DOE/NOAA/OTEC-32 (Vol. 3)(App)

Science Applications, Inc.
One Continental Plaza, Suite 310
101 Continental Boulevard
El Segundo, California 90245

OTEC MODULAR EXPERIMENT

COLD WATER PIPE

CONCEPT EVALUATION

VOLUME III APPENDICES

APRIL 1979

SAI-063-80R-008-LA

PREPARED FOR:

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

UNDER CONTRACT:

MO-A01-78-00-4142

ALBUQUERQUE • ANN ARBOR • ARLINGTON • BOSTON • CHICAGO • DENVER
HUNTSVILLE • LA JOLLA • LOS ANGELES • McLEAN • PALO ALTO • SANTA ANA

DISCLAIMER

DO NOT MICROFILM
COVER

MASTER

SCIENCE APPLICATIONS, INC.

LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest possible dissemination of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state, and local governments. Non-DOE originated information is also disseminated by the Technical Information Center to support ongoing DOE programs.

Although large portions of this report are not reproducible, it is being made available only in paper copy form to facilitate the availability of those parts of the document which are legible. Copies may be obtained from the National Technical Information Service. Authorized recipients may obtain a copy directly from the Department of Energy's Technical Information Center.

3

TABLE OF CONTENTS

APPENDIX A - MATERIALS AND ASSOCIATED DESIGN CRITERIA

APPENDIX A

MATERIALS AND ASSOCIATED DESIGN CRITERIA

Various materials have been proposed for the OTEC CWP structures. Among these are steel, concrete, fiberglass (FRP), rubber composites and plastics such as polyethelene. Although aluminum has been suggested, it was eliminated from consideration due to its extreme susceptability to corrosion in a marine environment. Each material appears to have properties beneficial to CWP cónstruction; however, no one material offers a panacea to offshore requirements.

Of greatest concern is the long term performance under cyclical loading in a saltwater environment. Definitive test data are lacking for all materials except possibly steel. Steel performance is known to be significantly degraded so corrosion protection schemes have been devised. The majority of the offshore oil industry experience with large structures involves steel; only recently have large concrete storage vessels been built for North Sea applications.

It would be unwise to dismiss a potentially attractive material from consideration merely because it had not been used previously, and we have no intention of doing so. Where definitive data and experience are lacking, confidence is lowered. For those materials/concepts in which cost and performance merits are attractive, test programs should be established immediately. In the following sections, material-related design criteria are described; nominal properties are summarized in Table A.1. It should be noted that for most materials, there is a significant difference between the static and dynamic (Young's) modulus of elasticity. This is especially important since the value which is most easily found is the former one, and the value which controls the dynamic response is the latter.

TABLE A.1 NOMINAL MATERIAL PROPERTIES

Material	Specific Gravity	Poisson's Ratio	Elastic Modulus (10^6 psi)	Yield (ksi)	Ultimate (ksi)
Steel					
A537	7.8	0.3	29	50	80
A36	7.8	0.3	29	36	65
A242	7.8	0.3	29	60	75
Concrete					
Light (APL)	1.2	-	1.2	-	4-5
Common	2.3	0.2	4.5	-	6
FRP (isotropic)	1.8	0.2	3.0	-	10
Nylon/Rubber	1.25	0.45	0.1/0.05	-	37.5
Polyethelene	0.96	-	0.1 short-term 0.04 long-term	-	(3% strain)

A.1 Steel

Steel is a material with a long history of development of predictible material properties. Before fabrication, the properties of the base metal can be determined and rejectible material (due to poor properties) need never become part of a finished structure. A properly designed steel structure accounts for the need for inspection of welds. The required electrodes for welding various steels can be determined from a wealth of experience. Post-welding treatment and inspection can be established during the design process. For steel, the static and dynamic values of the modulus of elasticity have a negligible difference. The value determined in 'static' tests is most adequate for determining the natural frequencies of the modes of dynamic response.

The steels considered are the typical ones used for structural and pipeline applications in the offshore industry. Thus, standard industry practices can be used for welding and inspection. A36 steel is commonly used in offshore structures from Alaska or the North Sea to the Gulf of Mexico. It is a ductile steel, but if there is a concern about its Charpy impact strength at low temperatures, A36 steel can be normalized.

Steels in the ocean are usually protected against corrosion by using consumable anodes (i.e., cathodic protection). In the splash zone where corrosion is a great problem (there is no splash zone on the CWP), steel structures are painted with a zinc-rich paint. Plastic and rubber coatings are used for some applications. Cathodic protection, perhaps in conjunction with some coating, can protect a steel CWP against unacceptable corrosion for the required design life.

Steel is available with adequate lead time for a mill order. Its availability and cost should not be unduely impacted in the event of a shortage of petroleum.

For steel, there exists standard offshore structural design practices which are codified in API RP 2A in the 'API Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms'and in the'AISC'Specification for the Design, Fabrication and Erection of Structural Steel for Buildings. The AWS S-N curves for steel are used in offshore steel design. For high cycle fatigue, the industry practice for cathodicly-protected steel is to extrapolate the straight line (on the log-log plot) out to 2×10^8 cycles, at which point the allowable stress no longer decreases with increasing cycles (i.e., the design line becomes flat).

A.2 Concrete

There is considerable offshore experience with common concrete. Questions about corrosion of the reinforcing or post-tensioning steel are perhaps extendable from common concrete to the APL lightweight concrete ($\sim$76 pounds per cubic foot). If this is the case, corrosion of the imbeded steel is not a problem.

Common concrete construction techniques may well not be applicable to the lightweight modified concrete. A problem of obtaining a nonuniform distribution of the lightweight aggregates exists in the industry's light concrete ($\sim$120 lb/ft^3). This results in varying material properties. The problem could be worse and more serious for lightweight modified concrete. Since this is still only a laboratory material, creep, relaxation, cure time and fatigue are not adequately characterized yet. Industry standards do not exist for designing with a laboratory material.

The remaining discussion summarizes the efforts by APL to develop a super lightweight concrete.

A.2.1 Presentation by Al Litvin of Portland Cement Association

1. The goal of the study was to develop a concrete with a weight of 65-70 pounds per cubic foot (PCF), a compressive strength (after 7 days) of at least 3000 PSI and a modulus of elasticity of 0.5 to 1.0 x 10^6 PSI.

2. The initial phase of this study was divided into three tasks:
   * Assess current practice
   * Determine available, suitable aggregates
   * Develop mix designs

3. For all tests of different mix designs, the following were considered:
   * Fresh concrete - Slump, air content, unit weight, yield, workability
   * Hardened concrete - Weight, strength, modulus, creep, shrinkage, absorption (to 3000 foot depth)

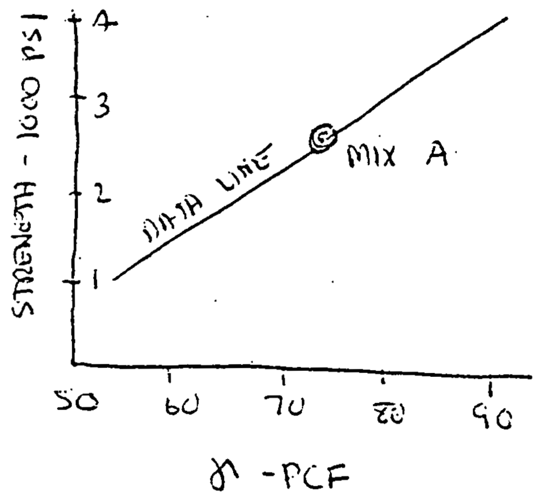
4. A cement based on ASTM C150, Type 1, was used. This cement has a nominal C_3A content of 7% and a maximum C_3A of 8% and is suitable for seawater uses.

5. With current practice, concretes with 15-120 PCF are feasible. 15-50 PCF are used for insulation, 100-120 PCF are used for structures with 2500 PSI or greater compressive strength. 50-100 PCF have generally not been used to date.

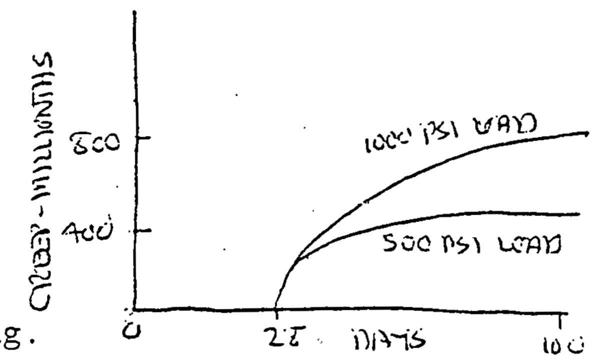
6. Considered various aggregates including:
   * Expanded shale
   * A P Green
   * Cenispheres
   * Styrospheres

Based on extensive preliminary studies it was decided to use livlite fines primarily. An original series of 40 mixes were tested for workability, placability under vibration, strength. Mixtures with resin (WRDA) and latex were generally not good.

7. Compressive tests yielded the general results shown in the figure. Tensile tests were also carried out. Based on these tests Mix A was selected for further testing. Variations on Mix A were then tested. Mix A is 68 PCF, 2860 PSI strength. Density is 92 PCF at 3000 foot depth (1400 PSI).



8. Mix A contains livlite, A P Green, cenispheres. It had the creep properties in the figure - for 7 days wet hardening, plus dry hardening.



9. Various other combinations of aggregate and additive were considered; these generally showed that compressive strength increased from about 3000 PSI at 75 PCF to 4000 PSI at 80 PCF.

10. A best mix was selected. This mix had the following properties:

* Density - 76 PCF-dry, 91 PCF-wet
* Strength - 4240 PSI
* Modulus of elasticity - 2 x 10^6 PSI

This mix, denoted Mix B, was not tested as a fully hardened material (28 days) due to lack of time.

11. Typical costs for concretes at the plant are:

* Normal concrete - $20/yard^3
* Lightweight - $30/yard^3
* Lightweight with latex- $105/yard^3

12. It is thus concluded that a satisfactory material is available and that water absorption stabilized at an acceptable level for this light weight material.

A.2.2 Presentation by Don Magura of ABAM and Dennis MErwood of Concrete Technology Corporation (CTC)

1. The primary task of ABAM was a loads analysis of CWP, as described on November 20. Considerable effort went into design of pad areas; this led to selection of 30 degree pad angle. Axial load reversals, with subsequent lift-off from pads, cannot be tolerated. The minimum CWP material density will be determined by CWP heave dynamics. From the analysis of November 20, the minimum saturated weight was determined to be 80-82 PCF. With 2-3 PCF for steel, the total density is 84 PCF.

2. The primary task of CTC was to develop a suitable mix design which could be used to manufacture the CWP and which used normal practices. The goals in the concrete were:
    * 5000 PSI compressive strength
    * 85 ± 2 PCF weight
    * Modulus of elasticity of 1×10^6 PSI or greater

3. The choice of mix designs was narrowed to three concepts:
    * Cadcrete - using cenospheres
    * Latex modified cenospheres concrete
    * Expanded shale aggregate with no fines, cenospheres, with/without latex

4. After extensive studies a mix design was selected. The weight and cost per cubic yard are:

Type III Concrete	1010 lb	\$35
Cenospheres	520 lb	\$130
Latex, antifoam	31.5 gallons	\$100
Water	25.25 gallons	-
	2033 lb	\$265

The net weight is 75.3 PCF dry with no steel.

5. Construction of CWP sections is compariable to the 18 foot diameter postensioning pipe sections built by Ameron for neuclear power plants.

6. The precasting process was considered as good quality control is needed for high strength and mixing procedure is very important. A special mixing procedure was developed. Water/cement ratio is also very important, as it effects both strength and density. Rate of set is also important; early set-up is not acceptable.

7. The initial set-up was determined by measuring the time to reach 500 PSI compressive strength, the limit of workability. At 100° F - 2.5 hours, at 50° F - 4 hours were required to reach this limit. Low density concretes need high amplitude vibrations; this is different than normal concretes which uses low amplitudes.

8. Accelerated curing is needed for light weight concrete. Steam curing could be used - a'la Ameron. The use of heat wires in the form appears more effective as it blocks moisture loss. With such curing an "optimum" time may be 18 hours in the forms plus 7 days of air drying. Typical compressive strengths are:

* Wet cure- 3820 PSI
* Air cure- 4200 PSI
* Oven dry cure - 5040 PSI (at 200°F)

9. Typical properties for various mixes considered are:

Mix	7-Day Compressive Strength	Tensile Strength	Modulus of RUPTURE	Percent Latex
43	4000	-	-	-
45	4000	216	115	0
46	4580	-	-	-
48	4080	430	550	20
49	4165	319	322	15
50	3930	280	200	10
53	5010	-	-	-

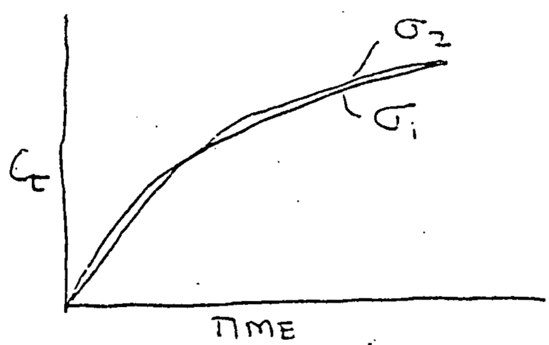
10. Typical design parameters for concretes with and without latex are:

Latex	Compressive Strength-PSI	Weight	Modulus of Elasticity-PSI
No	4600-4800	76-78	$1.4\text{-}1.5 \times 10^6$
Yes	4800-5000	71-74	$1.1\text{-}1.2 \times 10^6$

11. It is assumed that coefficient of variance (as per ACl-214) will be about 8%, producing a reduction of about 80-90 PSI in compressive strength.

12. It is felt that addition of latex will not cause greater shrinkage than with normal structural concrete.

13. Creep may be a problem - analyzed using an effective modulus method. Find a coefficient of creep, C_t, where $C_t = 1$ at $t = 0$: Tested at 20 and 50 percent of ultimate strength and found creep is proportional to stress. The variation of C_t with time is as shown in the plot. There is a greater pull-out problem for rebars than for regular concrete but don't think it is a serious problem, but it does need more study.



14. Water absorption at 3000 foot depth (1400 psi head) was measured for concrete after 7 days air drying. The absorption rate rose rapidly for five days, then increased at a lower rate up to about the theoretical limit of 22% increase in weight. It appears that an average density for 72-75 PCF dry concrete will be 84 PCF after prolonged submergence at 3000 PCF. Weight increase is less at lesser depths. At atmospheric pressure weight increase is about 1 PCF.

15. More work on light weight concrete is needed for

* Degredation of properties between lab and field
* Serviceability, durability and fatigue properties

16. The proposed CWP construction scheme is similar to that used for any concrete pipe; the technology is comparable to that used by Ameron.

17. Cost estimates are based on use of an existing pre-cast plant with the addition of some special handling equipment and cradle used to invert CWP, cast bell housings, etc.

18. The estimated CWP cost (at dock face) is $5.8M. Ameron made a rough estimate of $6.0M. These costs do not include overhead or profit, or cost inflation.

19. It is estimated that it would cost $8M to build a new U.S. pre-cast plant.

A.2.3 Concluding Remarks by Ralph Blevins - APL

1. A suitable concrete can be developed.
2. The phase II tests of CWP segments and materials should begin. If started in January, 1979, these would span the entire year of 1979.
3. The phase II tests would include:
   * Proof and characterization of mix
   * Model structural tests with minimum practical scale model (say 1/5 scale)
   * Full scale section fabrication (hinge area)
   * Hinge operation - characterization of elastomer pads
4. A detailed program will be developed during the next month.
5. One contractor will be selected to carry out these tests.

A.3 Fiberglass

Fiberglass reinforced plastics exhibit structural characteristics which can be made to vary over a broad spectrum. For example, the fabricator can control the percentage and the orientation of the glass fibers in the laminate. The glass fibers used would be the commonly used 'E' glass (referred to as such because of its initial development for electrical applications). This is a lime-alumina-borosilicate glass that is relatively soda-free. The glass fibers themselves have tensile strengths of about 400,000 pounds per square inch and a modulus of elasticity of about 10,500,000 pounds per square inch. Polyester resins are recommended for the binding matrix. (Epoxies would be used as adhesives to bond cured or semi-cured laminates together and/or to freshly lay-up fiberglass.)

The fibrous glass used as reinforcement is usually in the form of woven fabric, chopped fiber mat, continuous-fiber mat, warp, or roving. Each of these may be made in different ways to have different properties. The fiberglass CWP would be made basically by filament winding continuous fiber roving helically on a horizontal mandrel. Hence, its primary filament wound shell elements would be highly orthotropic. Some of its elements such as the webs could be made using chopped fiber mat, which is essentially isotropic in the plane of the mat. Other elements such as the layed-up joint reinforcement would be made up of woven fabric, layed-up with the warp of the fabric in the longitudinal direction (perpendicular to the joint) and the fill of the fabric in the circumferential direction (parallel to the joint). The woven fabric laminate is also orthotropic, having its greater strength and stiffness in the warp direction of the fabric, its intermediate strength and stiffness in the fill direction of the fabric, and its least strength and stiffness in a direction between that of the warp and the fill. The strength and stiffness of fiberglass-reinforced plastics are also a function of the loading conditions on the laminate. The flexural strength and stiffness properties are generally the highest, often as much as twice those in tension and compression.

The presence of water also affects the properties of fiberglass-reinforced plastics. The FRP's have about 15% more strength when dry than when wet. It is to be noted that most data for fiberglass is for its wet condition since most of its applications are in 'wet environments' (boats, pipes, buried tanks, etc.). Also, seawater is considered to have a less deleterious effect on the structural properties of fiberglass than fresh water; hence, the wealth of fresh water fiberglass data may be conservatively applied to the design of the OTEC CWP in seawater.

One excellent property of fiberglass is its immunity to corrosion in seawater. It also appears not to be detrimentally affected by marine organisms such as marine borers. However, this requires further investigation. One area of this, in particular, is the effect of fouling and/or fouling removal on the gelcoat surface finish of the fiberglass. Another is the incorporation of antifouling in the fiberglass.

Fiberglass-reinforced plastics exhibit good resistance to crack propagation and are quite insensitive to notch effects. This is due primarily to the nonhomogeneous fibrous structure of the FRP, and to the inherent presence of microstructure stress raisers.

The seawater fatigue characteristics of fiberglass are also very good; the fatigue strength of fiberglass at 10^6 cycles being about one-third of its ultimate strength. Note that this compares very favorably with steel. Although steel has an ideal fatigue strength in air at 10^6 cycles of about one-half of its ultimate strength, its fatigue strength in seawater is severely reduced without corrosion protection. Fiberglass does not have a yield point and a plastic zone between yield and ultimate. Instead, it is nearly linearly elastic from zero load to fracture failure. This lack of durability is a draw-back in comparison with ductile materials; and the selection of fiberglass design stress allowables must reflect this lack of ductility.

With the extreme variability of fiberglass properties (say E of $2.5 \times 10^6 \pm 2 \times 10^6$ psi and ν of 0.4 ± 0.25), it is difficult to select a set of properties. However, for conceptual design, it is not unreasonable to define a set of properties as follows. For fiberglass that is solidly filament wound on a mandrel:

$$E^*_{hoop} = 3.6 \times 10^6 \text{ psi}$$
$$E^*_{axial} = 1.8 \times 10^6 \text{ psi} \qquad \text{(A-1)}$$

where E* is the effective modulus of elasticity.

For fiberglass that is filament wound over stiffeners:

$$E^*_{hoop} = 1.8 \times 10^6 \text{ psi}$$
$$E^*_{axial} = 0.9 \times 10^6 \text{ psi.} \qquad \text{(A-2)}$$

For fiberglass that is filament wound with up to 40% spherical voids to form a fiberglass sandwich core:

$$E^*_{hoop} = 0.9 \times 10^6 \text{ psi}$$
$$E^*_{axial} = 0.45 \times 10^6 \text{ psi} \qquad \text{(A-3)}$$

For equal biaxial action, such as orthotropic plate buckling, E* is defined as:

$$E^{**} = \sqrt{(E^*_{hoop})\ (E^*_{axial})} \tag{A-4}$$

E* includes the plate effects of Poisson's ratio, i.e.,

$$E^* = \frac{E}{(1-\nu,\nu_2)} \tag{A-5}$$

This simplification is justified for conceptual design work because of the nebulas nature of both E and ν.

For wet stiffener plates,

$$E^* = 1.8 \times 10^6 \text{ psi.} \tag{A-6}$$

A.4 Elastomer Composites

Because the tensile strength and modulus of elasticity of the composite depend on the reinforcing material and its density and orientation, it is necessary to specifically design a composite for the task. For example, the properties of reinforcing fibers are tabulated in Table A.2. Under tensile loading, the endurance limit is usually given as 40% of ultimate stress, however, a safety factor of 4 is used in all designs where long life is desired. Elongation is a function of the wrap angle and type of reinforcing filament. Allowable strain of 2-30% can be designed into the structure.

The actual composite values of E, S_t, etc., which are available for the pipe construction, are influenced by the reinforcement material selected, by orientation of reinforcement fibers, by the number and size of the fibers in each layer and by the number of layers bonded together. The values give in Table A.3 are representative of single layers of composite with a specific fiber orientation angle and loading density.

Information from the Goodrich and Goodyear companies indicates that rubber composites have been used in ocean environments for about ten years. A relevant example is the sonar dome installed on Navy ships. Underwater repairs can be made. E. I. Dupont has furnished data on long-term exposure of neoprene and neoprene-coated pipes to seawater. The following examples were furnished:

- A 48-inch diameter steel pipe, 7863 feet long was coated with neoprene and has been in satisfactory seawater service since September, 1954, in Venezuala. The neoprene coating is 0.062 inches thick.
- A neoprene-coated nylon fabric dam (inflated by water) has been in service since 1959.

