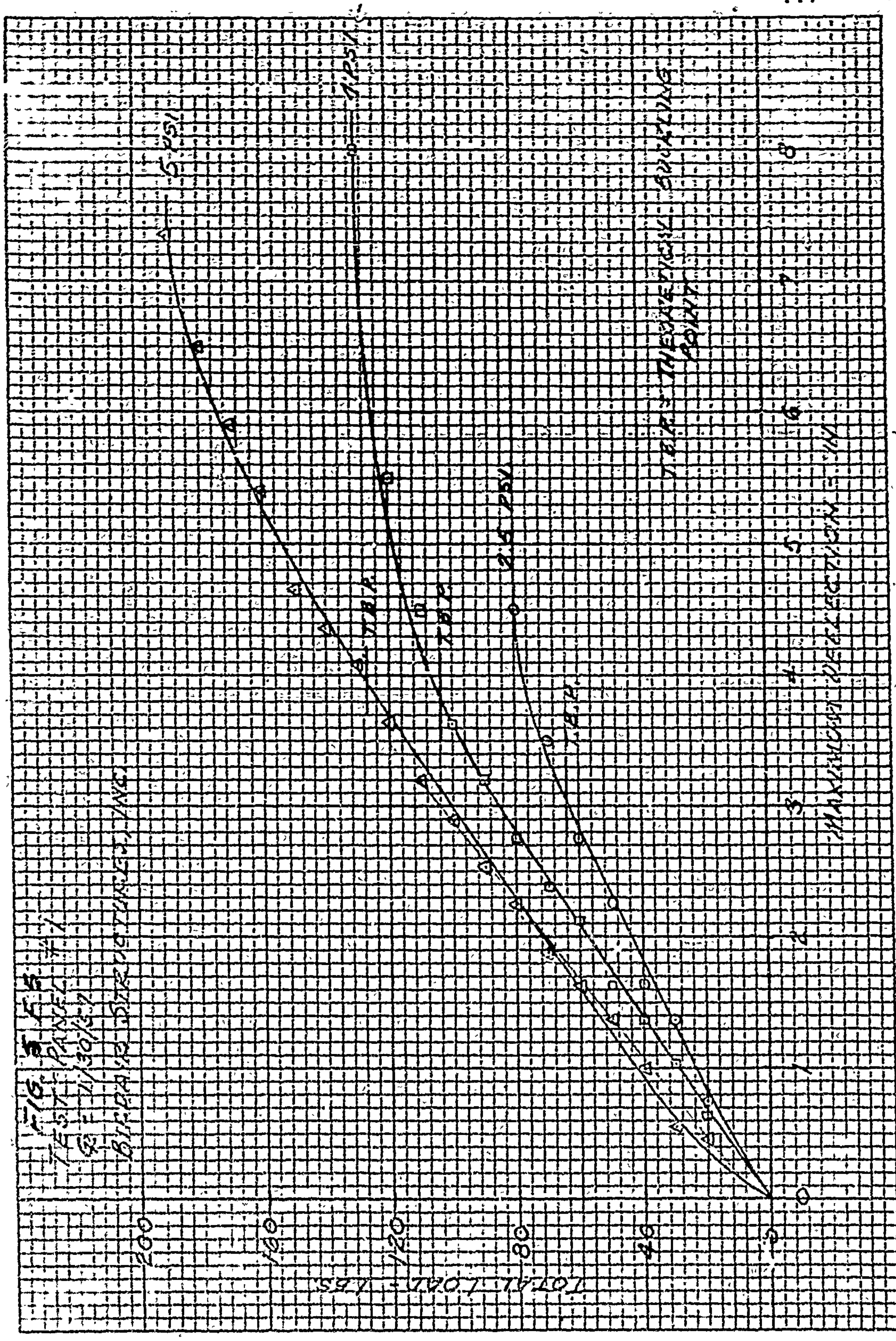


Fig. F

Concentrated load test of straight cellular panel


TEST PANEL #1
BIRDAIR STRUCTURES, INC.
TOTAL LOAD - LBS
MAXIMUM DEFLECTION - IN
5 PSI
1 PSI
2.5 PSI
T.B.P.
T.B.P.
T.B.P.
T.B.P. = THEORETICAL BUCKLING POINT
0
40
80
120
160
200
0
1
2
3
4
5
6
7
8