TABLE A.2 PROPERTIES OF REINFORCING FIBERS

Fiber	Modulus of Elasticity 10^5 psi	Specific Gravity	Tensile Strength 10^4 psi
Nylon	2.5	1.14	1.0
Rayon	1.8	1.50	0.4
Polyester	10.0	1.38	0.8
Kevlar	80.0	1.44	4.0
Steel	300.0	7.86	10.0

TABLE A.3 RUBBER COMPOSITE PROPERTIES
REINFORCEMENT - 20% BY VOLUME

	Reinforcement Material					
	Steel		Kevlar		Nylon	
Modulus (psi)	19×10^6		5×10^6		2×10^5	
Ply Angle	0^0	22^0	0^0	22^0	0^0	22^0
E_1 (psi)	3.7×10^6	87,000	1×10^6	79,000	40,000	20,000
E_2 (psi)	2,900	2,400	2,900	2,400	2,900	2,400
G_{12} (psi)	520	450,000	520	120,000	520	52,000

Rubber shear modulus = 500 psi

- In 1946, a neoprene coating, 0.063 inches thick was applied to the condenser tube plates at the Portishead 'A' power station on the Seven Estuary. Seawater is the cooling medium. When inspected in 1963, the coating was still resilient and unimpaired. In 1978, the coating is still in service, but some repairs were required to portions damaged by maintenance workers.

Industry design practice is to keep working stresses less than 25% of the ultimate stress. No degradation in seawater is expected if the stresses are thus limited; however, no definitive test data were supplied for the selected elastomer composite, nylon-reinforced neoprene.

Marine biofouling can be controlled by impregnating the composite with special compounds. Goodyear's MA852 antifouling neoprene is a vulcanizable elastomer originally developed for use on wire-reinforced rubber sonar domes. It is approximately 50% more expensive than other neoprene compounds. MA852 contains Bis (tri-n-butyl-tin) oxide (TBTO) toxicant which is the chemical used in many new antifouling paints. However, the amount of TBTO required in MA852 for long-term antifouling resistance is much less than that required in paint coatings because the TBTO is dissolved in the neoprene elastomer matrix. TBTO is virtually insoluble in water, so the elastomer, acting as a semi-permeable membrane and a reservoir for the TBTO, controls the diffusion to the surface of the rubber, thereby maintaining the concentration of TBTO in the water boundry layer on the surface of the rubber above the fouling threshold concentration. The antifouling performance of MA852 is then dependent on the amount of toxicant reservoir provided, i.e., on the thickness of rubber used, and the concentration of TBTO initially in the compound. Laboratory data indicates that the solubility of TBTO in neoprene is approximately 10% by weight.

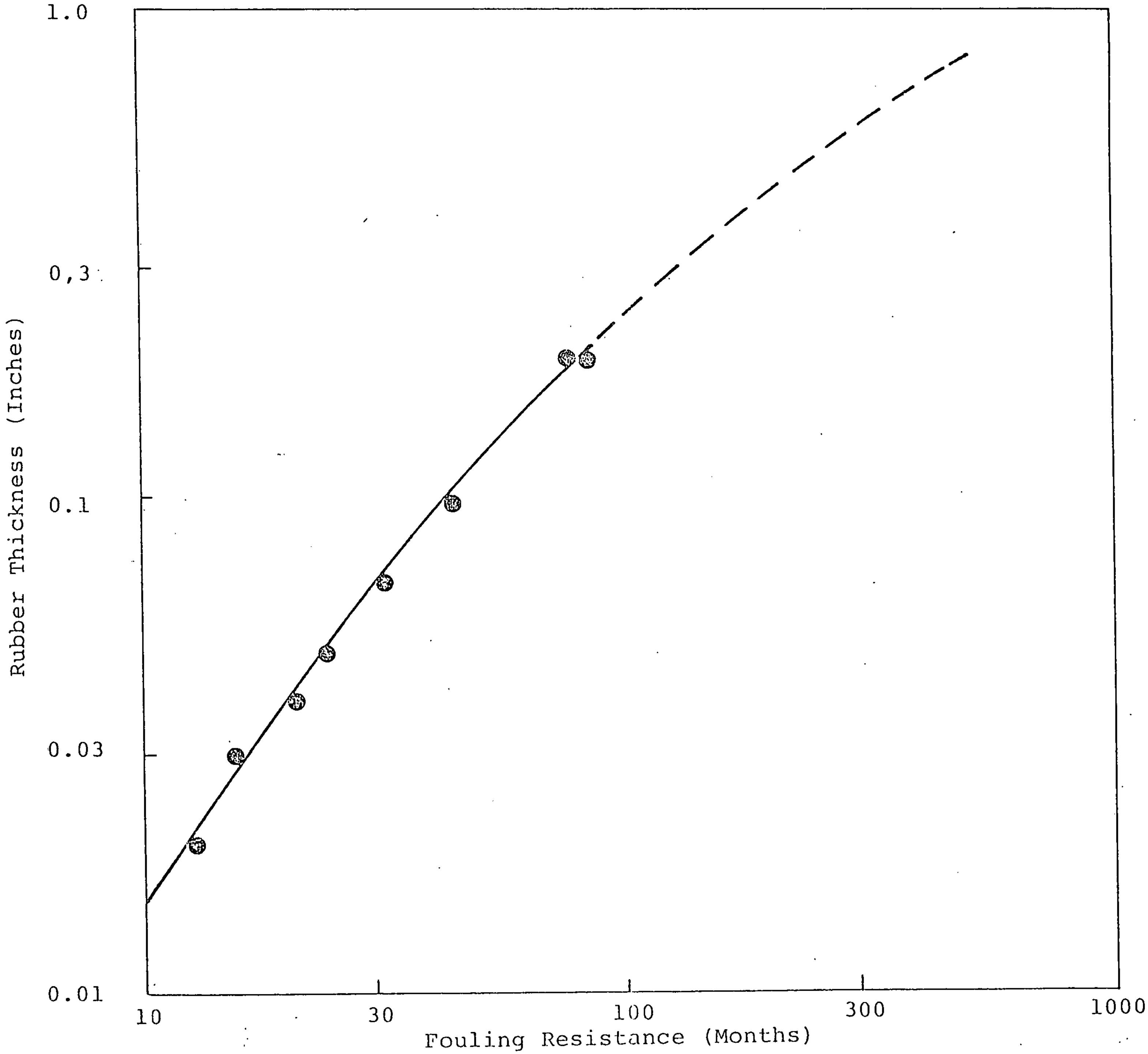
MA852 contains 5% TBTO by weight and the data shown in Figure A.1 indicates that 1/4" of this rubber will provide antifouling protection for 10 years. Scatter in long-term exposure data prevents us from making a more positive statement about the long-term performance of MA852. Most of this scatter is caused by our inability to control the environment in which samples are immersed. Data has been accumulated for over 7 years' immersion in Biscayne Bay, Miami Beach, Florida, one of the severest fouling areas in the world. Samples are also being evaluated in San Diego Bay, but have not been exposed long enough to make performance predictions.

Goodyear is also studying the effect of varying the concentration of TBTO in neoprene and has samples on test in Biscayne Bay which have been immersed for over 4 years. There is not enough data available yet to make long-term projections, but short-term data indicates the antifouling performance improves with increasing TBTO concentration which is in agreement with the diffusion theory.

Based on the available data, it appears that 30 years antifouling protection can be provided for the OTEC Cold Water Pipe by using a thick coating of MA852 or a rubber compound containing a higher concentration of TBTO. It is difficult to predict exactly how much antifouling compound will be required because the 30-year service life requirement is considerably outside the range of existing data. Changes in the physical properties of the antifouling compound during long-term ocean aging could affect TBTO diffusion rates and affect antifouling performance.

Note that all of the aforementioned data was obtained statically. Water flowing over the surface of the rubber will affect performance by tending to deplete TBTO on the surface of the rubber and in the water boundary layer, particularly where turbulent flow exists, and this could increase the rate of TBTO depletion from the rubber. However, with turbulent flow, fouling organisms may not settle.

FIGURE A.1 FOULING RESISTANCE OF MA852 VS THICKNESS



A.5 Polyethylene

The low apparent modulus of elasticity for long-term loading of polyethylene is a significant consideration in the design of a pipe 30 ft in diameter subject to static collapse pressure. The long-term modulus for polyethylene is approximately a factor of 1000 lower than for steel. Thus, this high-compliance can potentially lead to high wall thickness requirements to obtain the necessary structural rigidity, EI, for the pipc. The design approach presented in the next section utilizes circumferential steel ring reinforcement to provide this rigidity.

The material shows significant strain rate dependence. Thus, for loading which occurs over seconds, e.g., platform motion input, the material exhibits a higher apparent modulus. The associated natural frequencies and system dynamic loads are highly sensitive to this effect. For example, stress due to platform sway motion varies as the $\sqrt{E}$.

The combined strains arising from static and dynamic loads are the significant design criterion for polyethylene. According to the strain limit approach, total strains must not exceed 3%.

Polyethylene also offers the interesting property of a density less than that of water. Thus, potentially a polyethylene CWP is neutrally buouant in sea water. However, for the large pipe under consideration here, the ring stiffeners add considerable weight. At either of the OTEC sites under consideration, weight is also required to hold the CWP vertical. In many respects, the low density of polyethylene provides for flexibility in design.

The high coefficient of thermal expansion of polyethylene is not generally a consideration in OTEC loads because the pipe is free to accommodate expansion at the lower end. During assembly, thermal expansion is important; a 3000 ft pipe varies 13.5' in length during a 50° F temperature variation. A different material, steel, is recommended for the ring. Therefore, to eliminate thermal stresses during operation, it is suggested that the ring be mounted to the cylinder when both the ring and cylinder are within a few degrees of the operating temperature of the section.

Polyethylene is also thought to have desirable resistance to chemical action, provide a poor surface for the attachment of marine organisms, and to have low flow friction characteristics.

Polyethylene items are generally manufactured by an extrusion process. Subsequent joining of polyethylene is best done by fusion under pressure. Polyethylene can be joined by mechanically clamping; however, this should not be necessary except at the ends of the pipe.

APPENDIX B - SUMMARY OF RESULTS OF DYNAMIC FLOW AND TRANSPORTATION ANALYSES

INTER-OFFICE MEMO

Science Applications, Incorporated

DATE: March 12, 1979

TO: P. Grote FROM: D. Peterson

SUBJECT: SUMMARY OF RESULTS OF DYNAMIC FLOW ANALYSIS OF THE OTEC COLD WATER SYSTEM

Discussion

A study of the fluid flow dynamics was conducted. Figure 1 shows a schematic of the OTEC Cold Water System. The analysis included the fluid compressibility effects, which are combined into a single parameter, γ, which incorporates the pipe flexibility. One-dimensional flow equations describe the fluid flow throughout the system, which do not account for internal waves in the sump. The pump and condenser are modeled as resistance elements.

The mechanism which was considered was platform heave oscillations which cause internal velocity and pressure oscillations in the fluid. In addition, wave passage causes external pressure variations upon the CWP and at the cold water discharge.

The resulting differential pressure has several effects. On the CWP, the buckling loads are increased, and an increase in internal pressure causes a decrease in net tension. On the pumps, oscillating flows cause oscillating power requirements and impeller fatigue. On the heat exchangers, oscillating flows result in unsteady flow losses and unsteady heat transfer.

Results

For reference, Figure 2 shows pressure differential across the pipe wall due to steady internal flow. Figures 3 and 4 show the dynamic pressure variations relative to this steady pressure drop. The associated velocity fluctuations are given in Table 1.

Conclusions

- Dynamic pressure fluctuations significantly increase the ΔP across the pipe wall during survival conditions and during operations for inappropriate designs. The fluctuations are greater for the barge than for the spar.

- Retracting the CWP platform interface seal in survival sea states significantly reduces dynamic loads.

- Velocity fluctuations (2.5% of nominal) in sump and discharge line are not sensitive to CWP material.

- Pressure fluctuations are relatively insensitive to sump characteristics, as long as a free surface is provided.

DP:em

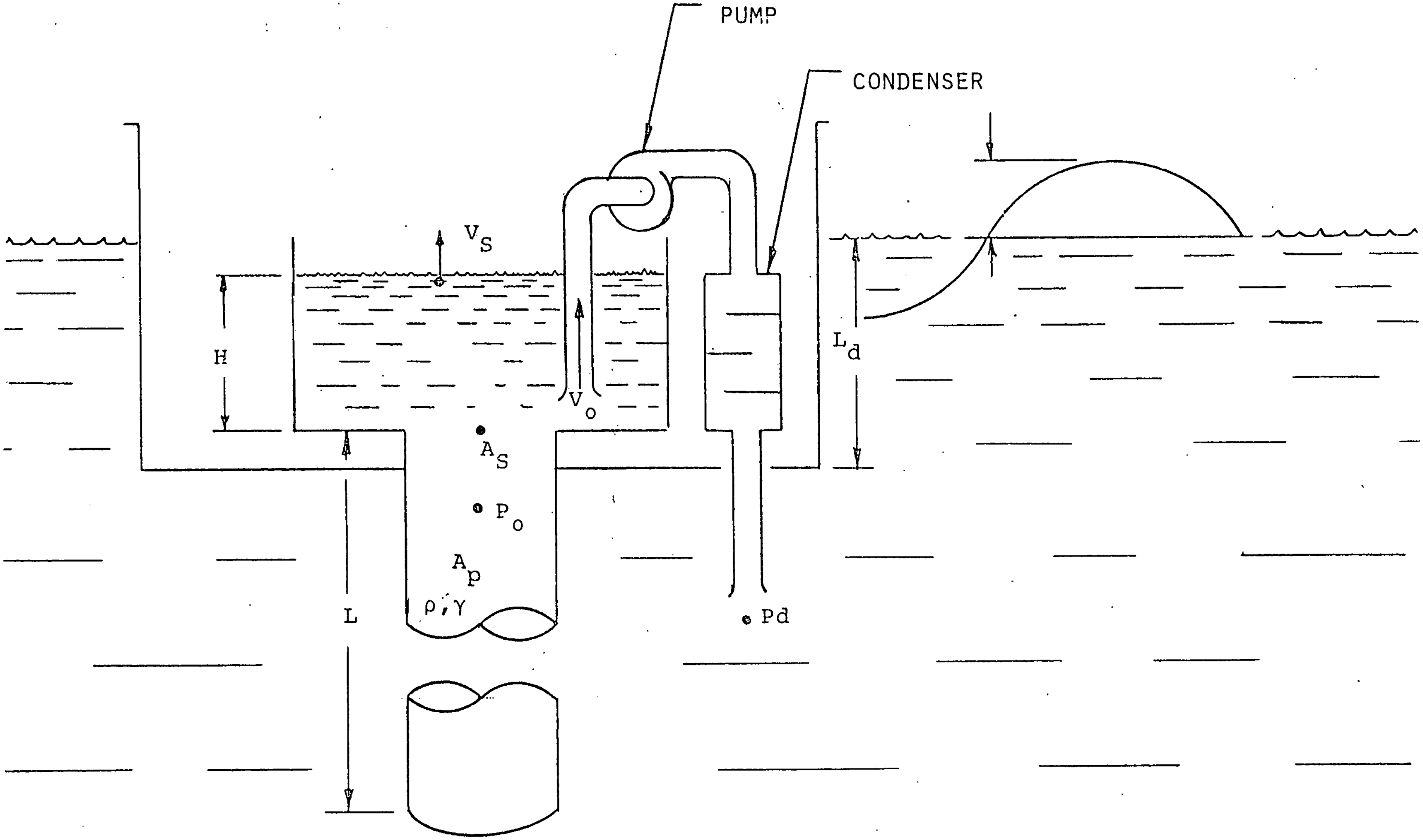


FIGURE 1
SCHEMATIC OF BARGE COLD WATER SYSTEM

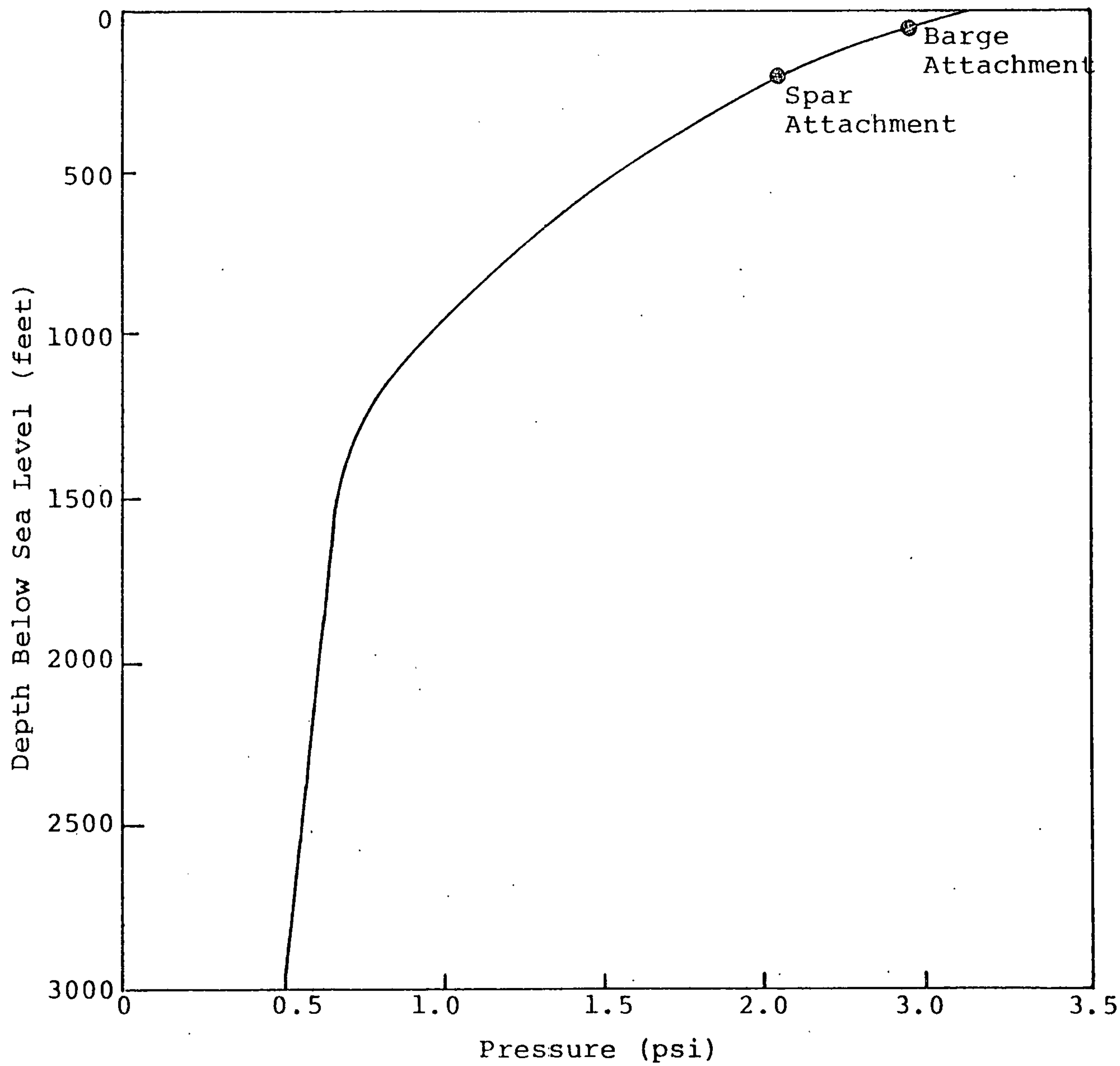


FIGURE 2. PRESSURE DIFFERENTIAL ACROSS CWP WALL DUE TO STEADY INTERNAL FLOW

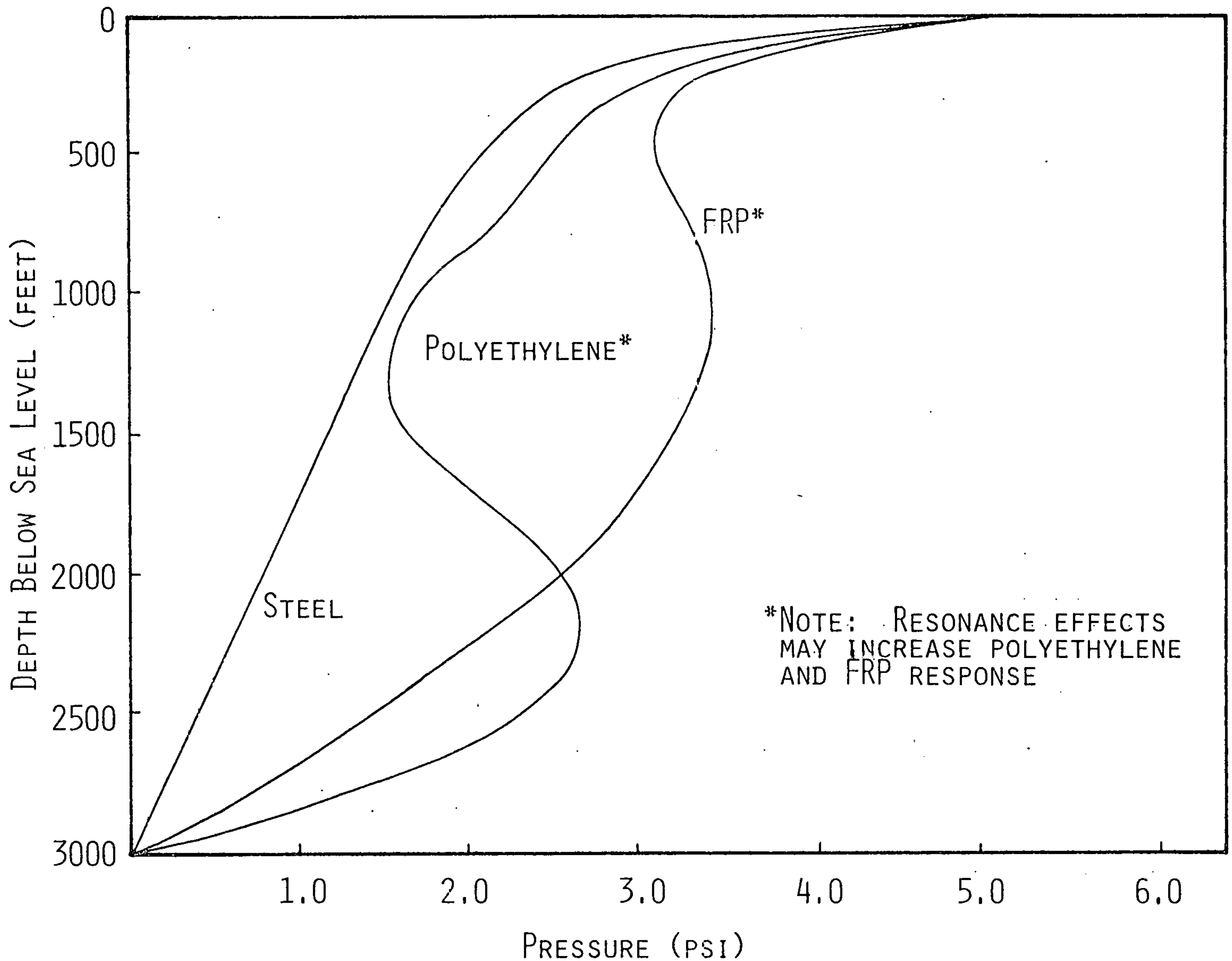


Figure 3. RMS Dynamic Pressure Variations During Survival Sea State

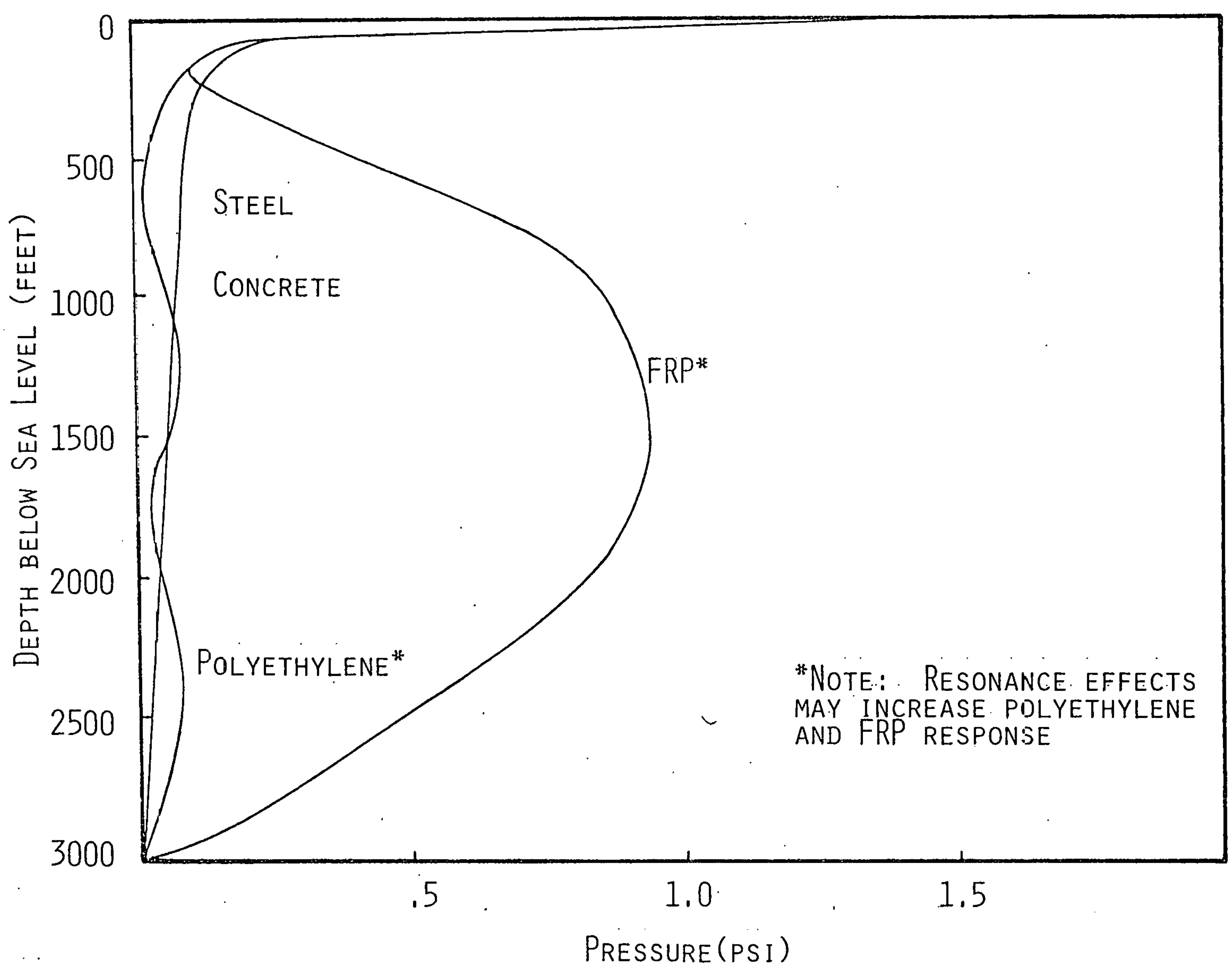


Figure 4. RMS Dynamic Pressure Variations during Maximum Operational Sea State

Table 1. RMS Dynamic Velocity Fluctuations For Barge Attached CWP's

MATERIAL	MAX. OPERATING S.S. SUMP LEVEL VELOCITY (FPS)	MAX. OPERATING S.S. DISCHARGE VELOCITY (FPS)	SURVIVAL S.S. SUMP LEVEL VELOCITY (FPS)	SURVIVAL S.S. DISCHARGE VELOCITY (FPS)
STEEL	.038	.159	.314	.933
CONCRETE	.038	.159	.312	.936
FRP	.038	.160	.309	.947
POLYETHYLENE	.037	.160	.319	.979

INTER-OFFICE MEMO

SCIENCE APPLICATIONS, INC.

DATE: 25 January 1979

TO: P. Grote FROM: D. Peterson

SUBJECT Preliminary OTEC Cold Water Pipe Transportation Analysis Results

SUMMARY

The objective of the CWP transportation analysis is to determine feasibility of horizontal deployment of the CWP. Preliminary calculations indicate that horizontal deployment of either a steel or fiberglass CWP is feasible. The fiberglass CWP may be towed either on the surface or at least 200 feet submerged, at any heading, in any sea state up to 5 ($\overline{H}_s$ = 12 ft.). The steel pipe cannot be towed on the surface, but may be towed submerged at least 200 feet, at any heading, in any sea state up to 5.

DISCUSSION

The response of the pipe has been characterized by bending of a uniform pipe in two orthogonal planes: horizontal and vertical. Torsional response has been neglected, as discussed later. The vertical-plane bending response is given by a heave model, and the horizontal plane response is given by a sway model. The total stress is derived from the combined response.

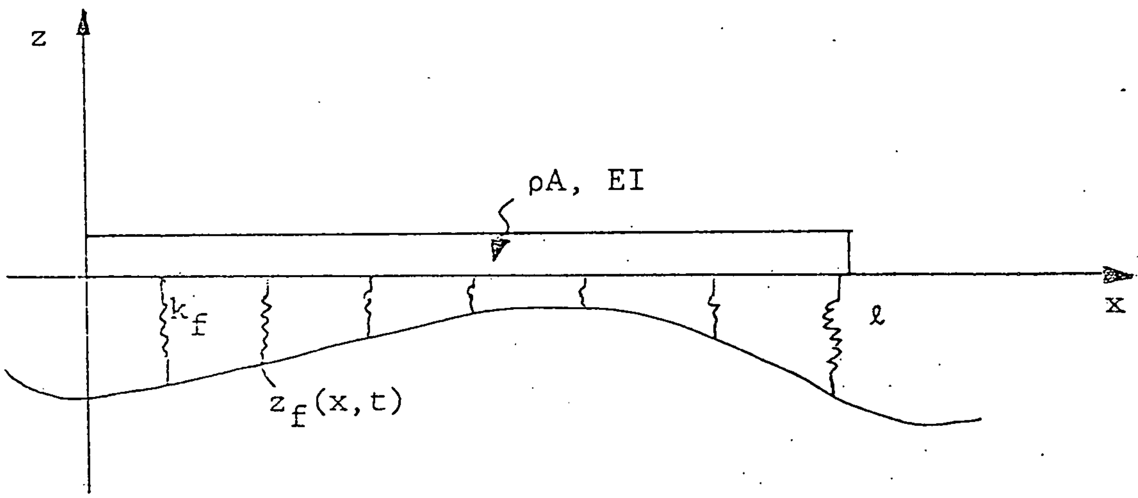
Heave Model-

The heave model is shown in Figure 1. The corresponding equation of motion for the heave model is,

$$\rho A \frac{\partial^2 z}{\partial t^2} + b \frac{\partial z}{\partial t} + EI \frac{\partial^4 z}{\partial x^4} + k_f z = m_f \frac{\partial^2 z_f}{\partial t^2} + b \frac{\partial z_f}{\partial t} + k_f z_f \qquad (1)$$

FIGURE 1

HEAVE MODEL



The pipe is considered uniform, with mass per unit length, ρA, and stiffness, EI. The mass per unit length includes the pipe mass, the mass of internal fluid (if any) and the external added mass. For the case where the pipe is towed, floating on the surface, the internal fluid mass is zero, and the external added mass will be less than for the submerged case.

The hydrodynamic buoyancy stiffness, represented by k_f, is found by linearizing the buoyancy force about the calm water force. It is equal to,

$$k_f = \rho g B_w \tag{2}$$

where ρ = sea water density,

g = acceleration of gravity

B_w = waterline beam

The linearization is accurate for water displacement relative to the calm water lines that are small. For larger displacements, the linear assumption results in conservative loads.

The damping coefficient, b, represents the sum of the viscous damping and wave-making damping,

$$b = b_w + b_v \tag{3}$$

The coefficient of viscous damping, b_v, represents an equivalent linear damping coefficient. The true viscous damping is a function of velocity squared, and thus cannot be included in a linear model. The equivalent damping coefficient, b_v, was selected as one which dissipates the same energy per cycle as the true viscous damper. It is equal to,

$$b_v = \frac{4}{3\pi} \rho h C_D V_o \tag{4}$$

where h = projected height,

C_D = drag coefficient,

V_o = peak relative velocity.

Because the damping coefficient is a function of peak relative velocity, it is necessary to iterate on the damping until the response corresponds to the value of damping assumed.

The coefficient of wave-making damping was obtained from curves available in Reference 1. It is not a function of amplitude, but it is a function of frequency, and thus is different for each frequency component of an irregular wave. The wave-making damping is maximum at the surface, but decreases rapidly with depth. For depths greater than 2.5 pipe diameters, the wave-making damping is practically zero.

The quantity, m_f, is an effective inertia which results from a hydrostatic pressure force plus an inertia force. Both these forces are proportional to the fluid particle acceleration, and therefore the quantity m_f may be identified. From Reference 2, is is equal to,

$$m_f = 1.1 \frac{\pi}{2} \rho D^2 \tag{5}$$

where D = outside diameter.

It should be noted that m_f is 10% greater than twice the added mass, and thus represents a theoretical value with a slight correction. For the case of the pipe towed floating on the surface, m_f should be set equal to zero, as it is small and the formula of equation (5) is incorrect in this case.

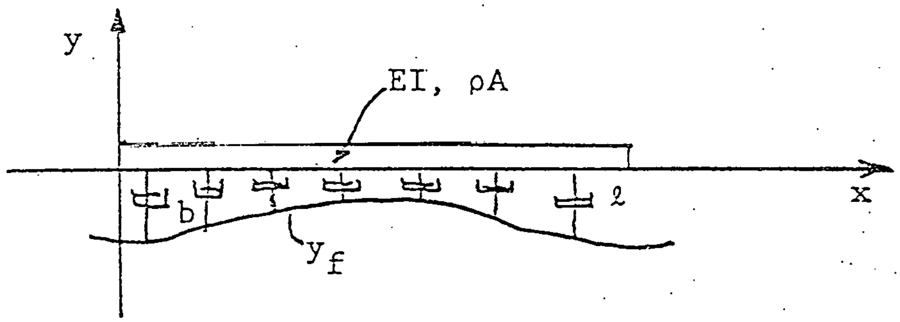
Sway Model

The sway model is shown in Figure 2, and a similar equation of motion applies,

$$\rho A \frac{\partial^2 y}{\partial t^2} + b \frac{\partial y}{\partial t} + EI \frac{\partial^4 y}{\partial x^4} = m_f \frac{\partial^2 y_f}{\partial t^2} + b \frac{\partial y_f}{\partial t} \tag{6}$$

FIGURE 2

SWAY MODEL



The major difference is that there is no buoyancy stiffness in sway ($k_f = o$). Because of this fact, the sway response is small compared to the heave response, and may be neglected for the case of the pipe towed on the surface.

Similarly, below the surface the heave response is always greater than or equal to the sway response. And, since the pipe is symmetrical, its responses in heave and sway are everywhere 90^o out of phase. Therefore, the maximum stress is the larger of the heave stress or sway stress. Finally, since the heave response is always greater than or equal to the sway response, only the heave response needs to be considered.

Therefore, from this point on, only the response to the heave equation of motion will be considered.

Input

Figure 3 shows the pipe subjected to regular, long-crested waves. Let the horizontal lines on the paper represent successive wave crests. As the heading angle, θ increases, the actual shape of the wave does not change, but the apparent wavelength, λ_e, as measured along the length of the pipe, increases. This relationship is shown graphically in the subfigure (3a), which is

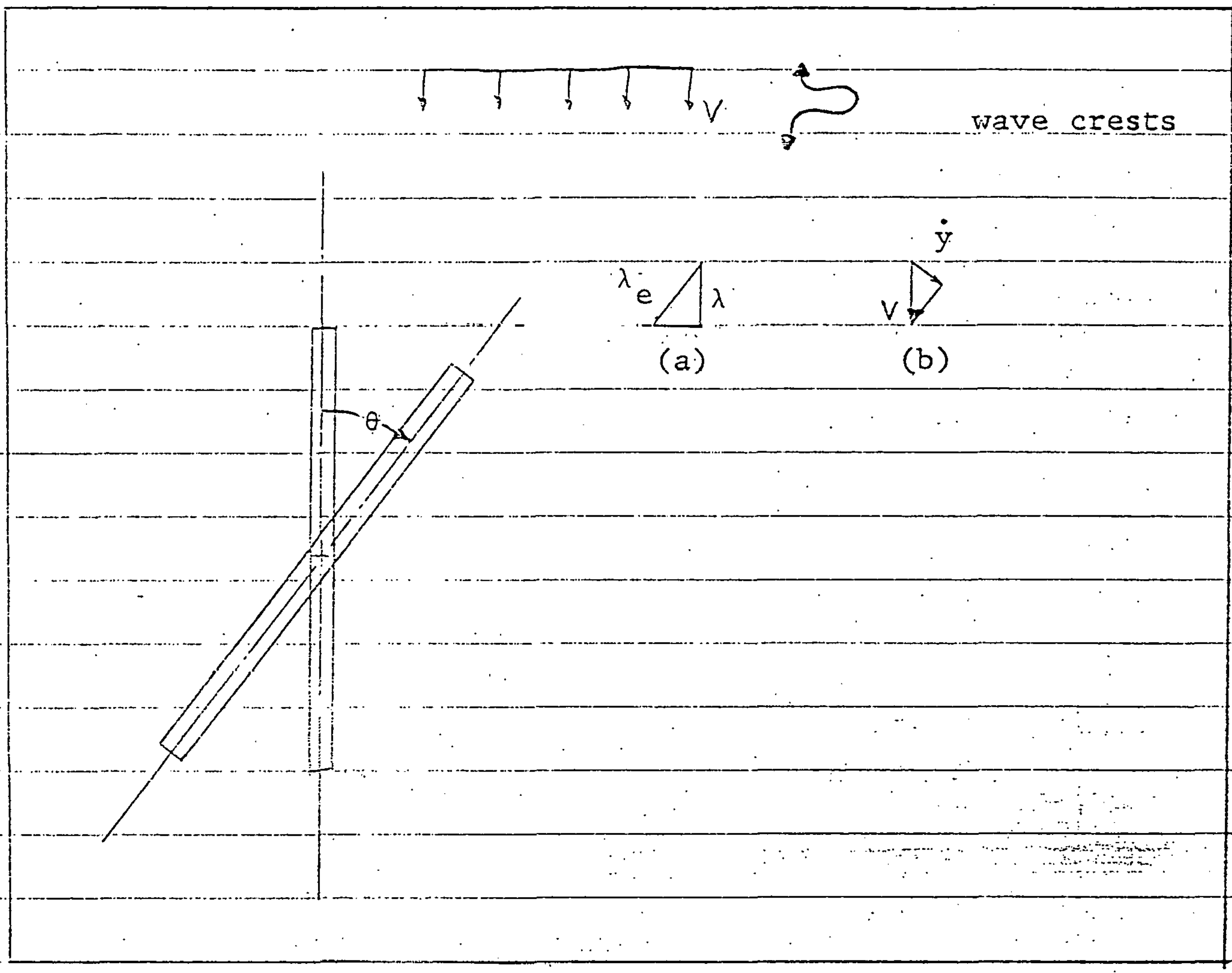
$$\lambda_e = \frac{\lambda}{\cos\theta} \tag{7}$$

or, in terms of the wave number, k, which is inversely proportional to λ,

$$k_e = k \cos\theta \tag{8}$$

FIGURE 3

INPUT OF OBLIQUE SEAS



Similarly, the transverse displacement, velocity and acceleration change with heading as shown in Figure (3b),

$$\dot{y} = v \sin \theta \tag{9}$$

The wave frequency, and the heave motions, are unaffected.

Therefore, the input for the case where the pipe is towed at a heading angle, θ, to the wave direction is,

$$z_f(x,t) = \mathrm{Re}\left[A\, e^{i(\omega t - k_e x)}\, e^{-kz_o}\right] \tag{10}$$

where k_e is given by equation (8) above, A is the wave amplitude and z_o is the submergence depth of the pipe.

Solution

The mathematical solution of equation (1) consists of a particular and a homogeneous part. The particular part constitutes the major portion of the forced response, and the addition of the homogeneous part is necessary to satisfy the boundary conditions. If the length of the pipe is much greater than the wavelength of the input, the pipe can be considered to be infinitely long, and then the particular part is a good approximation to the total solution. Physically, this means that the condition of zero bending stress at the ends of the pipe does not affect the response at the middle of the pipe, where the stresses are maximum. Since the pipe length is 3000 feet, and a typical wavelength is 500 feet, this is a good approximation and considerably simplifies the analysis.

Therefore, since the input is a regular wave given by

$$z_f(x,t) = \mathrm{Re}\left[A\, e^{i(\omega t - k_e x)}\, e^{-kz_o}\right] \tag{10}$$

the solution to Equation (1) is given by the transfer function,

$$H_{z-z_f}(\omega) = \frac{(-m_f\omega^2 + ib\omega + k_f)\; e^{-kz_o}}{-\rho A\omega^2 + ib\omega + EI\, k_e^4 + k_f} \tag{11}$$

the moment at any point in the pipe is,

$$M = EI \frac{\partial^2 y}{\partial x^2} \tag{12}$$

and the formula for bending stress is,

$$\sigma = \frac{Mc}{I} \tag{13}$$

Substituting (11) and (12) into (13) gives the transfer function for stress, given wave amplitude,

$$H_{\sigma-z_f}(\omega) = Ec\; k_e^2\; H_{z-z_f}(\omega) \tag{14}$$

The frequency response given by Equation (14) can be used to determine the response of the pipe in irregular waves as follows: The power spectral density (PSD) of wave amplitude is given in Reference 3 by $S_{z_f}(\omega)$. Then the PSD of stress in the pipe is given by,

$$S_\sigma(\omega) = \left| H_{\sigma-y_f}(\omega) \right|^2 S_{z_f}(\omega) \tag{15}$$

Then the RMS stress in the pipe is given by,

$$\sigma_{rms} = \sqrt{\int_0^{\infty} S_{\sigma}(\omega)\ d\omega}$$

$$= Ec \sqrt{\int_o^{\infty} k_e^4 \left| H_{z-z_f}(\omega) \right|^2 S_{z_f}(\omega)\ d\omega} \qquad (16)$$

RESULTS

Figure 4 shows the results of the transportation analysis. Maximum rms bending stress is plotted as a function of heading angle, for two pipe configurations at various depths. Also shown is a line representing an allowable stress. The acceptable range lies below this line. The assumed pipe parameters are given in Table 1.

Sea state 5, with a significant wave height of 12 feet was chosen as input. This sea state or milder occurs 99.6% of the time at the Punta Tuna, Puerto Rico, site. It is assumed that this represents the maximum sea state that could reasonably be expected to occur during the towing operation.

The peak in response, which occurs at a heading of about 60^o and at 75^o for fiberglass and steel pipes, respectively, results from a match between the wave driving frequency (ω) and mode shape (k_e), and the natural frequency and mode shape of the pipe. Because of the requirement of matching both ω and k_e, a peak in the response occurs at just a single value of ω (or k_e), rather than for a series of frqeucneis, as is normal in a continuous system.