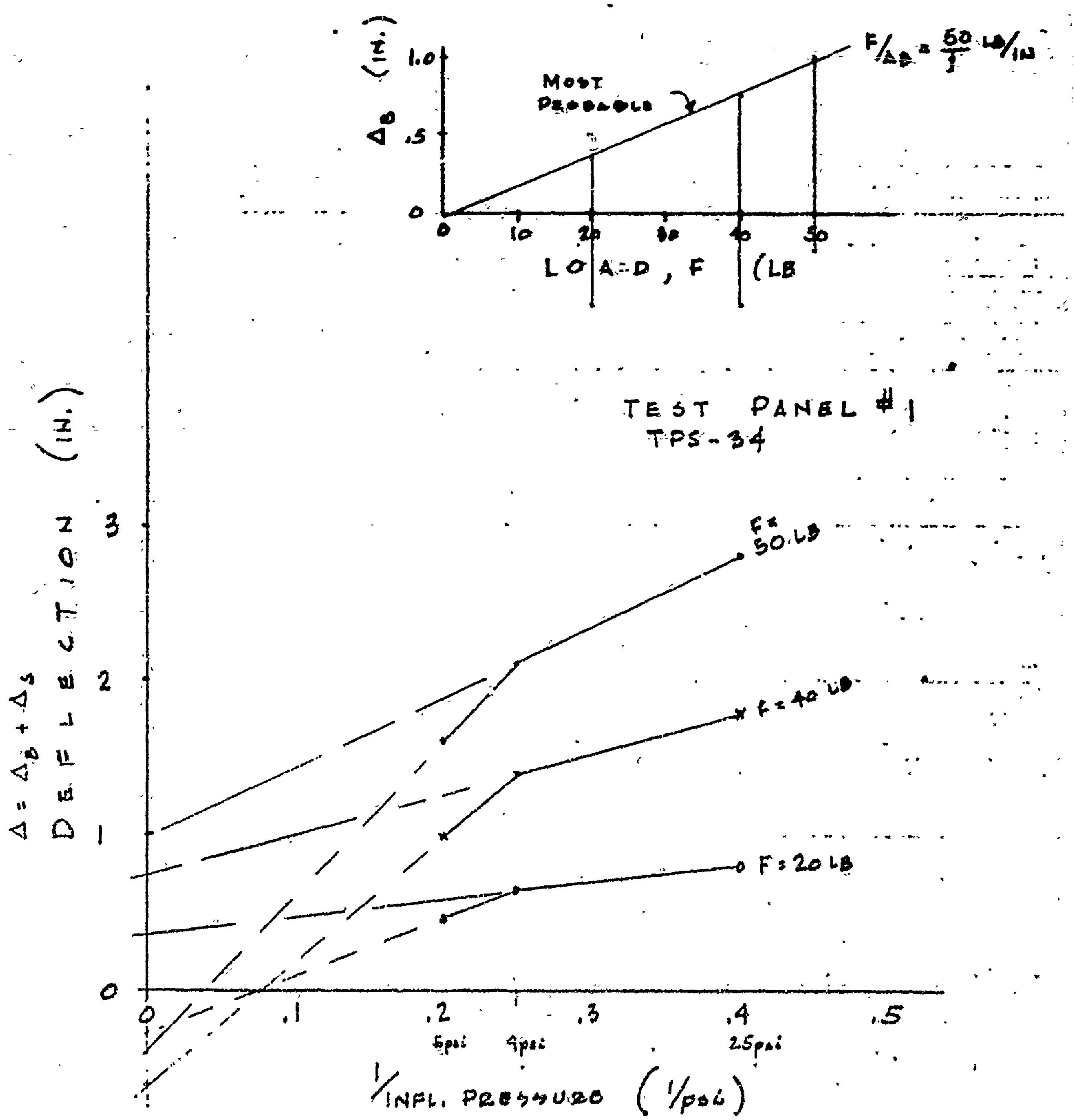


FIG. #F6

3/10/73
(1)

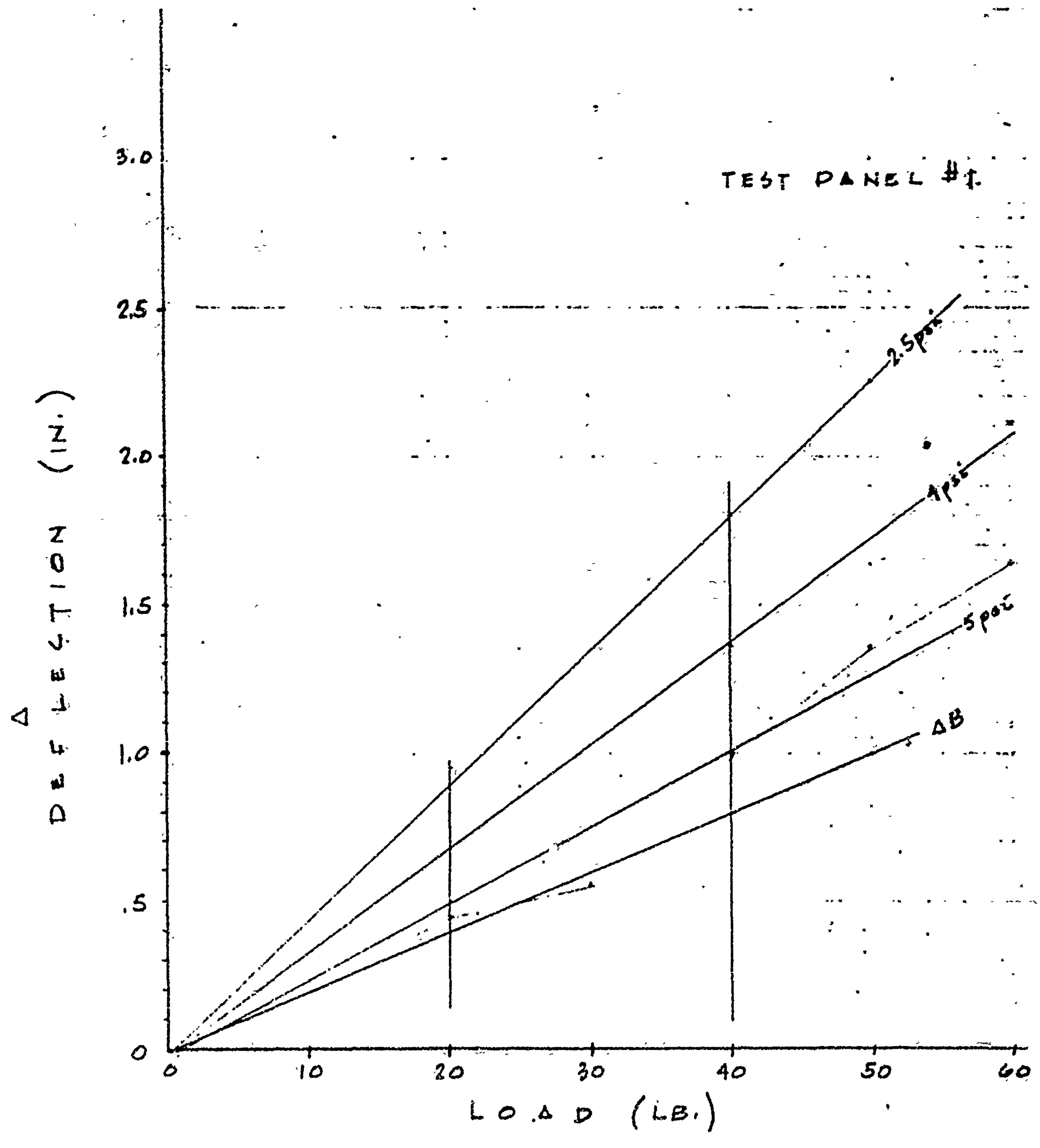
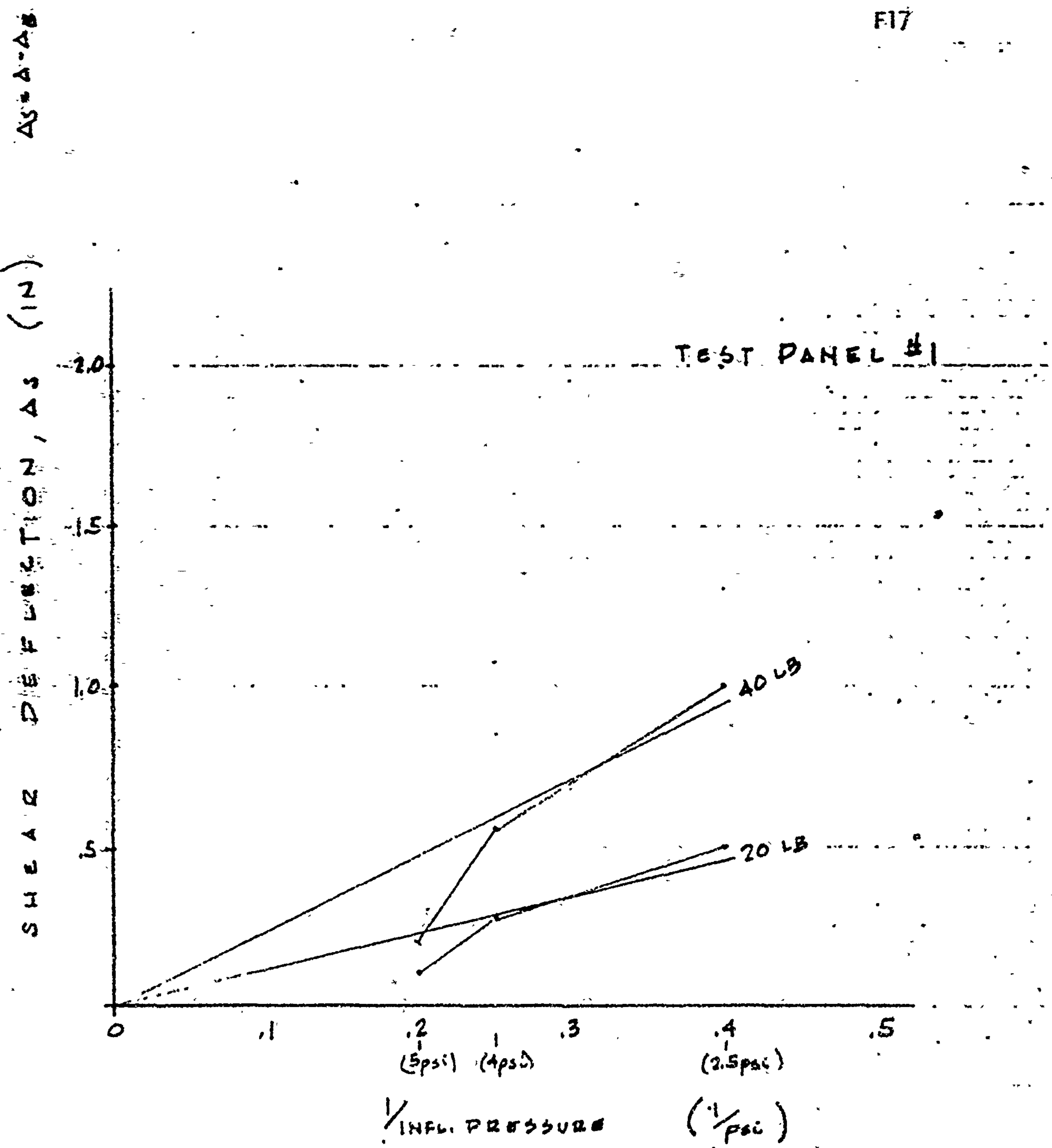