Physically speaking, the pipe is sensitive to wavelengths in a critical range. For very short waves, the pipe can bridge the span between wave crests without failing. In very large waves, the pipe conforms to the shape of the wave, and

FIGURE 4

RMS PIPE BENDING STRESS DURING SUBSURFACE TOW

OPERATIONAL SEA STATE 5 $\bar{H}_s = 12$ ft

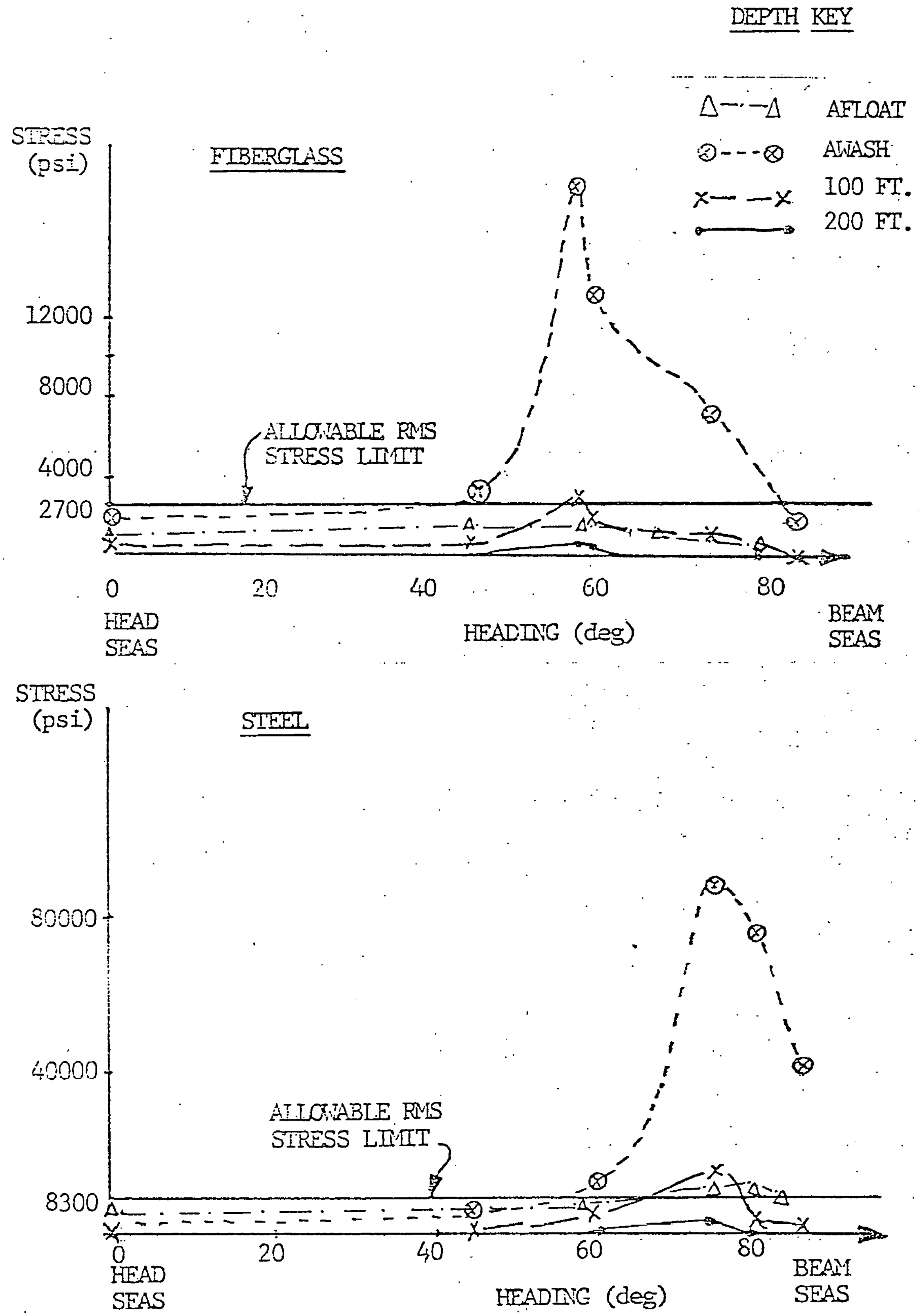


TABLE 1

ASSUMED PIPE PARAMETERS

PARAMETER	UNITS	VALUE	
		STEEL	FRP
ρA (floating)	$\frac{\text{slugs}}{\text{ft}}$	178.	78.6
ρA (submerged)	$\frac{\text{slugs}}{\text{ft}}$	2903.	3394.
b	$\frac{\text{lb/fps}}{\text{ft}}$	25-700	25-700
E	psf	4.32×10^9	1.44×10^8
I	ft^4	622.7	1380.
k_f	$\frac{\text{lb/ft}}{\text{ft}}$	1225.	985.5
m_f	$\frac{\text{slugs}}{\text{ft}}$	3095.	3690.
c	ft	15.0	16.38

because the curvature is small, the stress is low. However, for a middle length range of waves, the pipe can neither support itself nor follow the wave without exceeding an allowable stress. This description applies to fiberglass or steel pipes. For very flexible pipes, however, such as polyethelene, the pipe can follow the waves down to the very shortest wavelengths without failing. So horizontal towing is a lower risk operation for more compliant pipes.

The very high response which occurs in the awash condition results from a decrease in the wave-making damping which occurs as the pipe submerges. At shallow depths, even though the wave-making damping has decreased considerably, the wave action is still strong, and this results in high response.

Additional Considerations

Torsional response of the pipe to wave excitation was also considered. This excitation was shown to be negligible, resulting in a maximum bending stress of .62 psi. The reason this response is so low is that the input is very small. The only way torsional input can be applied to the pipe by ocean waves is by skin friction. All other pressure and inertia forces caused by the waves act against the pipe wall by pressure, which is normal to the surface. Since the pipe is circular, all pressure forces act through the center of the circle, and there is no torque.

Another horizontal tow load condition which has been postulated is pipe flutter caused by axial flow velocites external to the pipe. This may be of greater significance for compliant pipes. It is expected that this source of loading is not important. However, articles relevant to this phenomenon are in the literature and have been requested. When these have been received, its significance will be assessed.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

NOMENCLATURE

b	total damping coefficient
b_v	equivalent viscous damping coefficient
b_w	wave-making damping coefficient
B_w	waterline beam
c	pipe radius
C_D	drag coefficient
D	pipe diameter
E	elastic modulus
g	acceleration of gravity
h	projected height exposed to flow
I	pipe moment of inertia
k	wave number
k_e	effective wave number defined by Equation (8)
k_f	hydrodynamic buoyancy stiffness
M	moment
m_f	effective inertia defined by Equation (5)
$S_{z_f}(\omega)$	wave amplitude power spectral density
$S_\sigma(\omega)$	pipe bending stress power spectral density
v	wave celerity
V_o	peak relative velocity between pipe and fluid
x	distance along pipe
y	sway displacement
z	heave displacement
z_f	fluid displacement from calm water line
z_o	submergence depth to pipe centerline
[illegible]	heading angle
λ	wavelength
λ_e	effective wavelength defined by Equation (7)
ρ	fluid mass density
ρA	pipe mass per unit length
σ	pipe heading stress
σ_{rms}	RMS pipe bending stress
ω	angular frequency

REFERENCES

1. *Principles of Naval Architecture*, John P. Comstock, ed., SNAME, New York, 1967.

2. Barr, R. A., et al, *Methods for and Examples of Dynamic Load and Stress Analysis of OTEC Cold Water Pipe Design*, HYDRONAUTICS, Incorporated Technical Report 7825-2, November 1978.

3. *OTEC Demonstration Plant Environmental Package*.

APPENDIX C - CWP SIZING ANALYSES

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 1 OF 1[illegible]

CLIENT: DEPARTMENT OF ENERGY — JOB NO. ER-[illegible]

SUBJECT: ARTICULATED SHELL AND TEE CWP CONCEPT

BASED ON: — DRAWING NO.:

COMPUTER: S. PORTER — CHK'D. BY: [illegible] — APP'D. BY: — DATE: 23 FEB 19[illegible]

THIS IS A CONCEPTUAL ANALYSIS OF AN ARTICULATED SHELL AND TEE CWP DESIGNED TO WITHSTAND EXTREME STORM CONDITIONS AT THE BRAZIL SITE.

MANY DIFFERENT STRUCTURAL TEE SIZES AND SHELL THICKNESSES WERE STUDIED AND THE RESULTS ARE SHOWN BELOW: (JOINT AT 500-FT.)

SECTION	SHELL THICKNESS (30 FT. DIA.)	STRUCTURAL TEE
0-500	3/8-IN.	48-WT 9 X 57
500-1500	1/4-IN.	48-WT 9 X 27.5
1500-3000	3/16-IN.	48-WT 9 X 13

CIRCUMFERENTIAL TEES: 0-3000 FT.: WT 9X 20 @ 15 [illegible] SPACING

THE FOLLOWING WILL BE A CHECK AGAINST ALLOWABLE STRESS LEVELS AND INSTABILITY.*

THE EXPECTED MOMENTS, ACCORDING TO PREVIOUS ATTEMPTS, WILL BE AS FOLLOWS:

0-500 FT.: $M = 10 \times 10^7$ FT-LBS
500-1500 FT.: $M = 5 \times 10^7$ FT-LBS
1500-3000 FT.: $M = 2.5 \times 10^7$ FT-LBS

FROM SAI, THE PRESSURE DIFFERENTIAL ON THE CWP IS:
0-500 FT = 2.75 PSI, 500-1500 FT = 2.44 PSI, 1500-3000 PSI = 0.55 PSI

<u>ALL STEELS</u> HAVE A YIELD STRESS, σ_y = 36,000 PSI

*NORWEGIAN STANDARD NS 3472 E, "STEEL STRUCTURES, DESIGN [illegible]

FOR 1500 - 3000 FT: $M = 2.5 \times 10^7$ FT-LBS

$$I_{SHELL} = \frac{\pi}{64}\left((30.03\ FT)^4 - (30.00\ FT)^4\right) = 165.93\ FT^4$$

FOR 48 STIFFENERS: $\theta = \frac{360}{48} = 7.5°$

$$I_T = 48 I_{TEE} + Ad^2 \approx Ad^2$$

$$d^2 = 2(174.26\ IN)^2 \left(2 \sin 7.5° + 2 \sin 15° + 2 \sin 22.5° + \ldots + 2 \sin 82.5° + \sin 90°\right)^{(12)} \left(\frac{1\ FT}{12\ IN}\right)^2 = 5061.1\ FT^2$$

$$I_T = Ad^2 = (3.84\ IN^2)\left(\frac{1\ FT}{12\ IN}\right)^2 (5061.1\ FT^2) = 134.96\ FT^4$$

$$I = 300.89\ FT^4$$

$$\text{CROSS-SECTIONAL AREA} = (30\ FT)(12\ IN/FT)\pi(0.1375\ IN) + 48(3.84\ IN^2)$$

$$A = 396.38\ IN^2$$

$$\text{TOTAL WEIGHT (IN AIR)} = (396.38\ IN^2)\left(\frac{1\ FT}{12\ IN}\right)^2 (1500\ FT)(490\ LB/FT^3) + \left(\frac{1500}{15}\right)(31.11\ FT)\pi(20\ LB/FT)$$

$$W = 2,218,660\ LBS$$

$$\text{TOTAL WEIGHT (IN WATER)} = P = \left(\frac{490 - 64}{490}\right)(2,218,660\ LBS)$$

$$P = 1,928,875\ LBS$$

CHECK AGAINST ALLOWABLE STRESS LEVELS:

$$\sigma_{x_1} = \frac{P}{A} = \frac{1,928,875\ LBS}{396.38\ IN^2} = 4865\ PSI$$

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 3 OF 1[illegible]

CLIENT ______ JOB NO. EE-09[illegible]

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY [illegible] APP'D. BY ______ DATE 26 FEB 19[illegible]

$$\sigma_{x_2} = \frac{Mc}{I} = \frac{(2.5 \times 10^7 \text{ FT-LBS})(15 \text{ FT})}{(300.84 \text{ FT}^4)(12 \text{ IN/FT})^2} = 5655 \text{ PSI}$$

$$\sigma_h = -p\left(\frac{r}{t} - 0.4\right) = -0.55 \text{ PSI}\left(\frac{180 \text{ IN}}{0.1375 \text{ IN}} - 0.4\right) = -525 \text{ PSI}$$

CALCULATE PRINCIPAL STRESSES:

$$A = \frac{\sigma_{x_1} - \sigma_{x_2} + \sigma_h}{2} = \frac{4865 - 8655 - 530}{2} = -2160 \text{ P[illegible]}$$

$$B = \frac{\sigma_{x_1} + \sigma_{x_2} - \sigma_h}{2} = \frac{4865 + 8655 + 530}{2} = 7025 \text{ PSI}$$

$$\sigma_1 = A + B = (-2160) + 7025 = 4865 \text{ PSI}$$

$$\sigma_2 = A - B = (-2160) - 7025 = -9185 \text{ PSI}$$

CALCULATE MOHR SHEAR STRESSES:

$$\tau_{M_1} = \frac{\sigma_1 - \sigma_2}{2} \leq 0.4\sigma_y \Longrightarrow 7025 \text{ PSI} \leq 14,400 \text{ PSI}$$

$$\tau_{M_2} = \frac{\sigma_1}{2} \leq 0.4\sigma_y \Longrightarrow 2435 \text{ PSI} \leq 14,400 \text{ PSI}$$

$$\tau_{M_3} = \frac{\sigma_2}{2} \leq 0.4\sigma_y \Longrightarrow 4595 \text{ PSI} \leq 14,400 \text{ PSI}$$

CHECK AGAINST INSTABILITIES:

$$Z_2 = \frac{a^2}{Rt} = \frac{(15 \text{ FT})(12 \text{ IN/FT})^2}{(180 \text{ IN})(0.1375 \text{ IN})} = 960$$

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 4 OF 1

CLIENT ______ JOB NO. EE-072

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY ______ APP'D. BY ______ DATE 26 FEB 19

$$Z_3 = \frac{b^2}{Rt} = \frac{\left(\frac{(30\text{ FT})(12\text{ IN/FT})\pi}{48}\right)^2}{(180\text{ IN})(0.1875\text{ IN})} = \frac{(23.56\text{ IN})^2}{(180\text{ IN})(0.1875\text{ IN})} = 16.45$$

FOR COMPRESSIVE BUCKLING OF SHELL:

$$Z_3 > 10; \quad \sigma_{bi} = (0.4 + 0.32 Z_3) E\left(\frac{t}{b}\right)^2$$

$$= (0.4 + (0.32)16.45)\,30(10)^6\text{ PSI}\left(\frac{0.1875\text{ IN}}{23.56\text{ IN}}\right)^2 = 10,760\text{ PSI}$$

FOR EXTERNAL LATERAL COMPRESSIVE PRESSURE:

$$Z_2 > 100; \quad \sigma_{pi} = 0.79\sqrt{Z_2}\, E\left(\frac{t}{a}\right)^2 = 0.79\sqrt{960}\,\left(30(10)^6\text{ PSI}\right)\left(\frac{0.1875}{180}\right)^2$$

$$\sigma_{pi} = 800\text{ PSI}$$

CALCULATE USAGE FACTOR:

$$\left|\frac{\sigma_{x_1} + \sigma_{x_2}}{\sigma_{bi}} + \frac{\sigma_h}{\sigma_{pi}}\right| \leq 1.00$$

$$\left|\frac{4365 - 8655}{10,760} + \frac{-525}{800}\right| \leq 1.00$$

$$1.00 \leq 1.00$$

LOCAL BUCKLING CHECK:

LONGITUDINAL STIFFENERS:

$$I = I_T + Ad^2 = 23.3\ in^4 + (3.84\ in^2)(5.85\ in)^2$$

$$I = 154.0$$

$$\frac{2\pi R}{b} = 45 \Longrightarrow \gamma = \left(25\frac{A}{ht} + 3\right)\left(\frac{a}{b}\right)^2 + 6$$

$$\gamma = \left(25\frac{3.84\ in^2}{(1130.97)(0.19)} + 3\right)\left(\frac{180\ in}{23.56\ in}\right)^2 + 6 = 207.5$$

$$I > 0.1ht^3\gamma = 0.1(1130.97\ in)(0.1875\ in)^3(207.5) = 154.7\ in^4$$

$$154.0 \geq 154.7 \quad \text{(CLOSE ENOUGH)}$$

LATERAL STIFFENERS:

$$I > \left(\frac{\sigma_{Pi}}{E}\right)\frac{taR^2}{3} = \left(\frac{800\ psi}{30(10)^6\ psi}\right)\frac{(0.19\ in)(180\ in)(180\ in)^2}{3} = 9.72\ in^4$$

$$I = I_T + Ad^2 = 44.9 + (5.88)(6.75)^2 = 313.1\ in^4$$

$$313.1\ in^4 \gg 9.72\ in^4 \quad \text{(OVERDESIGNED)}$$

FOR 500 – 1500 FT: $M = 5.0 \times 10^7$ FT-LBS

$$I_{SHELL} = \frac{\pi}{64}\left((30.04\text{ FT})^4 - (30.00\text{ FT})^4\right) = 221.35\text{ FT}^4$$

$$I_T = Ad^2 = (8.10\text{ IN}^2)2(173.10\text{ IN})^2(12)\left(\frac{1\text{ FT}}{12\text{ IN}}\right)^4 = 280.91\text{ FT}^4$$

$$I = 502.26\text{ FT}^4$$

$$\text{CROSS-SECTIONAL AREA} = (30\text{ FT})(12\text{ IN/FT})\pi(0.25\text{ IN}) + \cdot 48(8.10\text{ IN}^2)$$

$$A = 671.54\text{ IN}^2$$

$$\text{TOTAL WEIGHT (IN AIR)} = (671.54\text{ IN}^2)\left(\frac{1\text{ FT}}{12\text{ IN}}\right)^2(1000\text{ FT})(490\text{ LB/FT}^3) + \left(\frac{1000\text{ FT}}{15\text{ FT}}\right)(31.11\text{ FT})\pi(20\text{ LB/FT}) + 2,213,660\text{ LBS}$$

$$W = 4,634,085\text{ LBS}$$

$$\text{TOTAL WEIGHT (IN WATER)} = \left(\frac{490-64}{490}\right)(4,634,085\text{ LBS})$$

$$P = 4,028,815\text{ LBS}$$

CHECK AGAINST ALLOWABLE STRESS LEVELS:

$$\sigma_{x_1} = \frac{P}{A} = \frac{4,028,815\text{ LBS}}{671.54\text{ IN}^2} = 6000\text{ PSI}$$

$$\sigma_{x_2} = \frac{Mc}{I} = \frac{(5.0 \times 10^7\text{ FT-LBS})(15\text{ FT})}{(502.26\text{ FT}^4)(12\text{ IN/FT})^2} = 10,370\text{ PSI}$$

$$\sigma_h = -p\left(\frac{r}{t} - 0.4\right) = -2.44\text{ PSI}\left(\frac{180\text{ IN}}{0.25\text{ IN}} - 0.4\right) = -1755\text{ PSI}$$

CLIENT ______ JOB NO. E2-092

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY ______ APP'D. BY ______ DATE 27 FEB 19__

$$A = \frac{\sigma_{x_1} - \sigma_{x_2} + \sigma_h}{2} = \frac{6000 - 10{,}370 - 1755}{2} = -3065 \text{ PSI}$$

$$B = \frac{\sigma_{x_1} + \sigma_{x_2} - \sigma_h}{2} = \frac{6000 + 10{,}370 + 1755}{2} = 9065 \text{ PSI}$$

$$\sigma_1 = A + B = (-3065) + 9065 = 6000 \text{ PSI}$$

$$\sigma_2 = A - B = (-3065) - 9065 = -6065 \text{ PSI}$$

$$\tau_{M_1} = \frac{\sigma_1 - \sigma_2}{2} \leq 0.4\,\sigma_y \Longrightarrow 6035 \text{ PSI} \leq 14{,}400 \text{ PSI}$$

$$\tau_{M_2} = \frac{\sigma_1}{2} \leq 0.4\,\sigma_y \Longrightarrow 3000 \text{ PSI} \leq 14{,}400 \text{ PSI}$$

$$\tau_{M_3} = \frac{\sigma_2}{2} \leq 0.4\,\sigma_y \Longrightarrow 3035 \text{ PSI} \leq 14{,}400 \text{ PSI}$$

CHECK AGAINST INSTABILITIES:

$$Z_2 = \frac{a^2}{Rt} = \frac{(180 \text{ IN})^2}{(180 \text{ IN})(0.25 \text{ IN})} = 720$$

$$Z_3 = \frac{b^2}{Rt} = \frac{(23.56 \text{ IN})^2}{(180 \text{ IN})(0.25 \text{ IN})} = 12.34$$

$$Z_3 > 10; \quad \sigma_{bi} = (0.4 + 0.32 Z_3)\, E\left(\frac{t}{b}\right)^2$$

$$= (0.4 + (0.32)12.34)\, 30(10)^6 \text{ PSI} \left(\frac{0.25}{23.56}\right)^2 = 14{,}685 \text{ PSI}$$

$$Z_2 > 100; \quad \sigma_{pi} = 0.79\sqrt{Z_2}\, E\left(\frac{t}{a}\right)^2 = 0.79\sqrt{720}\,(30(10)^6 \text{ PSI})\left(\frac{0.25}{180}\right)^2$$

$$\sigma_{pi} = 1225 \text{ PSI}$$

BY PLACING MORE LATERAL STRUCTURAL TEES OF A SMALLER SIZE ON THE CWP, SHELL BUCKLING CAN BE ELIMINATED. LET THE SPACING BE FIVE FEET.

$$Z_2 = \frac{a^2}{Rt} = \frac{(60\,in)^2}{(180\,in)(0.25\,in)} = 80$$

$$1 < Z_2 \leq 100;\ \sigma_{pi} = (3.557 + 0.043 Z_2) E \left(\frac{t}{a}\right)^2$$

$$= (3.557 + (0.043)80)\,30(10)^6 \,PSI \left(\frac{0.25}{60}\right)^2 = 3645\ PSI$$

CALCULATE USAGE FACTOR:

$$\left| \frac{\sigma_{x_1} + \sigma_{x_2}}{\sigma_{bi}} + \frac{\sigma_h}{\sigma_{pi}} \right| \leq 1.00$$

$$\left| \frac{6000 - 10{,}370}{14{,}685} + \frac{-1755}{3645} \right| \leq 1.00$$

$$0.78 \leq 1.00$$

LOCAL BUCKLING CHECK:

LONGITUDINAL STIFFENERS:

$$I = I_T + Ad^2 = 59.6\,in^4 + (8.10\,in^2)(6.99\,in)^2 = 455.3\,in^4$$

$$Y = \left(25 \frac{8.10\,in^2}{(1130.97)(0.25)} + 3\right)\left(\frac{60\,in}{23.56\,in}\right)^2 + 6 = 30.10$$

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 9 OF 1?

CLIENT ____ JOB NO. ER-092?

SUBJECT ____

BASED ON ____ DRAWING NO. ____

COMPUTER S. PORTER CHK'D. BY ____ APP'D. BY ____ DATE 27 FEB 197?

$$I > 0.1ht^3\gamma = 0.1(1130.97 \text{ IN})(0.25 \text{ IN})^2(30.10) = 53.19$$

$$455.8 \text{ IN}^4 > 53.19 \text{ IN}^4$$

FOR 0-500 FT: $M_{MAX} = 1.0 \times 10^8$ FT-LBS @ 250 FT.

$$I_{SHELL} = \frac{\pi}{64}\left((30.06 \text{ FT})^4 - (30.00 \text{ FT})^4\right) = 332.38 \text{ FT}^4$$

$$I_T \doteq Ad^2 = (16.8 \text{ IN}^2)\, 2\,(172.61 \text{ IN})^2\, 12\left(\frac{1 \text{ FT}}{12 \text{ IN}}\right)^4 = 579.33 \text{ FT}^4$$

$$I = 911.71 \text{ FT}^4$$

$$\text{CROSS-SECTIONAL AREA} = (30 \text{ FT})(12 \text{ IN/FT})\pi(0.375 \text{ IN}) + 48(16.8 \text{ IN}^2) = 1230.52 \text{ IN}^2$$

$$\text{WEIGHT (@ 250 FT)} = (1230.52 \text{ IN}^2)\left(\frac{1 \text{ FT}}{12 \text{ IN}}\right)^2(250 \text{ FT})(490 \text{ LB/FT}^3) + \left(\frac{250}{15}\right)(31.11 \text{ FT})\pi(20 \text{ LB/FT}) + 4{,}634{,}035 \text{ LBS}$$

$$W = 5{,}713{,}455 \text{ LBS}$$

$$\text{WEIGHT (IN WATER)} = \left(\frac{490-64}{490}\right) 5{,}713{,}455 \text{ LBS} = 4{,}967{,}210 \text{ LBS}$$

CHECK AGAINST ALLOWABLE STRESS LEVELS:

$$\sigma_{x_1} = \frac{P}{A} = \frac{4{,}967{,}210 \text{ LBS}}{1230.52 \text{ IN}^2} = 4035 \text{ PSI}$$

$$\sigma_{x_2} = \frac{Mc}{I} = \frac{(10^8 \text{ FT-LBS})(15 \text{ FT})}{(911.71 \text{ FT}^4)(12 \text{ IN/FT})^2} = 11{,}425 \text{ PSI}$$

$$\sigma_h = -p\left(\frac{r}{t} - 0.4\right) = -2.75 \text{ PSI}\left(\frac{180 \text{ IN}}{0.375 \text{ IN}} - 0.4\right) = -1320 \text{ PSI}$$

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 10 OF 1?