FIG #F7

3/15/73
(2)



P	F	Δ_S	F/Δ_S (LB/IN.)
2.5	20	.5	40
2.5	40	.95	42.1
4.0	20	.28	71.4
4.0	40	.59	67.8

FIG. # F8

3/15/73
(5)

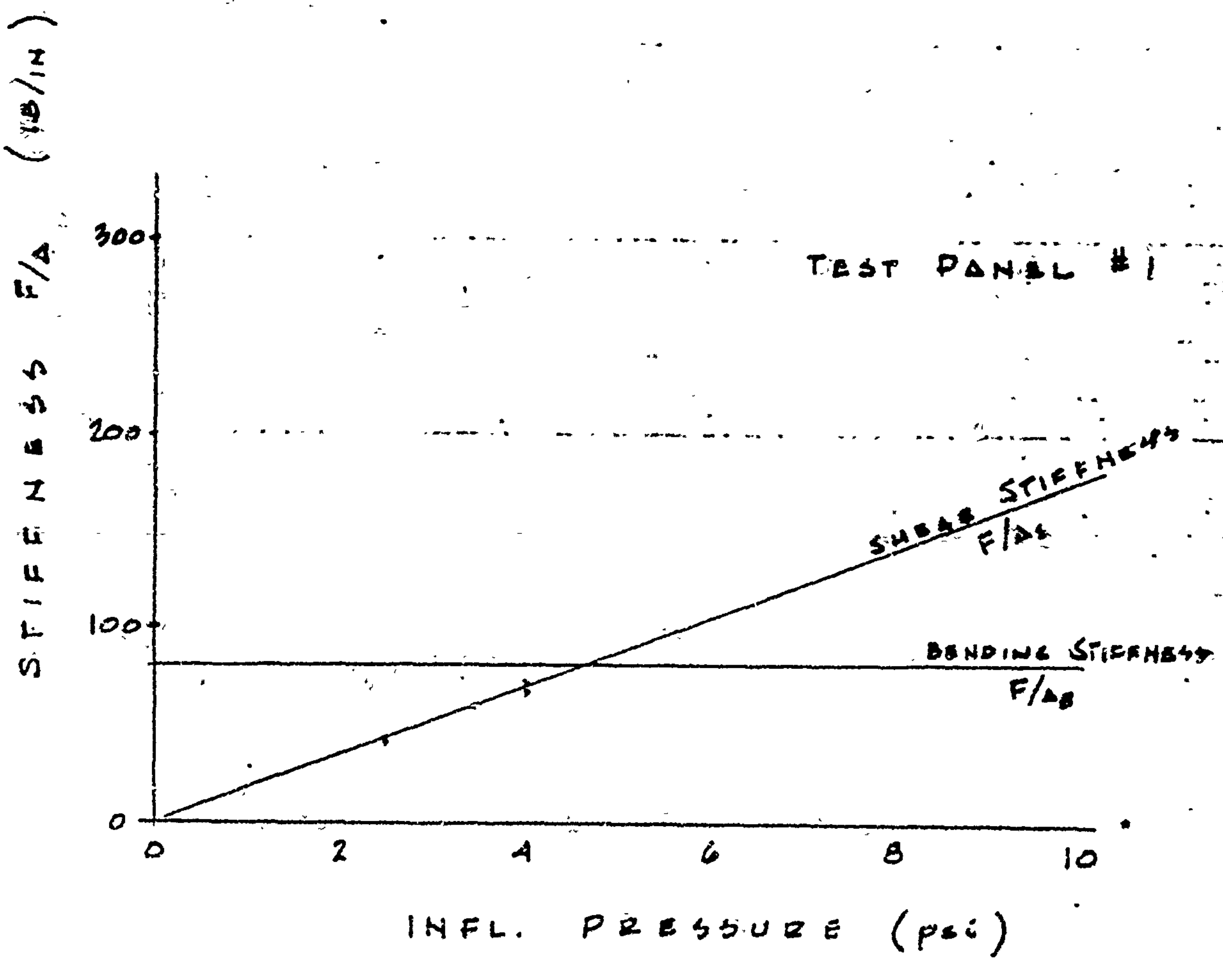
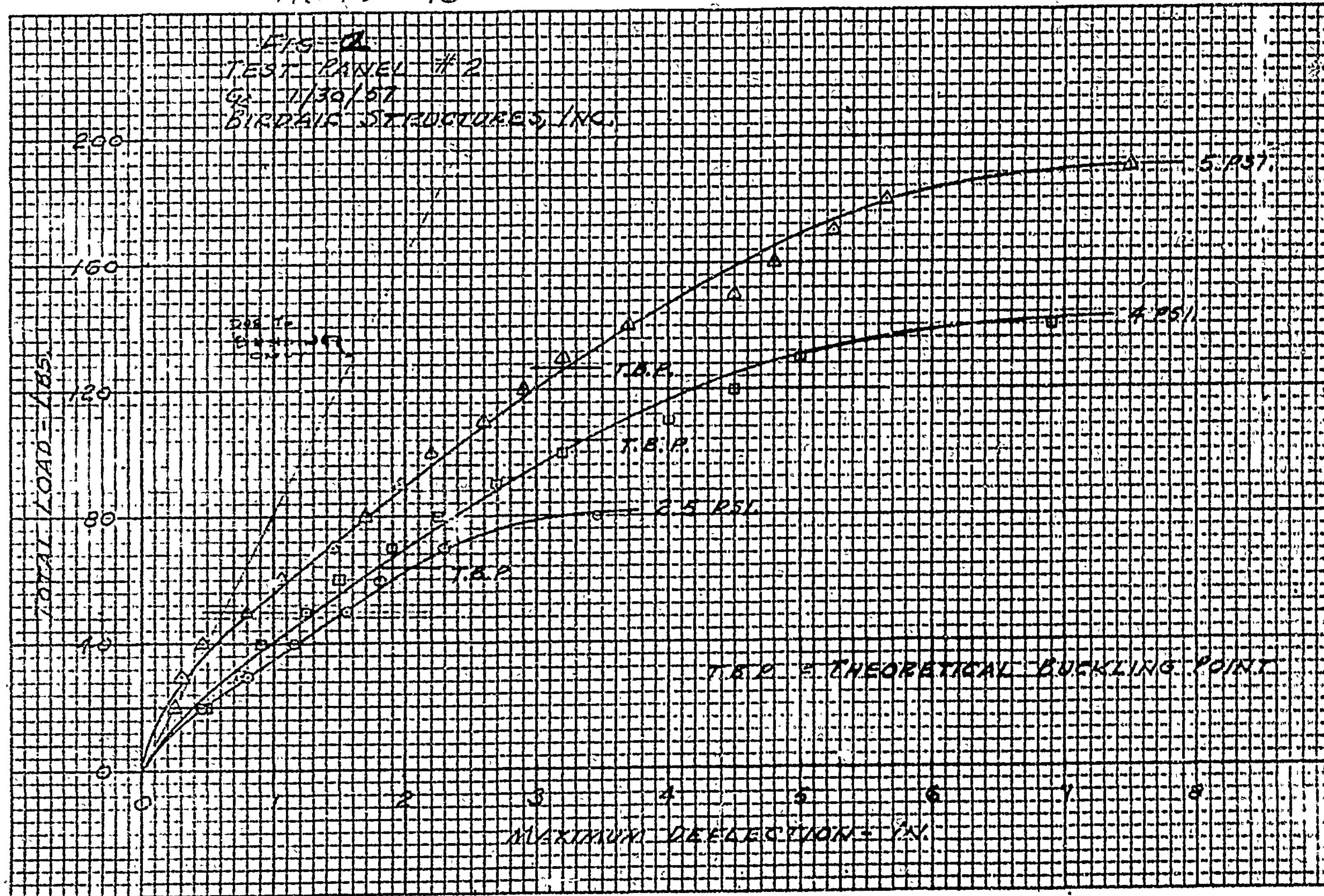