CLIENT ______ JOB NO. EE-092

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY ______ APP'D. BY ______ DATE 27 FEB 19__

$$A = \frac{\sigma_{x_1} - \sigma_{x_2} + \sigma_h}{2} = \frac{4035 - 11,425 - 1320}{2} = -4355 \text{ PSI}$$

$$B = \frac{\sigma_{x_1} + \sigma_{x_2} + \sigma_h}{2} = \frac{4035 + 11,425 + 1320}{2} = 8390 \text{ PSI}$$

$$\sigma_1 = A + B = (-4355) + 8390 = 4035 \text{ PSI}$$

$$\sigma_2 = A - B = (-4355) - 8390 = -6375 \text{ PSI}$$

$$\tau_{M_1} = \frac{\sigma_1 - \sigma_2}{2} \leq 0.4\sigma_y \longrightarrow 5205 \text{ PSI} \leq 14,400 \text{ PSI}$$

$$\tau_{M_2} = \frac{\sigma_1}{2} \leq 0.4\sigma_y \Longrightarrow 2020 \text{ PSI} \leq 14,400 \text{ PSI}$$

$$\tau_{M_3} = \frac{\sigma_2}{2} \leq 0.4\sigma_y \Longrightarrow 3190 \text{ PSI} \leq 14,400 \text{ PSI}$$

CHECK AGAINST INSTABILITIES:

$$Z_2 = \frac{a^2}{Rt} = \frac{(60 \text{ IN})^2}{(180 \text{ IN})(0.375 \text{ IN})} = 5.33$$

$$Z_3 = \frac{b^2}{Rt} = \frac{(23.56 \text{ IN})^2}{(180 \text{ IN})(0.375 \text{ IN})} = 8.22$$

$$Z_3 \leq 10; \quad \sigma_{bi} = 3.6E\left(\frac{t}{b}\right)^2 = (3.6)30(10)^6 \text{PSI}\left(\frac{0.375 \text{ IN}}{23.56 \text{ IN}}\right)^2 = 27,355 \text{ PSI}$$

$$1 < Z_2 \leq 100; \quad \sigma_{pi} = (3.557 + 0.043 Z_2)E\left(\frac{t}{a}\right)^2$$

$$= (3.557 + (0.043)5.33)30(10)^6 \text{PSI}\left(\frac{0.375 \text{ IN}}{60 \text{ IN}}\right)^2$$

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 11 OF 1

CLIENT ____ JOB NO. E2-0935

SUBJECT ____

BASED ON ____ DRAWING NO. ____

COMPUTER S. PORTER CHK'D. BY ____ APP'D. BY ____ DATE 27 FEB 19__

CALCULATE USAGE FACTOR:

$$\left| \frac{\sigma_{x_1} + \sigma_{x_2}}{\sigma_{bi}} + \frac{\sigma_h}{\sigma_{Fi}} \right| \le 1.00$$

$$\left| \frac{4035 - 11,425}{27,355} + \frac{-1320}{4435} \right| = 0.57 \le 1.00$$

LOCAL BUCKLING CHECK:

LONGITUDINAL STIFFENERS:

$$I = I_T + Ad^2 = 103 \text{ IN}^4 + (16.5 \text{ IN}^2)(7.45 \text{ IN})^2 = 1034.9 \text{ IN}^4$$

$$\gamma = \left(25 \frac{16.5}{(1130.97)(0.375)} + 3\right)\left(\frac{60 \text{ IN}}{23.56 \text{ IN}}\right)^2 + 6 = 31.88$$

$$I > 0.1 h t^3 \gamma = 0.1(1130.97 \text{ IN})(0.375 \text{ IN})^3(31.88) = 190.1 \text{ IN}^4$$

$$1034.9 \text{ IN}^4 > 190.1 \text{ IN}^4$$

LATERAL STIFFENERS:

$$I > \left(\frac{\sigma_{Fi}}{E}\right)\frac{t a R^2}{3} = \left(\frac{4435 \text{ PSI}}{30(10)^6 \text{ PSI}}\right)\frac{(0.375 \text{ IN})(60 \text{ IN})(180 \text{ IN})^2}{3}$$

$$I > 35.92 \text{ IN}^4$$

$$I = I_T + Ad^2 = 44.9 \text{ IN}^4 + (5.83 \text{ IN})(6.75 \text{ IN})^2 = 313.1 \text{ IN}^4$$

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 12 OF 1

CLIENT ______ JOB NO. EE-042

SUBJECT ______

BASED ON ______ DRAWING NO. ______

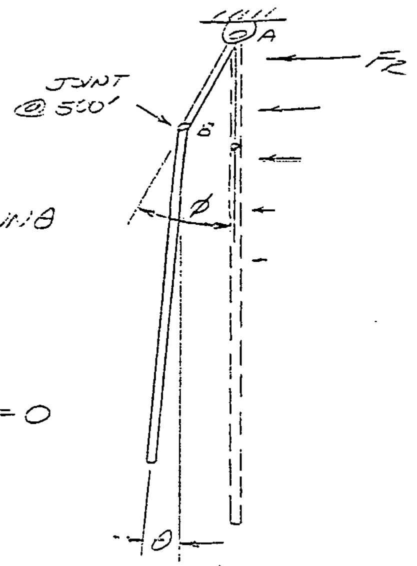
COMPUTER S. PORTER CHK'D. BY ______ APP'D. BY ______ DATE 27 FEB 19

COMPUTE THE MAXIMUM BENDING MOMENTS ASSUMING THE CWP IS PINNED AT THE TOP AND ALLOWED TO SWING FREE AT THE BOTTOM. THE RESULTANT FORCE, F_R, IS CALCULATED FROM THE WAVE AND CURRENT FORCES ACTING ON THE CWP AT BRAZIL DURING EXTREME 100-YEAR STORM CONDITIONS. BREAKING THE CWP INTO 200-FT. SECTIONS:

	SECTION	F_W WEIGHT	F_B BUOYANCY	F_N NET FORCE	F_R RESULTANT
1	0 - 200 FT	863,500 LBS	112,785 LBS	750,715 LBS	927,420 LBS
2	200 - 400 FT	863,500 LBS	112,785 LBS	750,715 LBS	507,740 LBS
3	400 - 500 FT JOINT	431,750 LBS	56,390 LBS	375,360 LBS	154,165 LBS
4	500 - 600 FT	241,545 LBS	31,550 LBS	209,995 LBS	113,080 LBS
5	600 - 800 FT	483,085 LBS	63,095 LBS	419,990 LBS	150,950 LBS
6	800 - 1000 FT	483,085 LBS	63,095 LBS	419,990 LBS	85,635 LBS
7	1000 - 1200 FT	483,085 LBS	63,095 LBS	419,990 LBS	37,835 LBS
8	1200 - 1400 FT	483,085 LBS	63,095 LBS	419,990 LBS	17,395 LBS
9	1400 - 1600 FT	389,455 LBS	50,870 LBS	338,585 LBS	15,645 LBS
10	1600 - 1800 FT	295,820 LBS	38,640 LBS	257,180 LBS	13,955 LBS
11	1800 - 2000 FT	295,820 LBS	38,640 LBS	257,180 LBS	12,165 LBS
12	2000 - 2200 FT	295,820 LBS	38,640 LBS	257,180 LBS	10,290 LBS
13	2200 - 2400 FT	295,820 LBS	38,640 LBS	257,180 LBS	8535 LBS
14	2400 - 2600 FT	295,820 LBS	38,640 LBS	257,180 LBS	6795 LBS
15	2600 - 2800 FT	295,820 LBS	38,640 LBS	257,180 LBS	5005 LBS
16	2800 - 3000 FT	295,820 LBS	38,640 LBS	257,180 LBS	3215 LBS
	TOTAL	6,792,830 LBS	887,240 LBS	5,905,590 LBS	

TO FIND THE ANGLE WHERE THE CWP IS IN EQUILIBRIUM FIRST LOOK AT THE LOWEST 2500 FEET.

FOR 500 - 3000 FT: $\sum M_B = 0$



$$F_{R_4}(50)\cos\theta + F_{R_5}(200)\cos\theta + F_{R_6}(400)\cos\theta$$

$$+ \ldots + F_{R_{16}}(2400)\cos\theta - F_{N_4}(50)\sin\theta - F_{N_5}(200)\sin\theta$$

$$- \ldots - F_{N_{16}}(2400)\sin\theta = 0$$

$$(2.2037 \times 10^8)\cos\theta - (4.4295 \times 10^9)\sin\theta = 0$$

$$\theta = 2.848°$$

FOR 0-500 FT: $\sum M_A = 0$

$$F_{R_1}(100)\cos\phi + F_{R_2}(300)\cos\phi + F_{R_3}(450)\cos\phi - F_{N_1}(100)\sin\phi$$

$$- F_{N_2}(300)\sin\phi - F_{N_3}(450)\sin\phi - \sum_{i=4}^{16} F_{N_i}(500)\cos\theta\sin\phi = 0$$

$$(3.144 \times 10^8)\cos\phi - (2.481 \times 10^9)\sin\phi = 0$$

$$\phi = 7.223°$$

TO CALCULATE MOMENTS ON THE CWP:

FOR 0-500 FT: $F_R' = F_R - F_N \sin\phi$

FOR 500-3000 FT: $F_R' = F_R - F_N \sin\theta$

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 14 OF

CLIENT

JOB NO. E2-092

SUBJECT

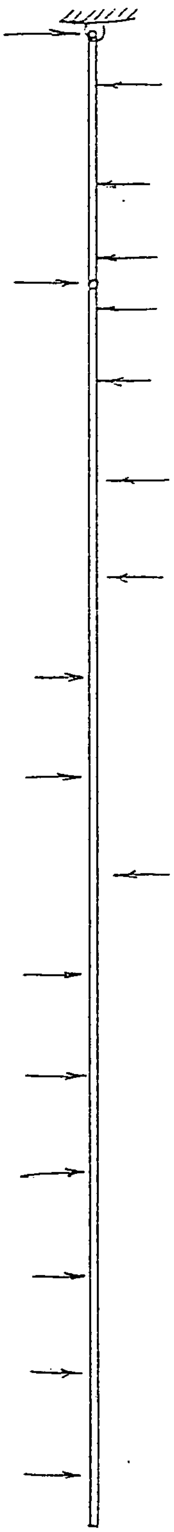
BASED ON

DRAWING NO.

COMPUTER S. PORTER CHK'D. BY D. F. APP'D. BY

DATE 27 FEB 19

MOMENT ANALYSIS:



	$F_?'$ (LBS)	M)+ (FT-LBS)
0	−1,073,000	0
100	+833,030	1.073 X 10⁸
300	+413,350	4.002 X 10⁷
450	+106,970	1.402 X 10⁷
500	−250,350	0
550	+102,645	1.402 X 10⁷
700	+130,080	4.067 X 10⁷
900	+64,765	5.020 X 10⁷
1100	+16,965	4.677 X 10⁷
1300	−3475	3.995 X 10⁷
1500	−1180	3.382 X 10⁷
1700	+1175	2.793 X 10⁷
1900	−615	2.131 X 10⁷
2100	−2490	1.555 X 10⁷
2300	−4195	1.005 X 10⁷
2500	−5935	5.331 X 10⁶
2700	−7775	1.913 X 10⁶
2900	−9565	0
3000		0

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 15 OF

CLIENT ______ JOB NO. FZ-09

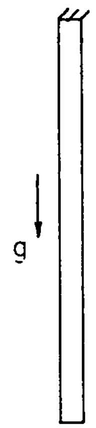
SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY ______ APP'D. BY ______ DATE 28 FEB 19

AS CAN BE SEEN ON THE PREVIOUS PAGE, THE MOMENTS CALCULATED WERE MOST NEARLY THE SAME AS THE MOMENTS ASSUMED. UNTIL A DYNAMIC ANALYSIS IS COMPLETED, THIS STATIC ANALYSIS GIVES ACCEPTABLE PRELIMINARY RESULTS.

Problem 1 - STATIC



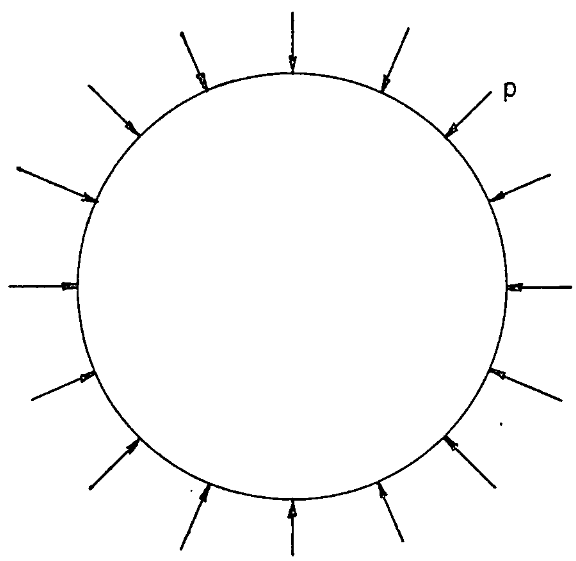
NOMINAL AXIAL STRESS AT TOP DUE TO WEIGHT OF CWP

= (BOUYANT WEIGHT)/(CROSS SECTIONAL AREA)

$= (\gamma_x - \gamma_w) L$

γ_s = Weight Density of Pipe
γ_w = Weight Density of Salt Water

Problem 2.

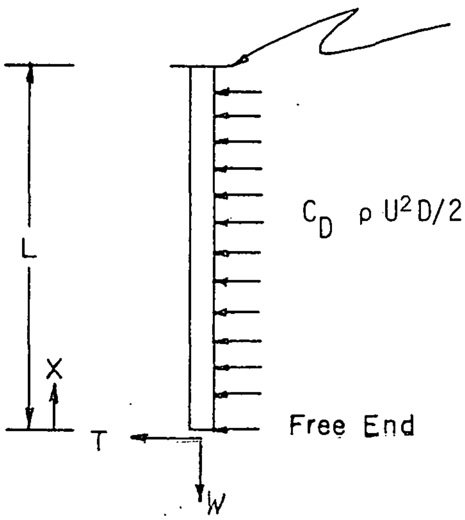


Buckling Pressure For Thin Walled Cylinder

$= 2.1978\ E\ t^3/D^3$

E = Young's Modulus
t = Thickness
D = Diameter

Problem 3.



C_D = Drag Coefficient

ρ = Mass Density of Water

U = Magnitude of Uniform, Deep Sea Current

D = Diameter of Pipe

T = Horizontal Force at Lower End

W = Vertical Force at Lower End

= WFRAC*(Pipe Weight)

Governing Equation

$$EI \; \theta'' - W\,\theta = 1/2 \quad C_D \; \rho \; U^2 \; D \; X + T$$

θ = slope (dy/dx)

EI = pipe bending stiffness

For Simply Supported Case:

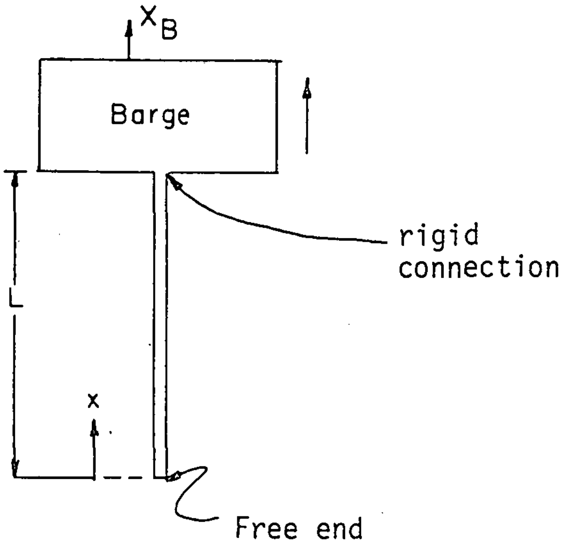
MAXIMUM BENDING STRESS = BENDING STRESS AT L/2 = E D θ'(L/2) /2.

E = Young's modulus

For Built In Case:

MAXIMUM BENDING STRESS = BENDING STRESS AT BARGE = E D θ'(L)/2.

Program 2 - HEAVE



$$(H_o \cos \omega t - X_B)\ A_B\ \gamma_w + (-H_o \omega \sin \omega t - X_B)\ \ C_B$$

$H_o \cos \omega t$ = wave height

$X_B = X_B(t)$ = heave position of barge

C_B = damping from the sea on the barge

$A_B\ \ \gamma_w$ = (area of barge at waterline) * (weight density of sea water)

Governing Equations

$$\left.\begin{aligned} &\rho_p\, U + C_p\ \dot{u} - E\ \ u_{,xx} = 0 \\ &\sigma = E\ \ u_{,x} \end{aligned}\right\}\ \text{for uniform pipe}$$

ρ_p = mass density of pipe material + virtual

C_p = pipe damping = $\dfrac{\sqrt{2}\ (\text{water viscosity})\ (\text{water mass density})\ \ \omega}{(\text{pipe wall thickness})}$

E = Young's modulus

u = vertical displacement of pipe = $u(x,t)$

σ = stress in pipe

$$M_{BV}\ \ddot{X}_B = (H_o \cos \omega t - X_B)\ A_B\ \gamma_w + (-H_o\, \omega\ \ \sin \omega t - \dot{X}_B)\ C_B - \sigma(L)\ A_p$$

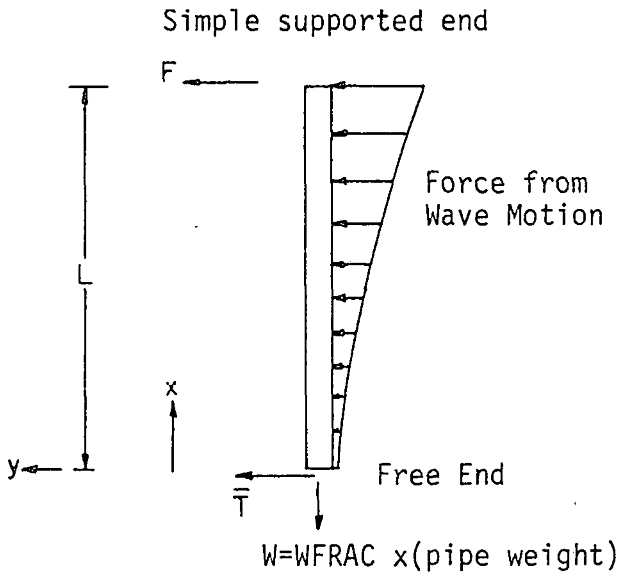
for barge

X_B = XBC cos ωt + XBS sin ωt

M_{BV} = mass of barge + virtual mass of barge

A_p = cross sectional area of CWP

Program 3 - HORIZONTAL, UNARTICULATED



horizontal wave displacement = y_w

$y_w = y_o\, e^{-(2\pi/\lambda)\ (L-x)} * \cos(2\pi t/T)$

$\lambda = (g/2\pi)\ T^2$ = wavelength

T = period

$y(L,t)$ = YC cos$(2\pi t/T)$+YS sin $(2\pi t/T)$

$\bar{T} = \bar{T}C \cos(2\pi t/T) + \bar{T}S \sin(2\pi t/T)$

F = FTOP cos$(wt + \rho)$

damping force on pipe from X to X+dx = $(4/\beta\pi))\ C_D\, \bar{\rho}\, D\, dx\, V\, (\dot{y}_w - \dot{y})$

C_d = drag coefficient

$\bar{\rho}$ = water mass density

D = pipe diameter

V = maximum relative velocity $(y_w - y)$ during oscillation

Governing Equations

$$EI\ y'''' - W\ y'' + (4./(3.\pi))\ C_D\ \bar{\rho}\ D\ V\ (\dot{y}-\dot{y}_w) + \rho\ddot{y} = 0$$

$$F = -EI\ y'''(L,t)$$

$$\sigma = (E\ D/2)\ y''(x,t)$$

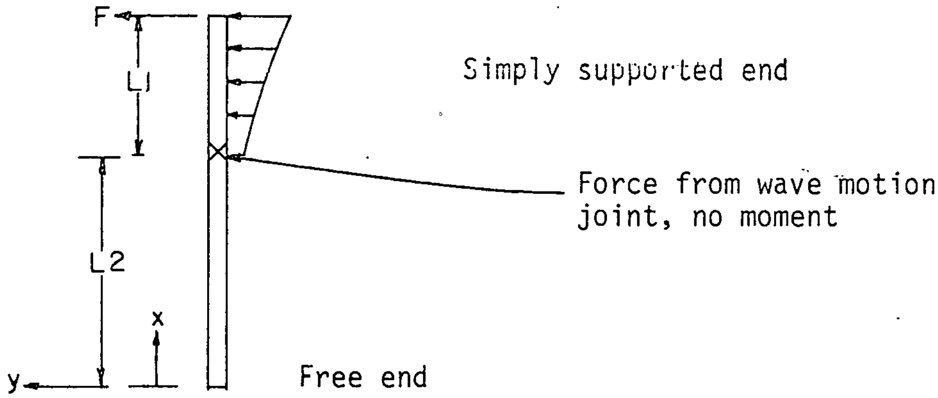
EI = bending stiffness

ρ = mass per unit length of pipe including virtual and untrained mass

σ = bending stress

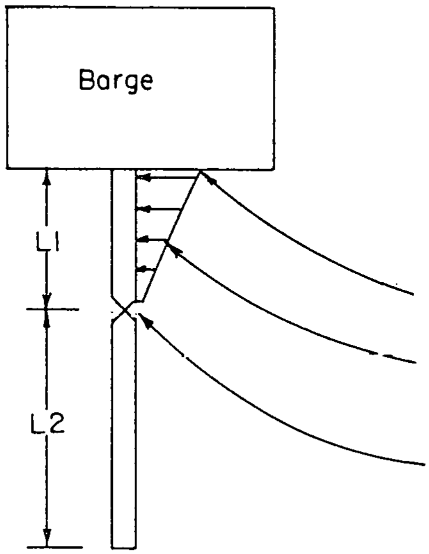
E D = (Young's modulus) x (diameter)

Program 4 - HORIZONTAL, ARTICULATED



This program was the same equation as the Horizontal, Unarticulated pipe. The two sections are attached using the conditions that the forces and displacements match at the joint. The motion at the top is prescribed and the resulting values of F and the stresses in the pipe are determined.

Program 5 - HORIZONTAL, BARGE, ARTICULATED



Barge can roll and sway

Waves apply horizontal forces and rolling moments to barge

Equations developed for the Horizontal, Articulated program are used to represent the CWP

Free end

Equations of motion for barge:

$$-\omega^2 M_{\eta\eta}\,\eta_r - w\,N_{\eta\eta}\,\eta_i - \omega^2 M_{\Psi\eta}\,\psi_r - \omega\,N_{\Psi\eta}\,\Psi_i = (F_{\eta r} + FTC)\,a$$

$$+\omega\,N_{\eta\eta}\,\eta_r - \omega^2 M_{\eta\eta}\,\eta_i + \omega\,N_{\Psi\eta}\,\Psi_r - \omega^2 M_{\Psi\eta}\,\Psi_i = (F_{\eta i} + FTS)\,a$$

$$-\omega^2 M_{\Psi\eta}\,\eta_r - \omega\,N_{\Psi\eta}\,\eta_i + (-\omega^2 M_{\Psi\Psi} + B_{\Psi\Psi})\,\Psi_r - \omega\,N_{\Psi\Psi}\,\Psi_i = (F_{\Psi r} + \ell_H\,FTC)\,a$$

$$+\omega\,N_{\Psi\eta}\,\eta_r - \omega^2 M_{\Psi\eta}\,\eta_i + \omega\,N_{\Psi\Psi}\,\Psi_r + (-\omega^2 M_{\Psi\Psi} + B_{\Psi\Psi})\,\Psi_i = (F_{\Psi i} + \ell_H\,FTS)\,a$$

Where FTC and FTS are forces at the top of the articulated pipe. FTC and FTS are deduced by matching the displacement of the barge and pipe at their attachment point.

Compatibility conditions:

$YTC = \eta_r + \ell_H \quad \Psi_r$

$YTS = \eta_i + \ell_H \quad \Psi_i$

In the above equations

ℓ_H = vertical distance from barge center of mass to barge-CWP attachment

ω = circular frequency of wave

η_r = component of sway in phase with the wave

η_i = component of sway out of phase with the wave

Ψ_r = component of roll in phase with the wave

Ψ_i = component of roll out of phase with the wave

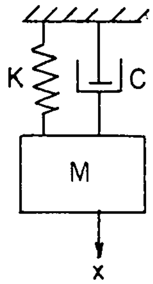
a = wave amplitude (wave height = a cos wt)

$M_{\eta\eta}$, $M_{\Psi\eta}$, $M_{\Psi\Psi}$, $N_{\eta\eta}$, $N_{\eta\Psi}$, $N_{\Psi\Psi}$, $B_{\Psi\Psi}$, $F_{\eta r}$, $F_{\eta i}$, $F_{\Psi r}$, $F_{\Psi i}$ can be determined from, for example, "Hydrodynamic Characteristics of Prismatic Barges" by C. H. Kim, C. J. Henry and F. Chou, OTC Paper No. 1417, copyright 1971.

CWP DAMPING - HORIZONTAL MOTION

To develop the appropriate damping in theory, the following study was needed.

1. Review



if $X = a \cos \omega t$

$\dot{X} = -\omega \; a \;\; \sin \omega t$

$C_c = 2 \sqrt{K M}$

$PE_{max} = \frac{1}{2} \cdot K a^2$

$KE_{max} = \frac{1}{2} M \omega^2 a^2$

$$DE/cyc = \int_{cyc} (\text{damping force})\, dx = \int_{cyc} (C\text{-}\dot{X})\,(\dot{X}\, dt) = C \int \dot{X}^2\, dt$$

$$= C\,\omega^2 a^2 \int_{\omega t=0}^{2\pi} \sin^2 \omega t \, dt = C\,\omega^2 a^2 \left[\frac{t}{2} - \frac{\sin 2\,\omega t}{2\omega} \right]_{t=0}^{2\pi/\omega}$$

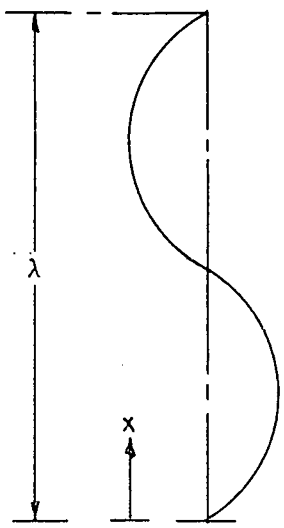
$$= \pi\, C\, \omega\, a^2$$

$$\sqrt{PE_{max} \cdot KE_{max}} = \frac{1}{2}\, \omega\, a^2 \sqrt{K M}$$

$$(DE/cyc) \,/\, \sqrt{PE_{max}\, KE_{max}} = 2\, \pi\, C / \sqrt{K M} = 4\, \pi\, C/C_c$$

$$C/C_c = (1/4\pi) \left[(DE/cyc) \,/\, \sqrt{PE_{max}\, KE_{max}} \right] \quad (1$$

2. Application to CWP, assuming CWP is a beam



y = lateral deflection of CWP

$= Y \sin 2\pi x/\lambda \ \cos \omega t = y_o(x) \ \cos \omega t$

$y_o'' = -Y\ (2\pi/\lambda)^2 \sin 2\pi x/\lambda$

$(y_o'')^2 = Y^2\ (2\pi/\lambda)^4 \sin^2 2\pi x/\lambda$

$\dot{y} = -\omega\ y_o(x) \quad \sin wt$

$\omega^2\ y_o^2 = \omega^2\ Y^2 \ \sin^2 2\pi x/\lambda$

EI = bending stiffness,

ρ = mass per unit length

$$PE_{max} = \int_{x=0}^{\lambda} \frac{1}{2} EI\,(y_o'')^2\,dx = \frac{1}{2} EI\ Y^2\ (2\pi/\lambda)^4 \int_{x=0}^{\lambda} \sin^2(2\pi x/\lambda)\,dx$$

$$= \frac{1}{2} \quad EI\ Y^2\ (2\pi/\lambda)^4 \left[x/2 - \sin(4\pi x/\lambda)\ /\ (4\pi/\lambda) \right]_{x=0}^{\lambda}$$

$$= \frac{\pi}{2} \quad EI \quad Y^2 \quad (2\pi/\lambda)^3$$

$$KE_{max} = \int_{x=0}^{\lambda} \frac{1}{2}\ \rho\ \omega^2\ y_o^2\ dx = \frac{1}{2}\ \rho\ \omega^2\ Y^2 \int_{x=0}^{\lambda} \sin^2\ (2\pi x/\lambda)\ dx$$

$$= \frac{\pi}{2} \quad \rho\ \omega^2\ Y^2 \quad (\lambda/2\pi)$$

$$DE/cyc = \int_{x=0}^{\lambda}\int_{t=0}^{2\pi/\omega} \bar{C}\,\dot{y}\,\dot{y}\,dt\,dx' = \bar{C}\,\omega^2\,Y^2 \int_{x=0}^{\lambda}\int_{t=0}^{2\pi/\omega} \sin^2(2\pi x/\lambda)\,\sin^2(\omega t)\,dt\,dx$$

$$= \bar{C}\,\omega^2\,Y^2\,\frac{\lambda}{2}\,\frac{\pi}{\omega} = \pi^2\,\bar{C}\,\omega\,Y^2\,(\lambda/2\pi)$$

$$C/C_c = \left[1/(4\pi)\right]\,\pi^2\,\bar{C}\,\omega\,Y^2\,(\lambda/2\pi)\,/\sqrt{\frac{\pi}{2}\,EI\,Y^2\,(2\pi/\lambda)^3\,\frac{\pi}{2}\,\rho\,\omega^2\,Y^2\,(\lambda/2\pi)}$$

$$= \bar{C}\,(\lambda/2\pi)^2\,/\,(2\,\sqrt{EI\,\rho}\,) \qquad (2$$

3. Estimate of Damping

F_a = classical drag force on dx length of pipe

$$= \frac{1}{2}\,C_D\,\bar{\rho}\,D\,dx\,|\dot{X}\,|-\dot{X}$$

E_a = energy dissipated per cycle in harmonic motion $= \int_{cyc} F_a \quad dx$

$$= \frac{1}{2}\,C_D\,\rho\,D\,dx \int_{cyc} |\dot{X}\,|\;\;\dot{X}^2\;\;dt, \qquad \dot{X} = -V\sin\omega t \qquad V = \text{constant} \geq 0$$

$$= C_D\,\bar{\rho}\,D\,dx/\omega \int_{\omega t=0}^{\pi} V^3\;\sin^3(\omega t)\;d(wt)$$

$$= (V^3\,C_D\,\bar{\rho}\,D\,dx/\omega)\,\left[-\cos(\omega t) + \frac{1}{3}\,\cos^3(\omega t)\right]_{\omega t=0}^{\pi}$$

$$= \frac{4}{3}\,C_D\,\bar{\rho}\,D\,dx\,V^3/\omega$$

F_s = linear drag force on dx length of pipe = $\bar{C}\,\dot{X}\,dx$

E_s = energy dissipated per cycle in harmonic motion/linear case $= \int_{cyc} F_s\, dx$

$$= \bar{C}\, dx \int_{cyc} \dot{X}^2\, dt \quad , \quad \dot{x} = -V \sin \omega t \quad , \qquad V = \text{constant} \geq 0$$

$$= (\bar{C}\, dx\, V^2/\omega) \int_{\omega t=0}^{2\pi} \sin^2(\omega t)\, d(\omega t) \quad = \quad \pi\, \bar{C}\, dx\, V^2/\omega$$

In order to have a valid approximation when the linear damping is used in analytical studies the two energies E_a and E_s are equated to give

$$\pi \bar{C}\, dx\, V^2/\omega = \frac{4}{3}\; C_D\, \bar{\rho}\, D\, dx\, V^3/\omega$$

$$\bar{C} = \frac{4}{3\pi}\; C_D\, \bar{\rho}\, D\, V \qquad (3$$

so that $\bar{C}$ is proportional to the velocity amplitude and

$$F_s = \frac{4}{3\pi}\; C_D\, \bar{\rho}\, D\, V\, X$$

When these results are introduced into equation 3 ,

$$C/C_c = 2\, C_D\, \bar{\rho}\, D\, V\, (\lambda/2\pi)^2 \;\; / \;\; (3\pi\sqrt{EI\, \rho}\,)$$

Replace V using

$$V = Y0 \quad \omega = \quad Y0 \quad 2\pi/T$$

YO is the displacement amplitude, T is the period and

$$C/C_c = C_D \bar{\rho} D \, YO \, \lambda^2/(3 \pi^2 T \sqrt{EI \rho}) \qquad (4$$

C_D = drag coefficient

$\bar{\rho}$ = mass density of water

D = pipe diameter

λ = wavelength along CWP

T = period

EI = pipe bending stiffness

4. Numerical example

C_D = 1.0

$\bar{\rho}$ = 2.0 $\text{lb-sec}^2\text{ft}^4$

D = 30.00 ft.

YO = 20.0 ft.

λ = 1000. ft. (from HORIZ 2 output for T = 12.8 sec.

T = 12.8 sec.

$EI = (30 \cdot 10^6 \cdot 144) \cdot (\pi \cdot 30^3 \cdot (1.5/12)/8.) = 5.73 \; 10^{12} \; \text{lb-ft}^2$

$\rho = (\pi \cdot 30 \cdot 12 \; 1.5 \; 0.3) \; 12/32.2 + 2. \; (\pi \cdot 30^2/4) \cdot 2$

$= 190. + 2827. = 3017. \; \text{lb-sec}^2/\text{ft}^2$

$$C/C_c = 1.0 \cdot 2.0 \cdot 30.0 \cdot 20 \cdot 1000.^2/(3. \cdot \pi^2 \cdot 12.8 \cdot \sqrt{5.73 \; 10^{12} \; 3017.})$$

= 0.0241

$$\text{amplification factor at resonance} \cong \frac{1}{2.(0.0241)} = 20.76$$

Steel CWP Performance Analysis

Brown & Root utilized the programs prepared by Mr. Paslay to determine performance of both steel conceptual designs. The scalloped and the longitudinal and ring stiffened (shell and tee) CWP designs were evaluated by varying several different parameters and analyzing the results of each run. The following runs and output were obtained:

STATIC Program - Both design concepts were analyzed for interface bending stresses with the variables; CWP Length = 2435 Ft., CWP Diameter = 30 Ft., Pipe thickness (scalloped) = .8244 in. and Pipe thickness (shell and tee)= .5528 in.

HEAVE Program - The design parameters used in the static runs were applied in the dynamic heave analysis utilizing values of T_W = .72 in. (scalloped) and T_W = 7.2 in. (shell and tee) for the thickness of the water virtual mass layer. Periods of 1 through 18 seconds were input for each design case.

For the scalloped design, additional runs for a period of 5 seconds with varying T_W (1.5 and 3.0) were made. The results from this analysis were plotted and are shown in Figure 50.

HORIZ1 Program - Both design concepts (unarticulated) were analyzed for CWP deflection, stresses, and forces with a pipe thickness of 1.1132 inches (scalloped) and .7368 inches (shell and tee). The wave periods applied in the analysis were 7, 12.8, and 18 seconds.

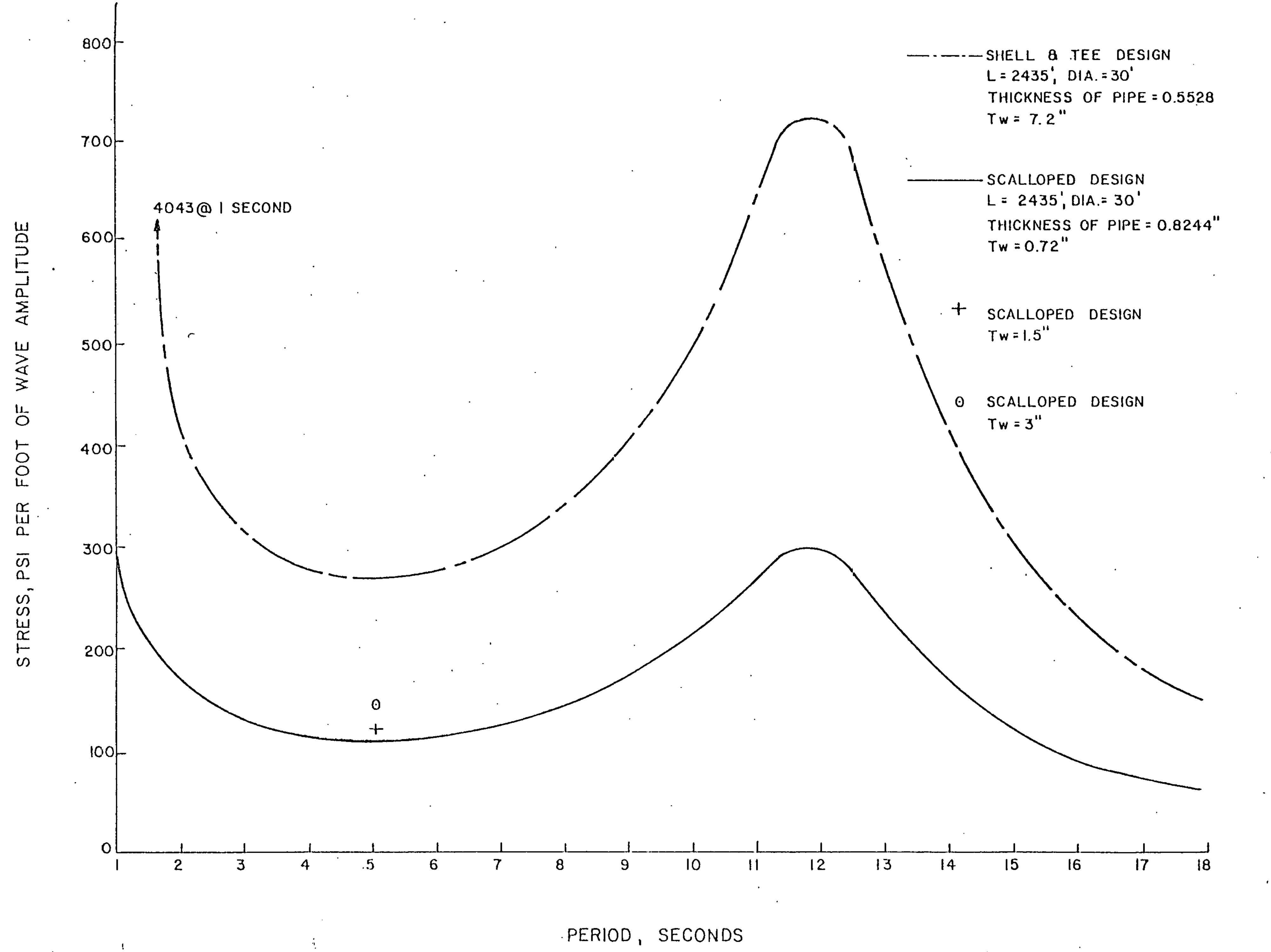
HORIZ2 Program - The two designs incorporating a joint at a distance X down from the OTEC hull/CWP interface were analyzed for different periods (7, 12.8, 18 seconds) and barge connection amplitudes. The distance x varied from 400 feet to 550 feet (in 50 feet increments) for the articulated joint placement.

The wave period was varied from 5 to 18 seconds for the 450 feet and 550 feet articulated shell and tee design for an in phase barge connection. Maximum stress in the upper CWP section, maximum CWP stress (along the entire length), and the amplification factor (Hinge/ Interface) are shown for each period in Figures 51 and 52.

Conclusions - From the results obtained, stresses appear to be significant in the upper portion of the CWP in the 450 feet articulated shell and tee during wave periods of around 12 seconds. The results of the shell and tee articulated at 550 feet indicate that the stress level in the CWP may be acceptable.

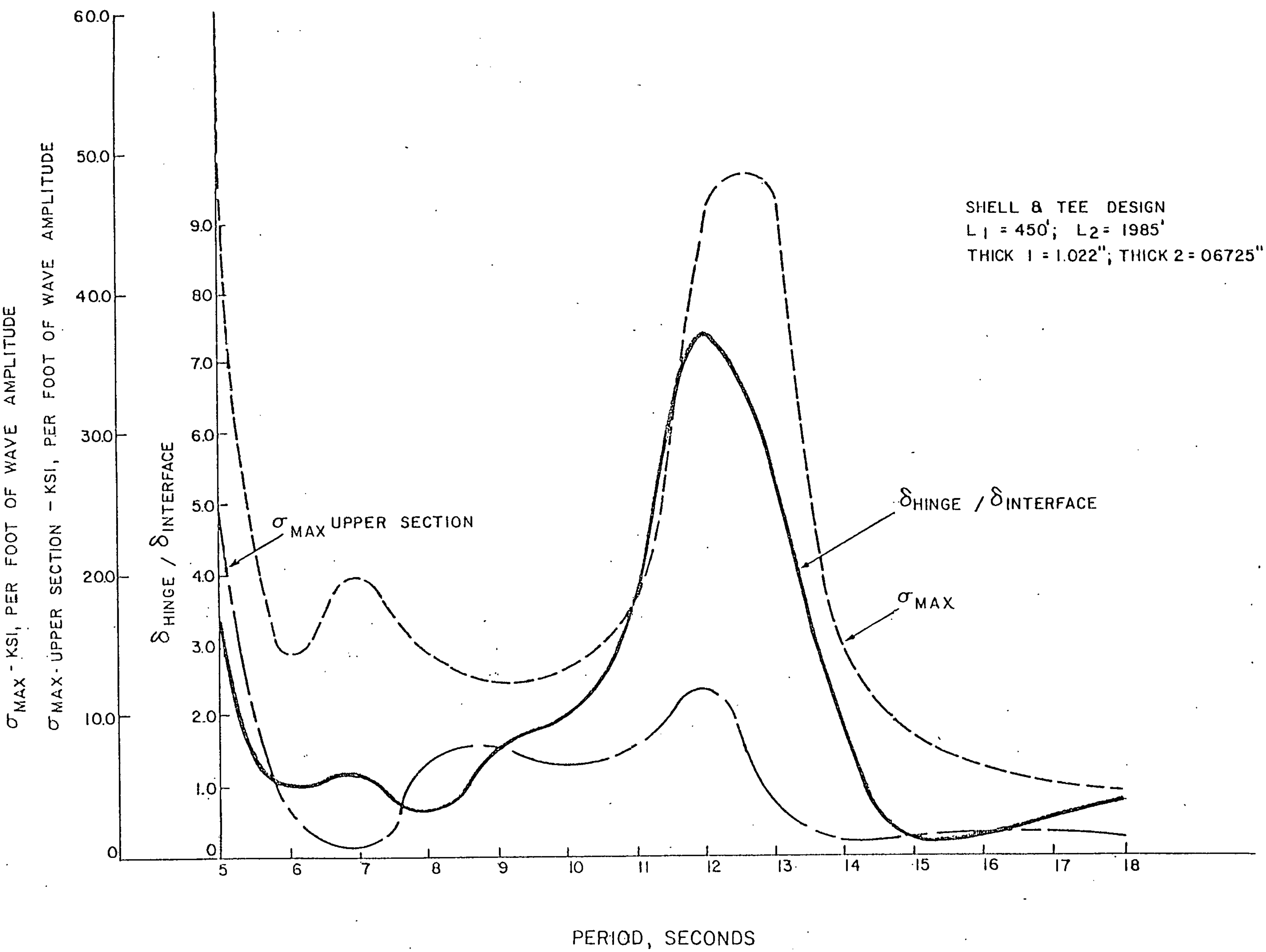
The response of the CWP in heave reveals high stresses for each unarticulated design during wave periods of around 12 seconds. The result thus far in the performance analysis of the steel CWP's indicate articulation is necessary and further joints (hinges) may be required.