Fig # F9

3/10/73
(4)



TEST PANEL #2
BIRDAIR STRUCTURES, INC.
200
160
120
80
40
0
TOTAL LOAD - LBS.
0
1
2
3
4
5
6
7
8
MAXIMUM DEFLECTION - IN.
5 PSI
4 PSI
2.5 PSI
T.B.P.
T.B.P.
T.B.P.
T.B.P. = THEORETICAL BUCKLING POINT

F19

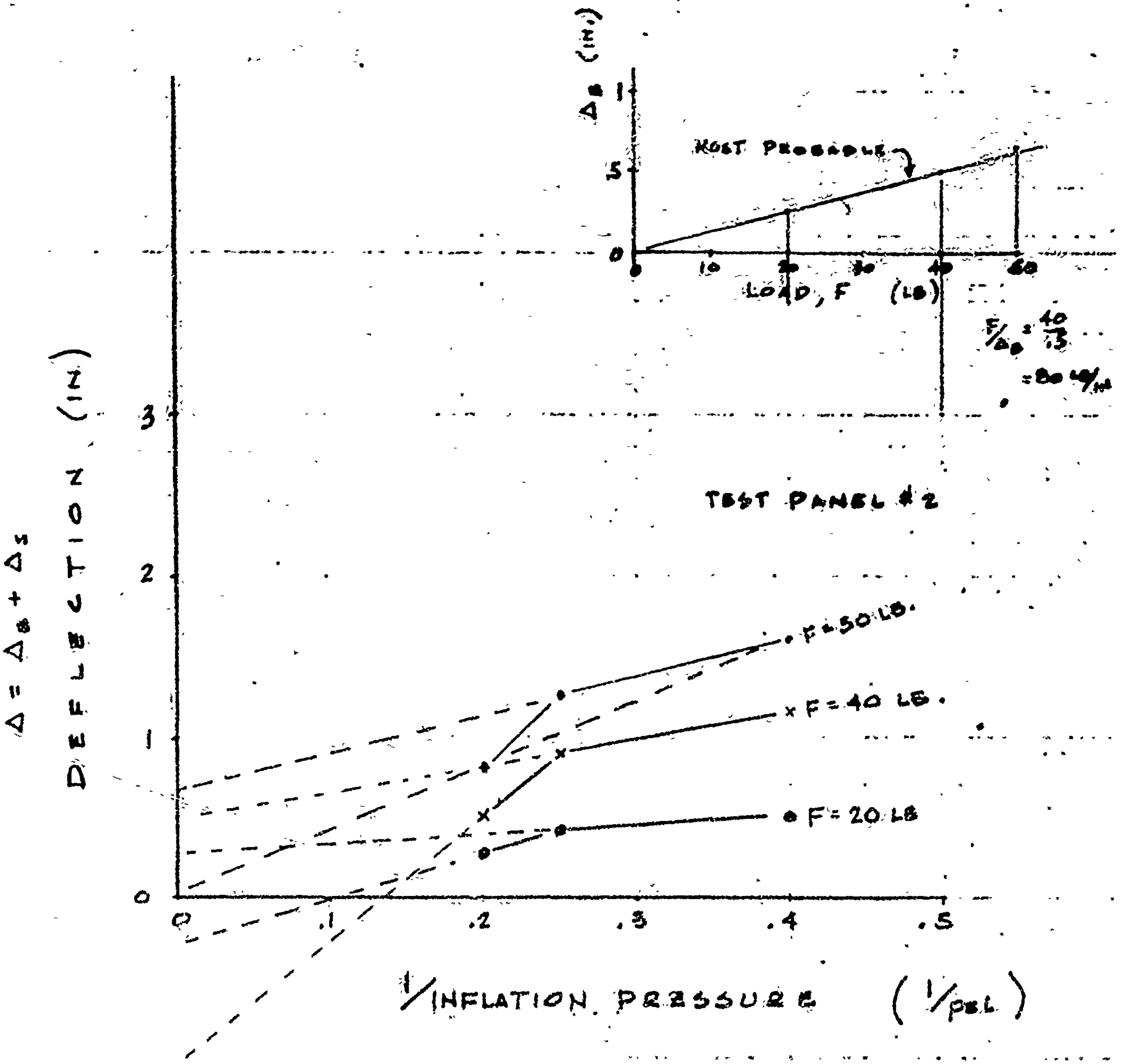


FIG. # F11

3.12.73
(1)

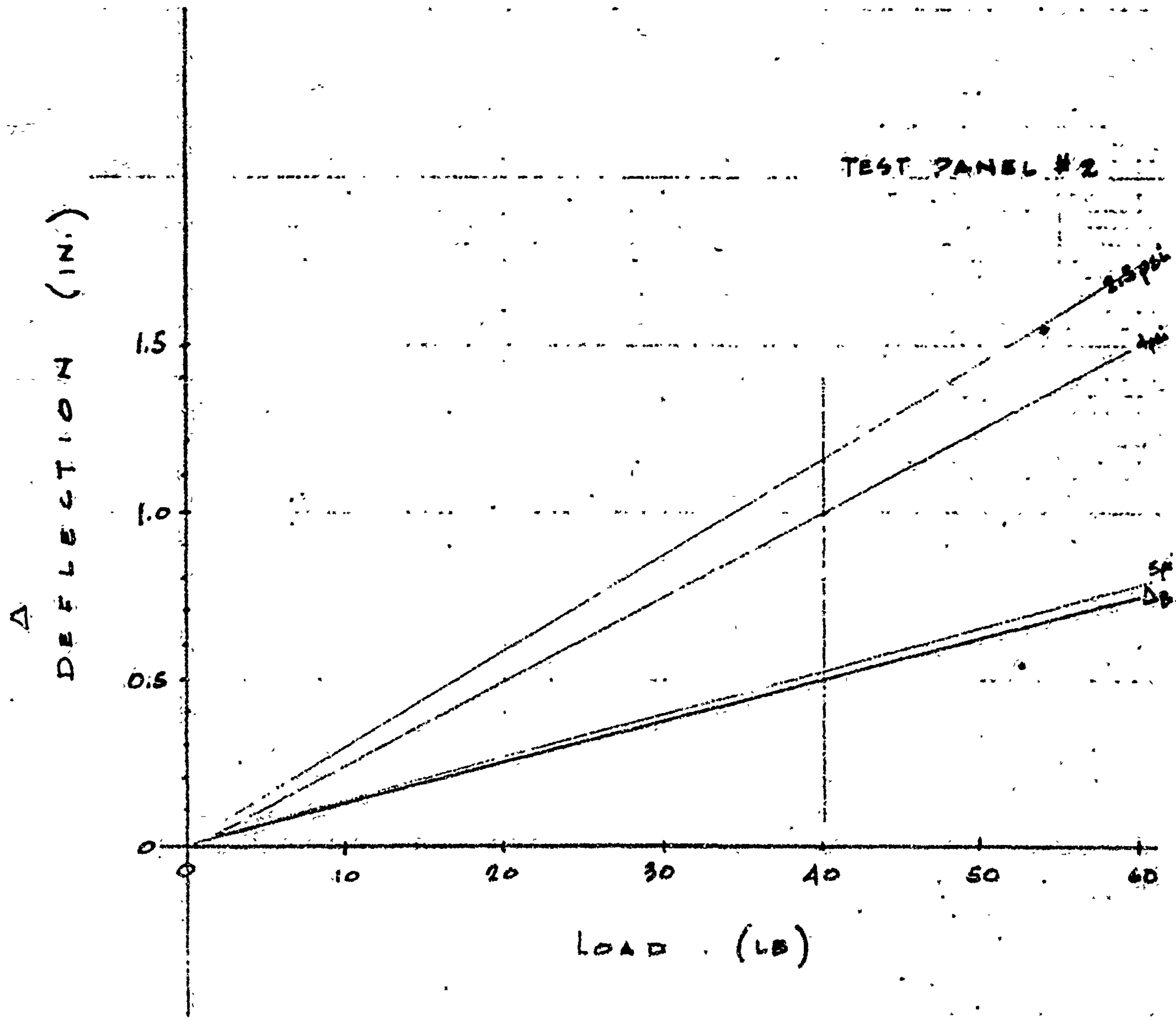
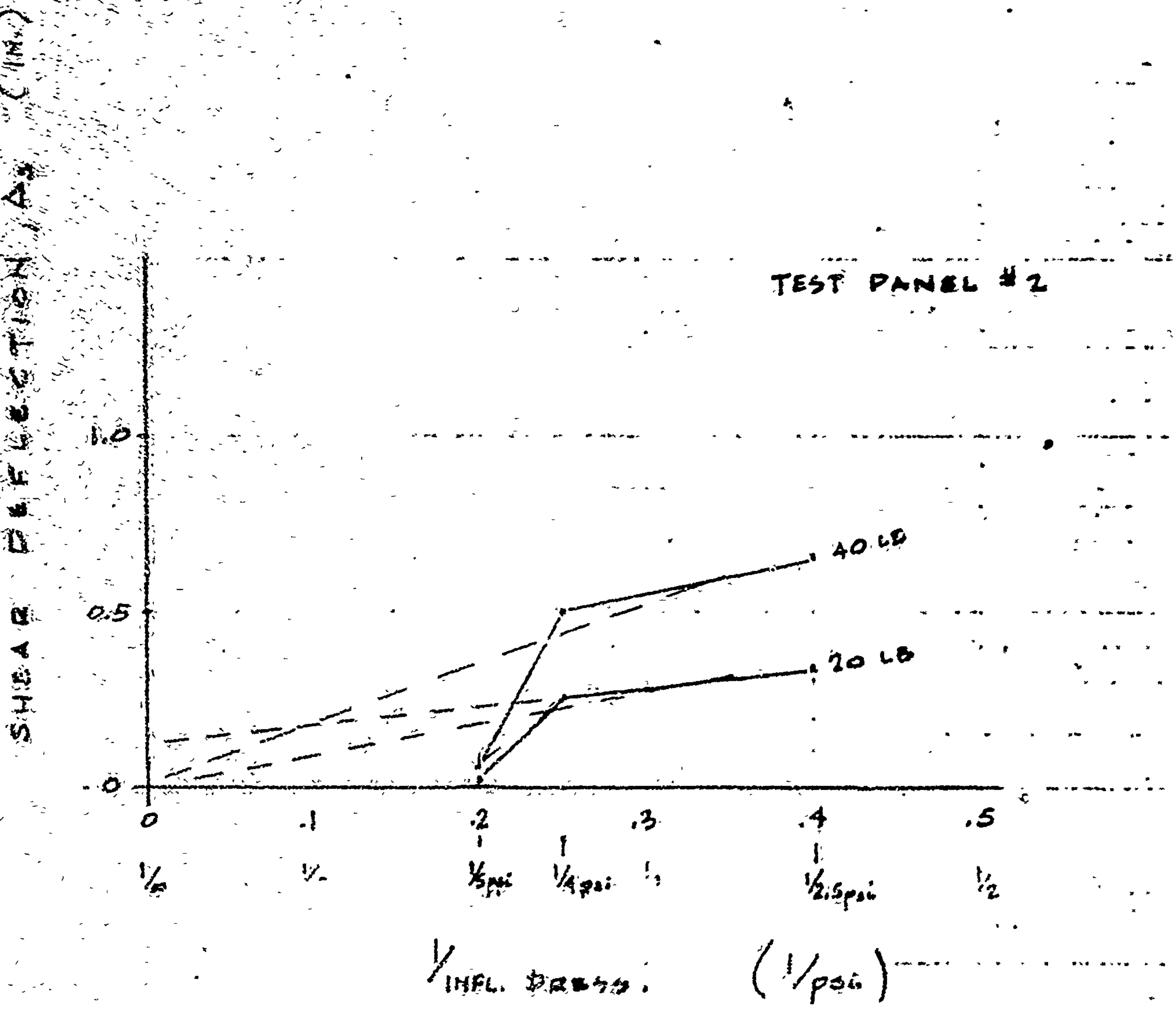