FIGURE E.1



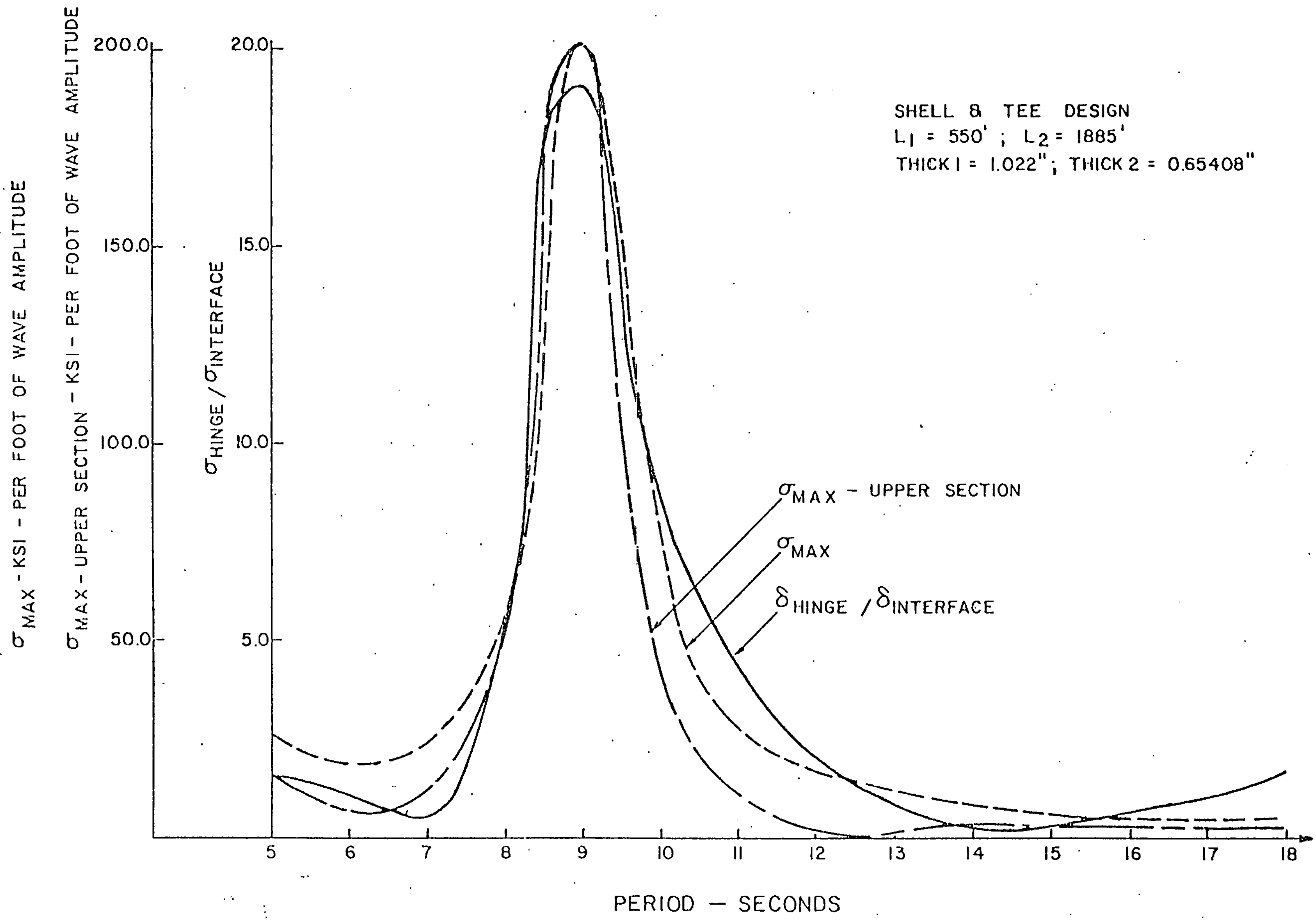
SHELL & TEE DESIGN
L = 2435', DIA. = 30'
THICKNESS OF PIPE = 0.5528
Tw = 7.2"
SCALLOPED DESIGN
L = 2435', DIA. = 30'
THICKNESS OF PIPE = 0.8244"
Tw = 0.72"
+ SCALLOPED DESIGN
Tw = 1.5"
0 SCALLOPED DESIGN
Tw = 3"
4043@ 1 SECOND
STRESS, PSI PER FOOT OF WAVE AMPLITUDE
PERIOD, SECONDS
0
100
200
300
400
500
600
700
800
1
2
3
4
.5
6
7
8
9
10
11
12
13
14
15
16
17
18

FIGURE E.2



SHELL & TEE DESIGN
L_1 = 450'; L_2 = 1985'
THICK 1 = 1.022"; THICK 2 = 06725"
σ_{MAX} UPPER SECTION
$\delta_{HINGE} / \delta_{INTERFACE}$
σ_{MAX}
σ_{MAX} - KSI, PER FOOT OF WAVE AMPLITUDE
σ_{MAX} - UPPER SECTION - KSI, PER FOOT OF WAVE AMPLITUDE
$\delta_{HINGE} / \delta_{INTERFACE}$
60.0
50.0
40.0
30.0
20.0
10.0
0
9.0
80
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
5
6
7
8
9
10
11
12
13
14
15
16
17
18
PERIOD, SECONDS

FIGURE E.3



SHELL & TEE DESIGN
L_1 = 550' ; L_2 = 1885'
THICK 1 = 1.022"; THICK 2 = 0.65408"
σ_{MAX} - KSI - PER FOOT OF WAVE AMPLITUDE
σ_{MAX} - UPPER SECTION - KSI - PER FOOT OF WAVE AMPLITUDE
$\sigma_{HINGE} / \sigma_{INTERFACE}$
200.0
150.0
100.0
50.0
20.0
15.0
10.0
5.0
σ_{MAX} - UPPER SECTION
σ_{MAX}
$\delta_{HINGE} / \delta_{INTERFACE}$
5
6
7
8
9
10
11
12
13
14
15
16
17
18
PERIOD — SECONDS

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 1 OF

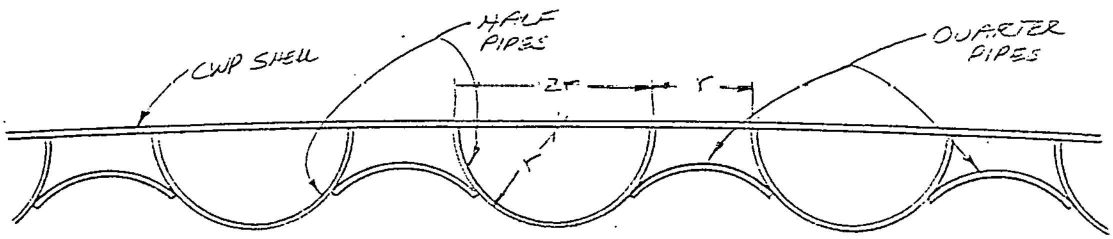
CLIENT DEPARTMENT OF ENERGY JOB NO. EE-092

SUBJECT SCALLOPED STEEL CWP CONCEPT

BASED ON EXTREME STORM CONDITIONS – BRAZIL DRAWING NO.

COMPUTER S. PORTER CHK'D. BY APP'D. BY DATE 21 JAN 19

THIS IS A ROUGH ANALYSIS OF A SCALLOPED CWP USING ONE-QUARTER AND ONE-HALF PIPES IN A TYPICAL CONFIGURATION SHOWN BELOW:



THE NUMBER AND SIZE OF THE PIPES [illegible] MUST BE OF A SIZE TO PROVIDE STRENGTH AGAINST BENDING AND BUCKLING. MANY DIFFERENT SIZES WERE STUDIED AND IT WAS DISCOVERED THAT A 28"Ø PIPE IS SUFFICIENT DIAMETER PREVENT SHELL BUCKLING.

$$\text{NUMBER OF PIPES} = n = \frac{(30 + 2r)\pi}{2r + r} = \frac{\left[30 + 2\left(\frac{14}{12}\right)\right]\pi}{3\left(\frac{14}{12}\right)}$$

$$n = 29.02 \text{ PIPES} \Longrightarrow \text{LET } n = 29$$

$$\text{SHELL DIAMETER} = D = \frac{(2r + r)n}{\pi} = \frac{3\left(\frac{14}{12}\right)29}{\pi} = 32.31 \text{ FT}$$

USE API 5LX, GRADE X-60 STEEL PIPE AND ASTM A242, GRADE 960-X STEEL PLATE TO BUILD THIS CWP. BOTH MATERIALS HAVE A YIELD OF 60,000 PSI.

ASSUME BENDING MOMENTS THE CWP MUST RESIST.

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 3 OF 1

CLIENT ______ JOB NO. EZ-0925

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY ______ APP'D. BY ______ DATE 22 JAN 197

$$\text{TOTAL WEIGHT} = (702.41\ \text{IN}^2)\left(\frac{1\ \text{FT}}{12\ \text{IN}}\right)^2(1000\ \text{FT})(490\ \text{LB/FT}^3)$$

$$W = 2,390,150\ \text{LBS}$$

BUOYANCY OF THE STEEL ELIMINATES SOME OF THE AXIAL LOAD:

$$P = \left(\frac{490-64}{490}\right)W = 2,077,970\ \text{LBS}$$

CHECK AGAINST ALLOWABLE STRESS LEVELS:

$$\sigma_{x_1} = \frac{P}{A} = \frac{2,077,970\ \text{LBS}}{702.41\ \text{IN}^2} = 2960\ \text{PSI}$$

$$\sigma_{x_2} = \frac{Mc}{I} = \frac{(0.5 \times 10^8\ \text{FT-LBS})\left(\frac{32.31\ \text{FT}}{2}\right)}{(604.14\ \text{FT}^4)(12\ \text{IN/FT})^2} = 9285\ \text{PSI}$$

TO CALCULATE HOOP STRESS, ASSUME AN EXTERNAL PRESSURE OF 10 PSI FOR 0-1000 FT, 7 PSI FOR 1000-2000 FT, AND 4 PSI FOR 2000-3000 FT.

$$\sigma_h = p\left(\frac{r}{t} - 0.4\right) = -4\ \text{PSI}\left(\frac{(16.15\ \text{FT})(12\ \text{IN/FT})}{0.1875\ \text{IN}} - 0.4\right) = -4135\ \text{PSI}$$

CALCULATE PRINCIPAL STRESSES:

$$A = \frac{\sigma_{x_1} - \sigma_{x_2} + \sigma_h}{2} = \frac{2960 - 9285 - 4135}{2} = -5230\ \text{PSI}$$

$$B = \frac{\sigma_{x_1} + \sigma_{x_2} - \sigma_h}{2} = \frac{2960 + 9285 + 4135}{2} = 8190\ \text{PSI}$$

$\sigma_1 = A + B = (-5230) + 8190 = 2960$ PSI

$\sigma_2 = A - B = (-5230) - 8190 = -13,420$ PSI

CALCULATE MOHR SHEAR STRESS:

$$\tau_{M_1} = \frac{\sigma_1 - \sigma_2}{2} \leq 0.40\,\sigma_y \Rightarrow 8190 \text{ PSI} \leq 24{,}000 \text{ PSI}$$

$$\tau_{M_2} = \frac{\sigma_1}{2} \leq 0.4\,\sigma_y \Rightarrow 1480 \text{ PSI} \leq 24{,}000 \text{ PSI}$$

$$\tau_{M_3} = \frac{\sigma_2}{2} \leq 0.4\,\sigma_y \Rightarrow 6710 \text{ PSI} \leq 24{,}000 \text{ PSI}$$

CHECK AGAINST INSTABILITIES:

$Z_3 = \frac{b^2}{Rt}$ WHERE b IS THE DISTANCE BETWEEN LONGITUDINAL STIFFENERS = 28 IN.

$$Z_3 = \frac{(28\text{ IN})^2}{\left(\frac{32.21\text{ FT}}{2}\right)(12\text{ IN/FT})(0.19\text{ IN})} = 21.57$$

FOR BENDING COMPRESSION: (BUCKLING ON THE COMPRESSIVE SIDE)

$$Z_3 > 10; \quad \sigma_{bi} = (0.4 + 0.32\,Z_3)\,E\left(\frac{t}{b}\right)^2$$

$$= \left(0.4 + (0.32)\,21.57\right) 30(10)^6 \text{ PSI} \left(\frac{0.1875\text{ IN}}{28\text{ IN}}\right)^2 = 9525 \text{ PSI}$$

THE USAGE FACTOR TAKES INTO ACCOUNT DIRECT SHEAR AND HOOP BUCKLING, BOTH OF WHICH ARE SMALL IN COMPARISON TO BENDING COMPRESSION. THEREFORE, NEGLECT DIRECT SHEAR AND HOOP BUCKLING IN THIS PART OF THE ANALYSIS.

CLIENT ______ JOB NO. ER-043

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY ______ APP'D. BY ______ DATE 22 JAN 197_

$$\text{USAGE FACTOR} = \eta = \left|\frac{\sigma_{x_2} + \sigma_{x_1}}{\sigma_{bi}}\right| = \left|\frac{-9285 + 2960}{9825}\right| = 0.64$$

WITH A USAGE FACTOR LESS THAN UNITY, INSTABILITY IS NOT A PROBLEM.

<u>FOR 1000-2000 FT</u>: LET THE SHELL THICKNESS BE 3/8-IN. AND THE PIPES REMAIN AT 1/4-IN. THICK.

$$I_{SHELL} = \frac{\pi}{64}\left((32.37\,FT)^4 - (32.31\,FT)^4\right) = 415.07\ FT^4$$

$$I_{TOTAL} = 811.93\ FT^4$$

$$A = (32.13\,FT)(12\,IN/FT)\pi(0.375\,IN) + (29)(0.75)\frac{\pi}{4}\left((28\,IN)^2 - (27.5\,IN)^2\right) = 930.79\ IN^2$$

$$W = (930.79\,IN^2)\left(\frac{1\,FT}{12\,IN}\right)^2(1000\,FT)(490\,LBS/FT^3) + 2{,}390{,}150\ LBS$$

$$W = 5{,}557{,}410\ LBS$$

$$P = \left(\frac{490-64}{490}\right)5{,}557{,}410\ LBS = 4{,}831{,}545\ LBS$$

<u>CHECK AGAINST ALLOWABLE STRESS LEVELS:</u>

$$\sigma_{x_1} = \frac{P}{A} = \frac{4{,}831{,}545\ LBS}{930.79\ IN^2} = 5190\ PSI$$

$$\sigma_{x_2} = \frac{Mc}{I} = \frac{(1.50 \times 10^8\ FT\text{-}LBS)\left(\frac{32.31}{2}\ FT\right)}{(811.93\ FT^4)(12\ IN/FT)^2} = 20{,}725\ PSI$$

$$\sigma_h = P\left(\frac{r}{t} - 0.4\right) = -7.0 \text{ PSI}\left(\frac{(16.15\text{ FT})(12\text{ IN/FT})}{0.375\text{ IN}} - 0.4\right) = -3615 \text{ PSI}$$

CALCULATE PRINCIPAL STRESSES:

$$A = \frac{\sigma_{x_1} - \sigma_{x_2} + \sigma_h}{2} = \frac{5190 - 20,725 - 3615}{2} = -9575 \text{ PSI}$$

$$B = \frac{\sigma_{x_1} + \sigma_{x_2} - \sigma_h}{2} = \frac{5190 + 20,725 + 3615}{2} = 14,765 \text{ PSI}$$

$$\sigma_1 = A + B = (-9575) + 14,765 = 5190 \text{ PSI}$$

$$\sigma_2 = A - B = (-9575) - 14,765 = -24,340 \text{ PSI}$$

CALCULATE MOHR SHEAR STRESSES:

$$\tau_{m_1} = \frac{\sigma_1 - \sigma_2}{2} \le 0.4\,\sigma_y \longrightarrow 14,765 \text{ PSI} \le 24,000 \text{ PSI}$$

$$\tau_{m_2} = \frac{\sigma_1}{2} \le 0.4\,\sigma_y \longrightarrow 2595 \text{ PSI} \le 24,000 \text{ PSI}$$

$$\tau_{m_3} = \frac{\sigma_2}{2} \le 0.4\,\sigma_y \longrightarrow 12,170 \text{ PSI} \le 24,000 \text{ PSI}$$

CHECK AGAINST INSTABILITIES:

$$Z_3 = \frac{b^2}{Rt} = \frac{(28\text{ IN})^2}{(16.15\text{ FT})(12\text{ IN/FT})(0.375\text{ IN})} = 10.78$$

$$Z_3 > 10;\ \sigma_{bi} = (0.4 + 0.32 Z_3)\,E\left(\frac{t}{b}\right)^2$$

$$= (0.4 + (0.32)\,10.78)\,30(10)^6 \text{ PSI}\left(\frac{0.375}{28}\right)^2 = 20,725 \text{ PSI}$$

CALCULATE USAGE FACTOR:

$$n = \left| \frac{\sigma_{x_1} + \sigma_{x_2}}{\sigma_{ai}} \right| = \left| \frac{5190 \text{ PSI} - 20,725}{24,725} \right| = 0.75$$

FOR 0-1000 FT: LET THE SHELL THICKNESS BE 9/16-IN. AND THE PIPES REMAIN AT 1/4-IN. THICK.

$$I_{SHELL} = \frac{\pi}{64}\left((32.40 \text{ FT})^4 - (32.31 \text{ FT})^4\right) = 623.50 \text{ FT}^4$$

$$I_{TOTAL} = 1020.41 \text{ FT}^4$$

$$A - (32.13 \text{ FT})(12 \text{ IN/FT})\pi(0.56 \text{ IN}) + (24)(0.75)\frac{\pi}{4}\left((28 \text{ IN})^2 - (27.5 \text{ IN})^2\right) = 1159.16 \text{ IN}$$

$$W = (1159.16 \text{ IN}^2)\left(\frac{1 \text{ FT}}{12 \text{ IN}}\right)^2 (1000 \text{ FT})(490 \text{ LB/FT}^3) + 5,557,410 \text{ LBS}$$

$$W = 9,501,730 \text{ LBS}$$

$$P = \left(\frac{490-64}{490}\right) 9,501,730 \text{ LBS} = 8,260,730 \text{ LBS}$$

CHECK AGAINST ALLOWABLE STRESS LEVELS:

$$\sigma_{x_1} = \frac{P}{A} = \frac{8,260,730 \text{ LBS}}{1159.16 \text{ IN}^2} = 7125 \text{ PSI}$$

$$\sigma_{x_2} = \frac{Mc}{I} = \frac{(2.5 \times 10^8 \text{ FT-LBS})(16.15 \text{ FT})}{(1020.41 \text{ FT}^4)(12 \text{ IN/FT})^2} = 27,435 \text{ PSI}$$

$$\sigma_h = p\left(\frac{r}{t} - 0.4\right) = -10.0 \text{ PSI}\left(\frac{(16.15 \text{ FT})(12 \text{ IN/FT})}{0.5625 \text{ IN}} - 0.4\right) = -3440 \text{ PSI}$$

CALCULATE PRINCIPAL STRESSES:

$$A = \frac{\sigma_{x_1} - \sigma_{x_2} + \sigma_h}{2} = \frac{7125 - 27,435 - 3440}{2} = -11,900 \text{ PSI}$$

$$B = \frac{\sigma_{x_1} + \sigma_{x_2} - \sigma_h}{2} = \frac{7125 + 27,435 + 3440}{2} = 19,025 \text{ PSI}$$

$$\sigma_1 = A + B = (-11,900) + 19,025 = 7125 \text{ PSI}$$

$$\sigma_2 = A - B = (-11,900) - 19,025 = -30,925 \text{ PSI}$$

CALCULATE MOHR SHEAR STRESSES:

$$\tau_{m_1} = \frac{\sigma_1 - \sigma_2}{2} \leq 0.4\sigma_y \Longrightarrow 19,025 \text{ PSI} \leq 24,000 \text{ PSI}$$

$$\tau_{m_2} = \frac{\sigma_1}{2} \leq 0.4\sigma_y \Longrightarrow 3563 \text{ PSI} \leq 24,000 \text{ PSI}$$

$$\tau_{m_3} = \frac{\sigma_2}{2} \leq 0.4\sigma_y \Longrightarrow 15,463 \text{ PSI} \leq 24,000 \text{ PSI}$$

CHECK AGAINST INSTABILITIES:

$$Z_3 = \frac{b^2}{Rt} = \frac{(28 \text{ IN})^2}{(16.15 \text{ FT})(12 \text{ IN/FT})(0.56 \text{ IN})} = 7.19$$

$$Z_3 \leq 10 ; \quad \sigma_{bi} = 3.6E\left(\frac{t}{b}\right)^2 = (3.6)30(10)^6 \text{ PSI}\left(\frac{0.5625 \text{ IN}}{28 \text{ IN}}\right)^2$$

$$\sigma_{bi} = 43,585 \text{ PSI}$$

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 9 OF 1[illegible]

CLIENT ______ JOB NO. ER-092[illegible]

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY [illegible] APP'D. BY ______ DATE 22 JAN 19[illegible]

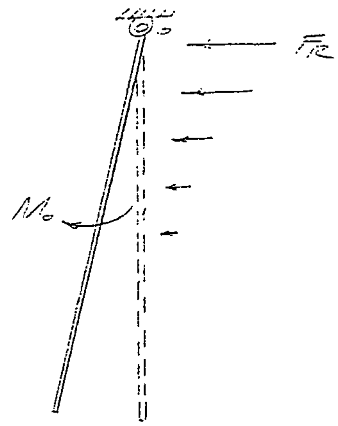
CALCULATE USAGE FACTOR:

$$n = \left| \frac{\sigma_{x_1} + \sigma_{x_2}}{\sigma_{bi}} \right| = \left| \frac{7125 - 27,485}{43,595} \right| = 0.47$$

COMPUTE THE MAXIMUM BENDING MOMENT ASSUMING THE CWP IS PINNED AT THE TOP AND ALLOWED TO SWING FREE AT THE BOTTOM. THE RESULTANT FORCE, F_R, IS CALCULATED FROM THE WAVE AND CURRENT FORCES ACTING ON THE CWP AT BRAZIL DURING EXTREME 100-YEAR STORM CONDITIONS. BREAKING THE CWP INTO 200-FT SECTIONS:

SECTION	F_W WEIGHT	F_B BUOYANCY	F_N NET FORCE	F_R RESULTANT FORCE
① 0 - 200 FT.	788,875 LBS	103,035 LBS	685,840 LBS	427,420 LBS
② 200 - 400 FT.	788,875 LBS	103,035 LBS	685,840 LBS	507,740 LBS
③ 400 - 600 FT.	788,875 LBS	103,035 LBS	685,840 LBS	267,245 LBS
④ 600 - 800 FT.	788,875 LBS	103,035 LBS	685,840 LBS	150,950 LBS
⑤ 800 - 1000 FT.	788,875 LBS	103,035 LBS	685,840 LBS	95,635 LBS
⑥ 1000 - 1200 FT.	633,455 LBS	82,735 LBS	550,720 LBS	37,525 LBS
⑦ 1200 - 1400 FT.	633,455 LBS	82,735 LBS	550,720 LBS	17,395 LBS
⑧ 1400 - 1600 FT.	633,455 LBS	82,735 LBS	550,720 LBS	15,645 LBS
⑨ 1600 - 1800 FT.	633,455 LBS	82,735 LBS	550,720 LBS	13,955 LBS
⑩ 1800 - 2000 FT.	633,455 LBS	82,735 LBS	550,720 LBS	12,165 LBS
⑪ 2000 - 2200 FT.	478,030 LBS	62,435 LBS	415,595 LBS	10,290 LBS
⑫ 2200 - 2400 FT.	478,030 LBS	62,435 LBS	415,595 LBS	8,525 LBS
⑬ 2400 - 2600 FT.	478,030 LBS	62,435 LBS	415,595 LBS	6,795 LBS
⑭ 2600 - 2800 FT.	478,030 LBS	62,435 LBS	415,595 LBS	5005 LBS
⑮ 2800 - 3000 FT.	478,030 LBS	62,435 LBS	415,595 LBS	3215 LBS
TOTAL	9,501,800 LBS	1,241,025 LBS	8,260,775 LBS	

FIND THE ANGLE AT WHICH THE CWP WILL REACH A[N] EQUILIBRIUM POSITION.



$$\Sigma M_o = 0 \quad)+$$

$$F_{R_1}(100)\cos\theta + F_{R_2}(300)\cos\theta + \ldots$$

$$\ldots + F_{R_{15}}(2900)\cos\theta - F_{N_1}(100)\sin\theta$$

$$- F_{N_2}(300)\sin\theta - \ldots - F_{N_{15}}(2900)\sin\theta = 0$$

$$(7.771 \times 10^{8})\cos\theta - (1.104 \times 10^{10})\sin\theta = 0$$

$$\theta = 4.0266°$$

$$F_R' = F_R - F_N \sin\theta$$

WHERE F_R' IS THE RESULTANT FORCE ACTING ON THE CWP AT ITS EQUILIBRIUM POSITION.