FIG # F12

3/12/73
(2)



p	F (LB)	Δ_s (IN)	F/Δ_s (LB/IN)
2.5	20	.33	61
2.5	40	.65	61.5
4.0	20	.25	80
4.0	40	.50	80
10	20	.09	225
4	20	.22	91

FIG. # FF3

3/12/73
(3)

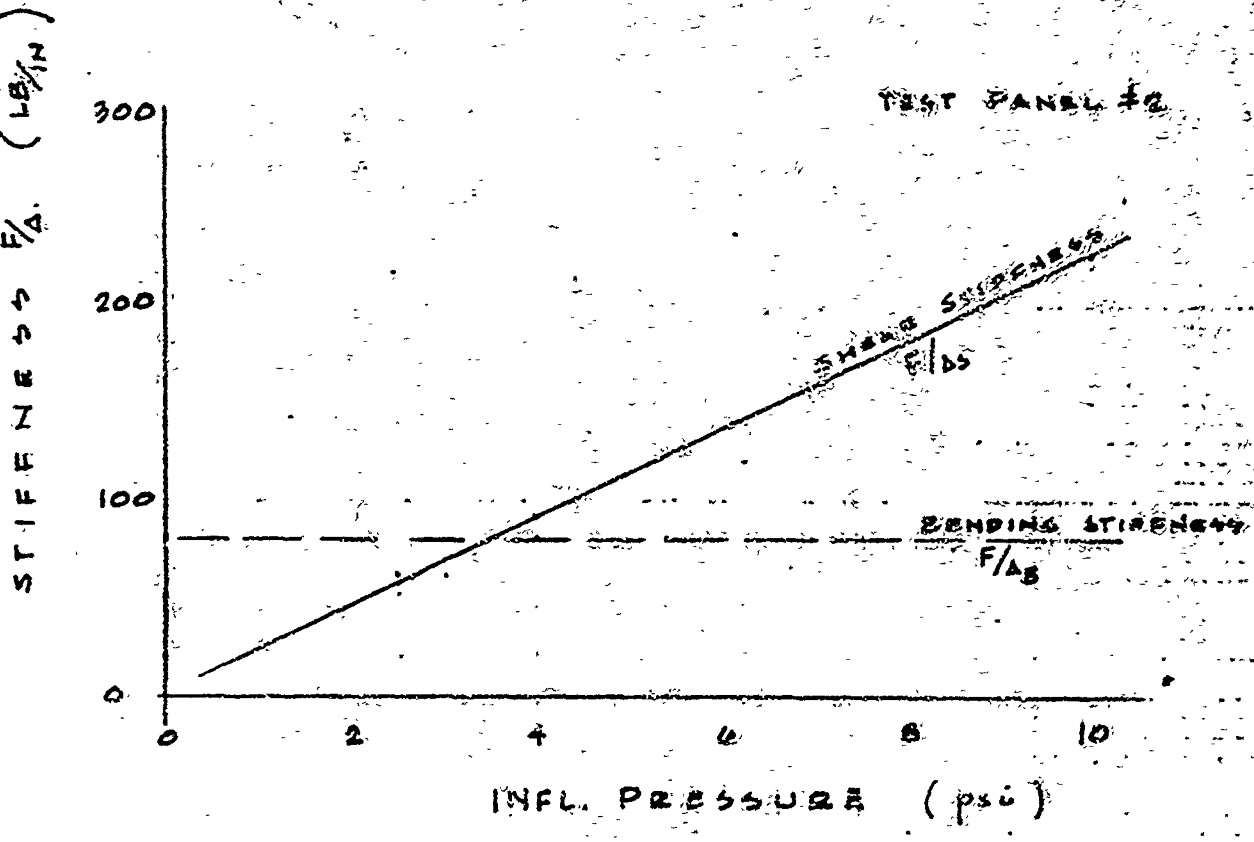


FIG. # F14

5/12/73
(4)

This has been done in the computer run (Fig. F15) and plotted in Figures F16 and F17 over the original measurements. In comparison, the results seem to give only a general indication of trends.

Even without further analysis, it is apparent that the actual details of the dual-wall beam construction can have extremely significant effect. It might be hypothesized that in a small beam the shear effect of the webs is extremely significant; likewise, the use of a bias web construction (or 2 ply biased) may yield unusually high stiffness. At this point it may be of interest to comment on the actual application of these test panels. The construction used in Panel #2 was utilized in the design of the TPS 34 dual-wall radome series, which has seen very satisfactory service in the Marine Corps and RAF since 1958. However, the construction is somewhat expensive, requiring very high quality workmanship; it was subsequently abandoned in favor of a simplier design less subject to errors in workmanship.

Further calculations of deflections are included in the detailed analysis for the specific configurations. Of special note are the calculations for configurations 2 and 10, and the experimental model. Likewise, the Pulson and Tutt reports give actual values for the English bridge experiments.

```
PUTERSEARCH
01/18/  '73 14:34
!LOGIN: 1507BRD,C,
ID= D
!BASIC
>10 FØR P=0 TØ 80 STEP 20
>20 D=((P/2)*54)/(2.5*216)
>30 PRINT P,D
>40 NEXT P
>50 PRINT
>60 FØR P1=0 TØ 140 STEP 20
>70 D1=((P1/2)*54)/(4*216)
>80 PRINT P1,D1
>90 NEXT P1
>100 PRINT
>110 FØR P2=0 TØ 180 STEP 20
>120 D2=((P2/2)*54)/(5*216)
>130 PRINT P2,C2
>140 NEXT P2
>150 END
>RUN
14:37   01/18
```

P	D	
0	0	
20	1	
40	2	φ = 2.5
60	3	
80	4	

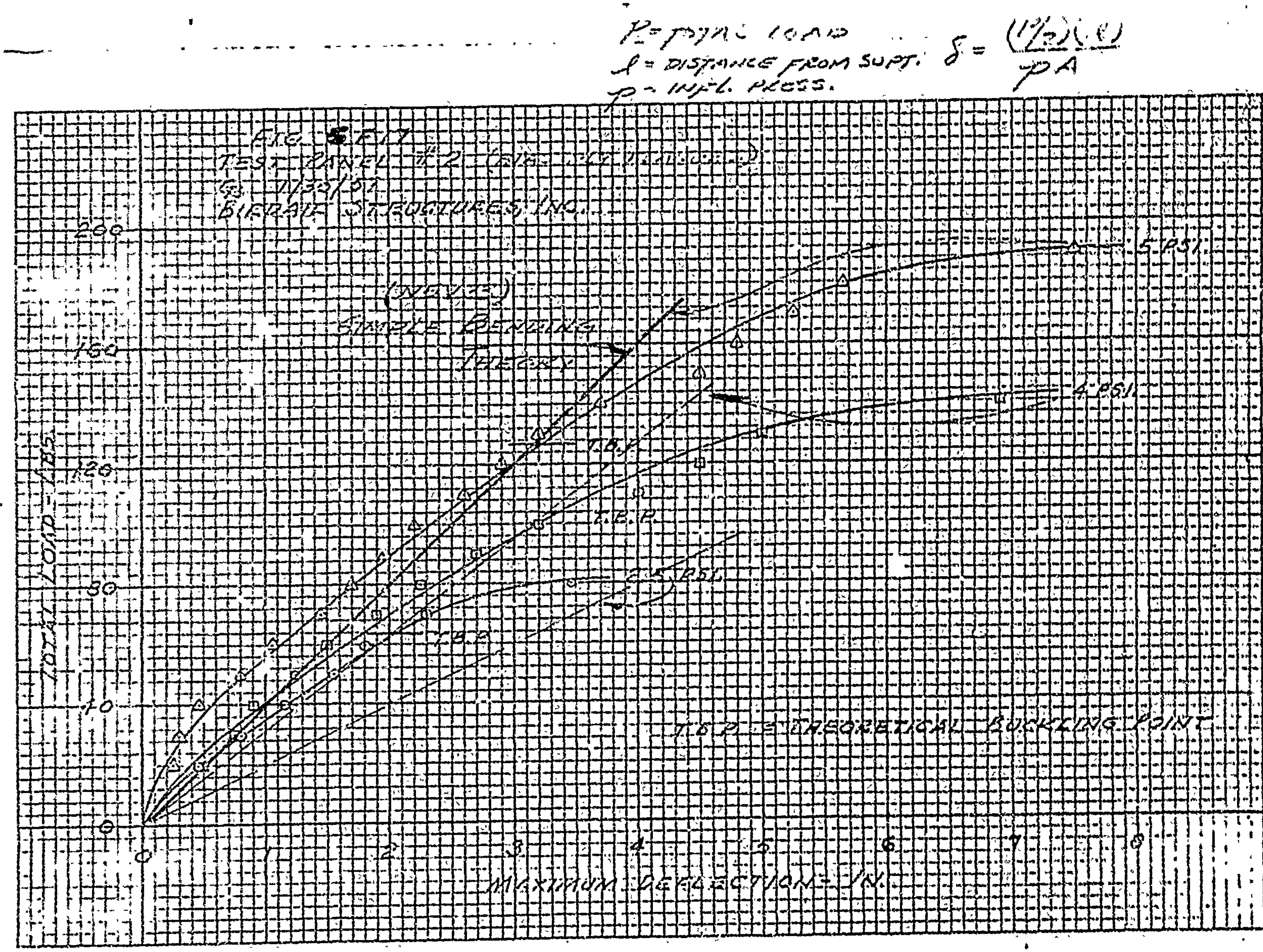
P1	D1	
0	0	
20	.625000	
40	1.25000	
60	1.87500	
80	2.50000	φ = 4.0
100	3.12500	
120	3.75000	
140	4.37500	

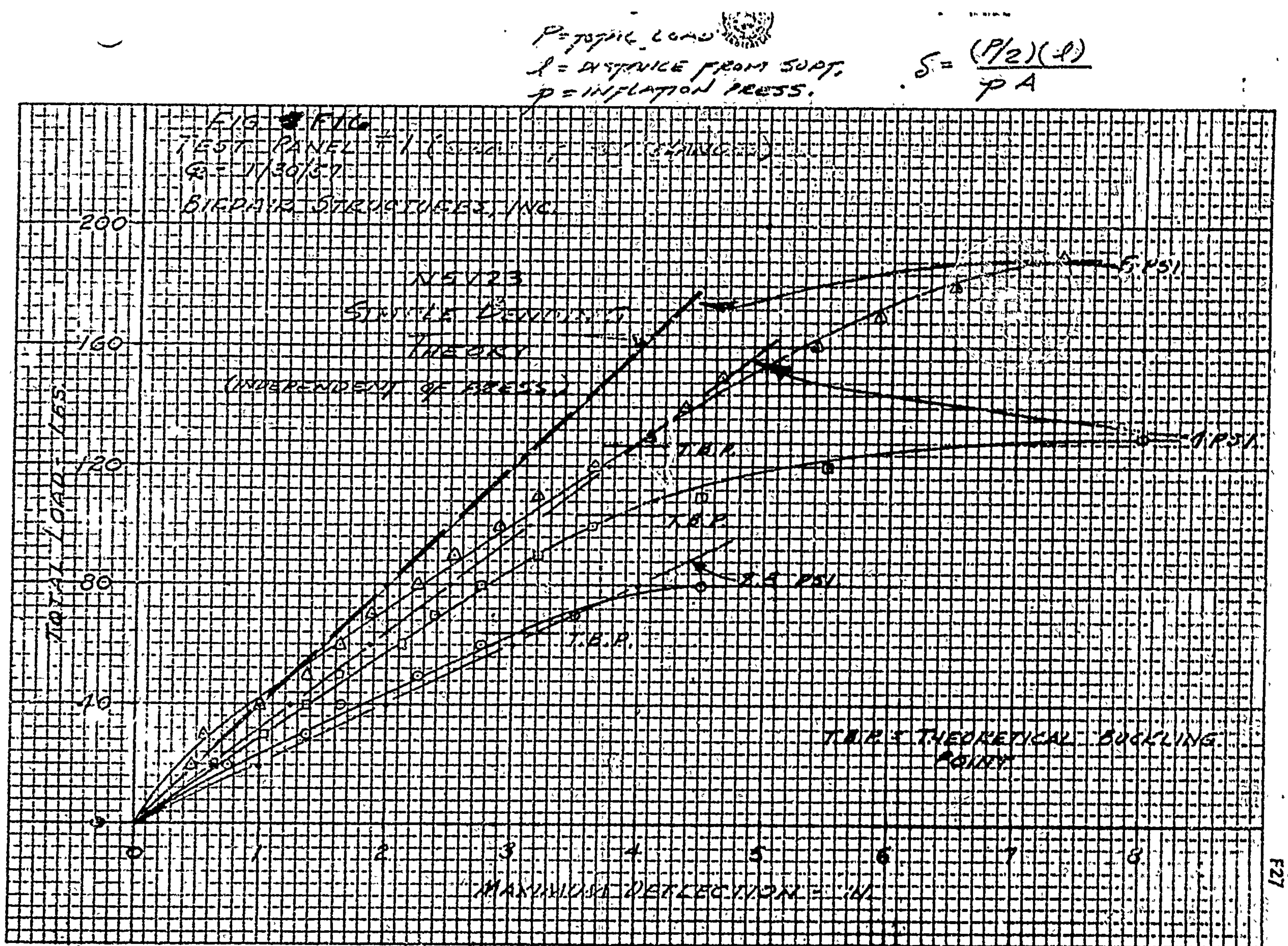
P2	D2	
0	0	
20	.500000	
40	1	
60	1.50000	
80	2	φ = 5.0
100	2.50000	
120	3	
140	3.50000	
160	4	
180	4.50000	

```
150 HALT
>SYS

!BYE
01/18/  '73 14:38
CLT 4
CCU 0.011
```

FIG. Nº F15


P = PUNC LOAD
l = DISTANCE FROM SUPT.
p = INFL. PRESS.
FIG. 5 F17
TEST PANEL #2
BIRDAIR STRUCTURES INC.
200
160
120
80
40
0
(WAVES)
SIMPLE BENDING
THEORY
5 PSI
4 PSI
T.B.P.
2.5 PSI
T.B.P. = THEORETICAL BUCKLING POINT
TOTAL LOAD - LBS.
0
1
2
3
4
5
6
7
8
MAXIMUM DEFLECTION - IN.


P = TOTAL LOAD
l = DISTANCE FROM SUPT.
p = INFLATION PRESS.
δ = (P/2)(l) / pA
TEST PANEL #1
BIRDAIR STRUCTURES, INC.
SIMPLE BENDING THEORY
(INDEPENDENT OF PRESS.)
5 PSI
T.B.P.
3.5 PSI
T.B.P. = THEORETICAL BUCKLING POINT
TOTAL LOAD - LBS
MAXIMUM DEFLECTION - IN.
0
40
80
120
160
200
1
2
3
4
5
6
7
8

APPENDIX-G

PRESSURIZATION

CALCULATIONS

Time required for inflation.

V of cell 17,954 $'^3$

Pressure required 3.6 psig.

In increments of 10% of the inflation pressure

$P_c = (3.6)(.1)$

$= .36$ psig ←

$\left[P_g = P - P_c \right]$

$= 3.6 - .36$

$= 3.24$ psig ←

$\left[P_a = \text{Press. Atmosp.} + P_g \right]$

$= 14.7 + 3.24$

$= 17.94$ psi ←

$$\left[\rho = 1.325 \frac{P_a}{T} \right]$$

$$= \frac{(1.325)(17.94)(2.036)}{(460 + 68)}$$

$= 0.0769$ #/'^{3} ←

NOTE: NOMENCLATURES ON G-5

$$\left[Q = 5.976\ K\ D_o^2 \sqrt{\frac{h}{\rho}}\right]$$

$$= (5.976)(.6)(4.625)^2 \sqrt{\frac{(3.60-.36)}{(.0769)(.03613)}}$$

$$= 2619 \text{ cfm}$$ ←

$$\left[W = \frac{Pa\ V}{R\ T}\right]$$

$$W = \frac{(17.94)(144)(17954)}{(53.3)(460+68)}$$

$$= 1648 \text{ lbs.}$$ ←

$$\left[W_d = W_2 - W_1\right]$$

$$W_d = 1681 - 1648$$

$$= 33 \text{ lbs.}$$ ←

$$\left[V = \frac{W_d}{\rho}\right]$$

$$= 33/.0769$$

$$= 429 \text{ cf}$$

$$\left[Q_a = \frac{Q_1 + Q_2}{2} \right]$$

$$= \frac{2793 + 2619}{2}$$

$$= 2706 \text{ CFM.} \longleftarrow$$

$$\left[T = \frac{V}{Q_a} \right]$$

$$= \frac{429}{2706}$$

$$= .158, \; .2 \text{ min.} \longleftarrow$$

The total time of inflation is the sum of T = <u>9.20 minutes</u>

TABLE I

P_c #/in²	P_g #/in²	P_a #/in²	ρ #/ft³	Q ft³/m	W	W_d	V	Q_e	T
0	3.6	13.3	.0751	2793	1681	-	17954	2793	6.4
.36	3.24	17.94	.0769	2619	1648	33	429	2206	.2
.72	2.88	17.58	.0789	2439	1615	33	419	2529	.2
1.08	2.52	17.22	.0800	2256	1581	34	422	2348	.2
1.44	2.16	16.88	.0825	2064	1530	31	376	2169	.2
1.80	1.80	16.50	.0843	1864	1575	35	415	1964	.12
2.16	1.44	16.14	.0862	1649	1482	33	383	1756	.12
2.52	1.08	15.78	.0880	1413	1450	32	364	1531	.12
2.88	.72	15.42	.0898	1142	1415	35	390	277	.3
2.94	.36	15.06	.0917	799	1383	32	349	970	.4
3.6	0	14.7	.0935	250	1350	33	353	524	.7
									9.20

Pc = Inflation pressure of the cell psig

Pg = Pressure differential across the orifice psig

Pa = Pressure in the cell--absolute psi

ρ = Density of air at the cell pressure lbs./cu. ft.

Q = Flow rate of inflation air into the cell cfm

ρ = as above

Wd = Incremental increase in weight in lbs.

V = Volume of the air weighing Wd. pounds

Qa = Average flow rate over the pressure increment cfm

T = Time required to complete the pressure increment in minutes