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 11 OF 13

CLIENT ______ JOB NO. EE-34[illegible]

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY [illegible] APP'D. BY ______ DATE 22 JAN 197[illegible]

MOMENT ANALYSIS:

	F_R' (LBS)	M)+ (FT-LBS)
0	−1,489,800	0
100	+879,260	1.490×10^8
300	+459,580	2.711×10^8
500	+219,035	3.013×10^8
700	+102,790	2.877×10^8
900	+37,475	2.535×10^8
1100	−835	2.113×10^8
1300	−21,275	1.703×10^8
1500	−23,025	1.330×10^8
1700	−24,715	9.848×10^7
1900	−26,505	7.077×10^7
2100	−18,895	4.836×10^7
2300	−20,600	2.973×10^7
2500	−22,390	1.522×10^7
2700	−24,180	5.194×10^6
2900	−25,970	0
3000		0

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 12 OF 13

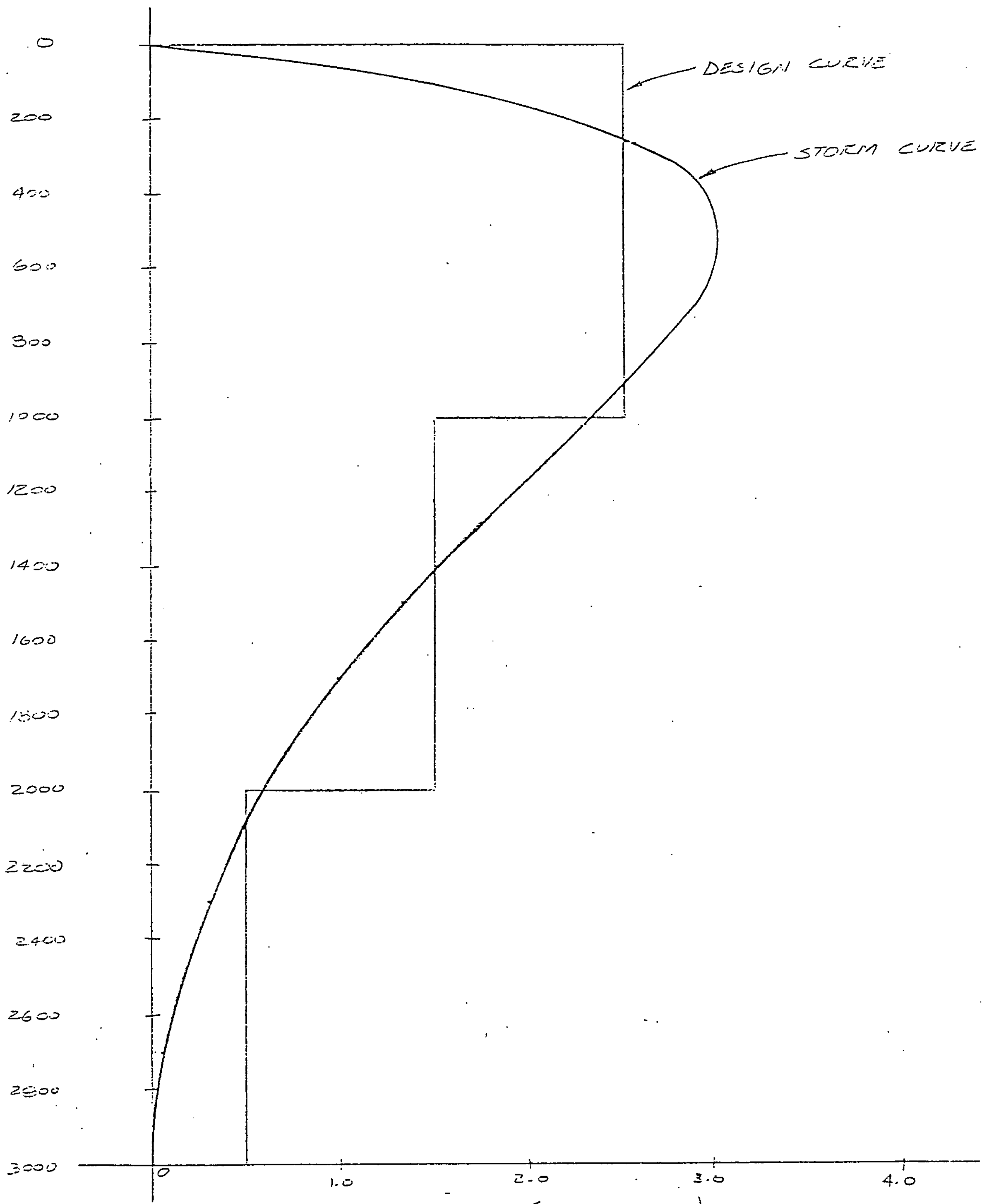
CLIENT ______ JOB NO. ER-?925

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY ______ APP'D. BY ______ DATE 22 JAN 197?

MOMENT DIAGRAM:



BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 13 OF 13

CLIENT ______ JOB NO. ER-[illegible]

SUBJECT ______

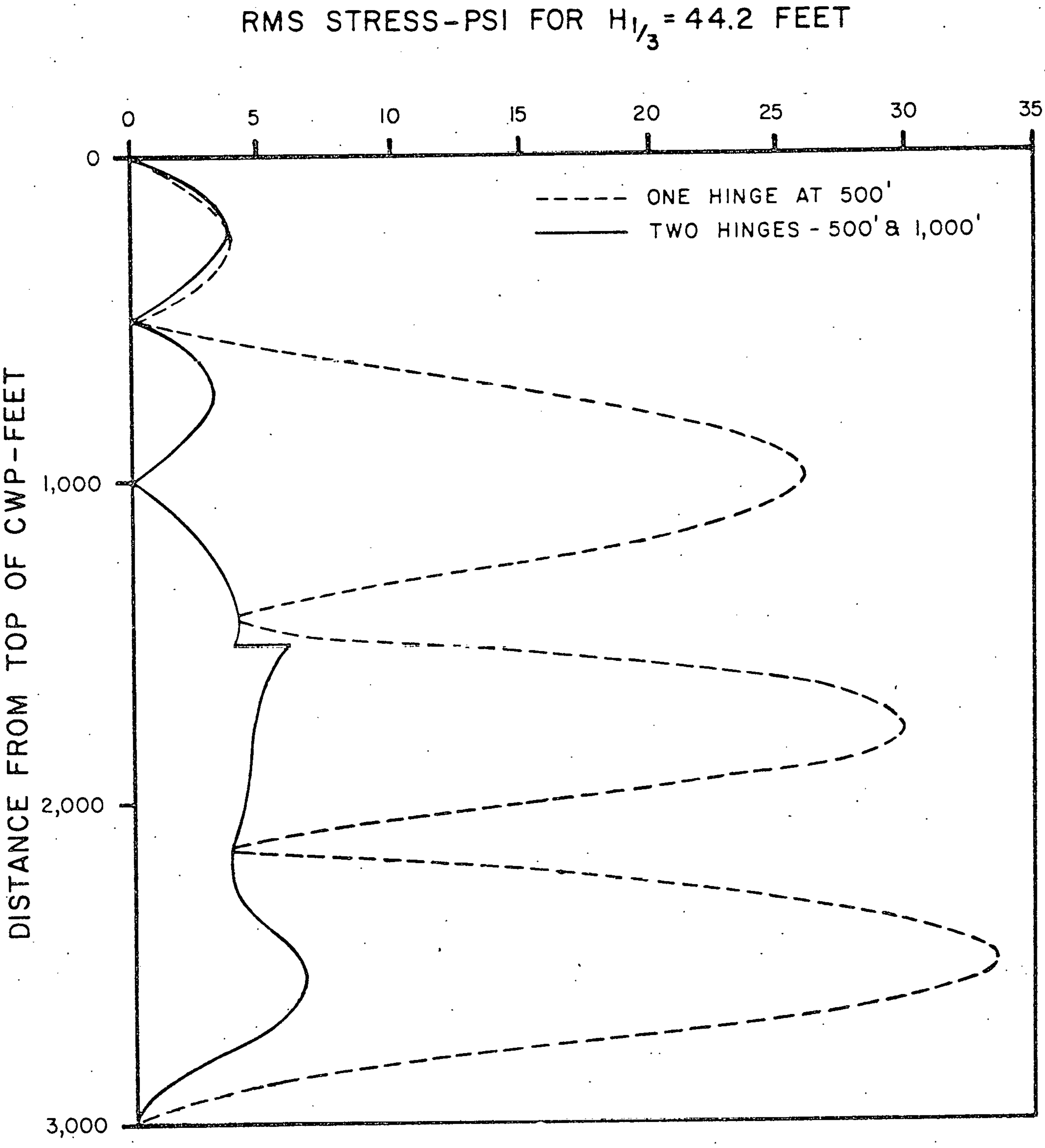
BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY [illegible] APP'D. BY ______ DATE 22 JAN 19[illegible]

NOW, KNOWING THE STORM CURVE, THE DESIGN CAN BE CHECKED AT THE CRITICAL POINTS. USING THE SAME APPROACH AS ON THE PREVIOUS PAGES, USAGE FACTORS CAN BE CALCULATED.

SECTION	SHELL t	PIPE t	USAGE FACTOR
0 – 1000 FT.	9/16 IN.	1/4 IN.	0.59
1000 – 1500 FT.	7/16 IN.	1/4 IN.	0.95
1500 – 2000 FT.	5/16 IN.	1/4 IN.	0.97
2000 – 3000 FT.	3/16 IN.	1/4. IN.	0.64

THE USAGE FACTORS FOR 1000-2000 FEET ARE QUITE HIGH BUT SINCE THIS ANALYSIS IS JUST A PRELIMINARY SIZING, ALL SIZES ARE ACCEPTABLE.



SHELL AND TEE C.W.P. ON SPAR PLATFORM

CLIENT OTEC - CWP JOB NO. EP-0925

SUBJECT BELLOWS - TYPE JOINT AT 300 FT.

BASED ON DRAWING NO.

COMPUTER S. PORTER CHK'D. BY GWD APP'D. BY DATE 29 JAN 1979

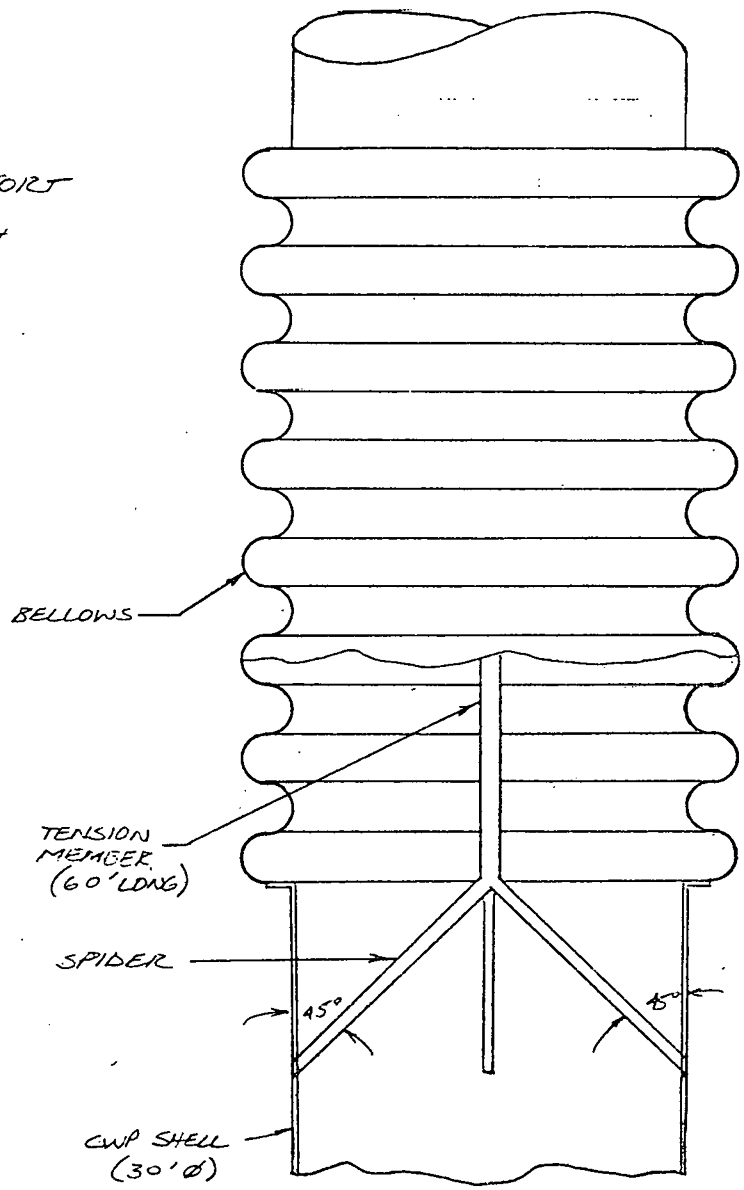
THE BELLOWS-TYPE JOINT IS MADE OF TWO COMPONENTS. THE FIRST, A TENSION MEMBER, SUPPORTS THE ENTIRE WEIGHT OF THE CWP BELOW THE JOINT. IT IS SURROUNDED BY A CORRUGATED STEEL BELLOWS.

LOCATION OF JOINT: 300 FT. FROM CONNECTION TO PLATFORM.

DESIGN A TENSION MEMBER AND SPIDER ASSEMBLY TO SUPPORT A LOWER CWP SECTION WITH THE FOLLOWING WEIGHTS:

a) 4,000,000 LBS
b.) 6,000,000 LBS
c) 8,000,000 LBS
d.) 10,000,000 LBS

USE A SAFETY FACTOR OF 4.0.



BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 2 OF 13

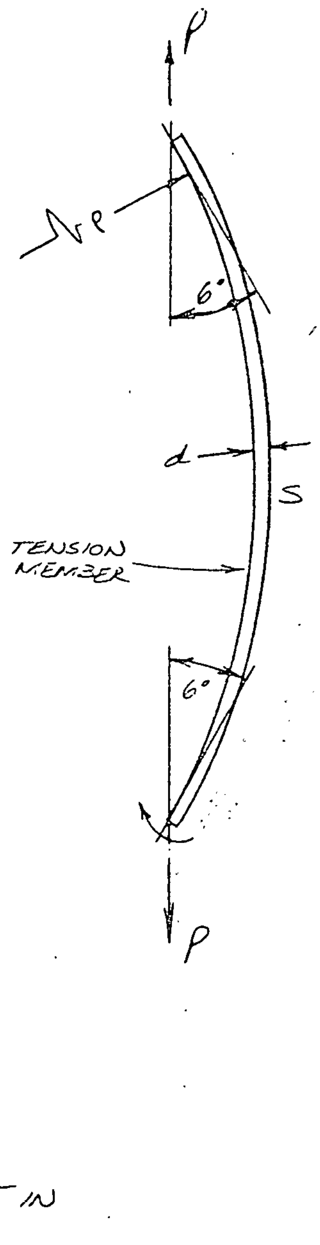
CLIENT ______ JOB NO. EZ-0925

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY GWD APP'D. BY ______ DATE 30 JAN 197–

TENSION MEMBER: A SOLID STEEL ROD OF AISC 4340 STEEL (σ_y = 69,000 PSI) IS USED TO ALLOW FLEXURE IN A JOINT 300 FT FROM THE TOP OF THE CWP.



ρ = RADIUS OF CURVATURE

$\theta = 6°$

S = LENGTH OF ARC = 60 FT = 720 IN

σ_a = STRESS ALLOWABLE

n = FACTOR OF SAFETY = 4.0

C = DISTANCE TO EXTREME FIBER = $\frac{d}{2}$

$$\sigma_a = \frac{\sigma_y}{n} = \frac{69{,}000 \text{ PSI}}{4.0} = 11{,}250 \text{ PSI}$$

$$\sigma_a = \frac{P}{A} + \frac{Mc}{I}$$

FOR A CURVED BEAM:

$$\frac{1}{\rho} = \frac{M}{EI} \quad \text{OR} \quad M = \frac{EI}{\rho}$$

REWRITING: $\sigma_a = \frac{P}{A} + \frac{Ec}{\rho}$

$$\sigma_a = \left(\frac{4P}{\pi}\right)\frac{1}{d^2} + \left(\frac{E}{2\rho}\right)d$$

TO FIND ρ: $S = (12°)\left(\frac{\pi}{180}\right)\rho \Longrightarrow \rho = 3437.75$ IN

REWRITING: $17{,}250 = \left(\frac{4P}{\pi}\right)\frac{1}{d^2} + (4363.32)d$

OR $(4363.32)d^3 - (17{,}250)d^2 + \frac{4P}{\pi} = 0$

THE ABOVE EQUATION WILL DIVERGE AND NOT REACH ANY REAL SOLUTION. LOOKING JUST AT THE EQUATION FOR BENDING:

$$\sigma_a = \left(\frac{E}{2\rho}\right)d \Longrightarrow d_1 = 3.95 \text{ IN.}$$

NOW, LOOKING ALSO AT THE EQUATION FOR THE AXIAL LOAD: (LET $P = 8{,}000{,}000$ LBS)

$$\sigma_a = \frac{4P}{\pi d^2} \Longrightarrow d_2 = 24.30 \text{ IN}$$

EQUATE AREAS TO CALCULATE THE NUMBER OF 3.95 IN RODS NECESSARY TO SUPPORT THE SAME AXIAL LOAD.

$$A_1 = \frac{\pi}{4}d_1^2 \quad ; \quad A_2 = \frac{\pi}{4}d_2^2$$

$$N = \frac{A_2}{A_1} = \frac{\frac{\pi}{4}d_2^2}{\frac{\pi}{4}d_1^2} = \frac{d_2^2}{d_1^2} = 37.78 \text{ OR ABOUT } 38$$

A BUNDLE OF 4 IN RODS WOULD NOT WORK BECAUSE THE STRESS AT THE EXTREME FIBER OF THE BUNDLE WOULD EXCEED THE ALLOWABLE STRESS LEVEL.

THE WHOLE CONCEPT OF USING A FLEXIBLE TENSION BAR TO ACT AS A JOINT IS NOT FEASIBLE. THE 24 IN. DIAMETER BAR, WHEN FLEXED TO A TOTAL OF 12° WOULD EXCEED ALLOWABLE STRESS LEVEL.

CLIENT ________ JOB NO. FR-0925

SUBJECT ________

BASED ON ________ DRAWING NO. ________

COMPUTER S. PORTER CHK'D. BY GWD APP'D. BY ________ DATE 30 JAN 1979

DESIGN A TENSION MEMBER USING WIRE ROPE INSTEAD OF A SOLID STEEL ROD. USE A STAINLESS STEEL ROPE, TYPE 304, 6X19 IWRC. USE A SAFETY FACTOR OF 4.

USING A 2" DIAMETER, BREAKING STRENGTH IS 293 KIPS

NUMBER OF ROPES REQUIRED = $N = \frac{4P}{293,000 \text{ LBS}}$

P	N	
4,000,000 LBS	54	(6 GROUPS OF 9)
6,000,000 LBS	81	(9 GROUPS OF 9)
8,000,000 LBS	108	(12 GROUPS OF 9)
10,000,000 LBS	135	(15 GROUPS OF 9)

WEIGHT OF WIRE ROPE: (TO SUPPORT 8,000,000 LBS)

$$W = (7.39 \text{ LBS/FT})(60 \text{ FT})(108) \Longrightarrow W = 48,000 \text{ LBS}$$

THIS WOULD BE AN ALTERNATIVE TO THE SOLID BAR CONCEPT. A SINGLE, LARGE ROPE COULD BE WOUND USING MANY SMALLER ROPES UNTIL THE DESIRED SIZE HAS BEEN FOUND.

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 5 OF 13

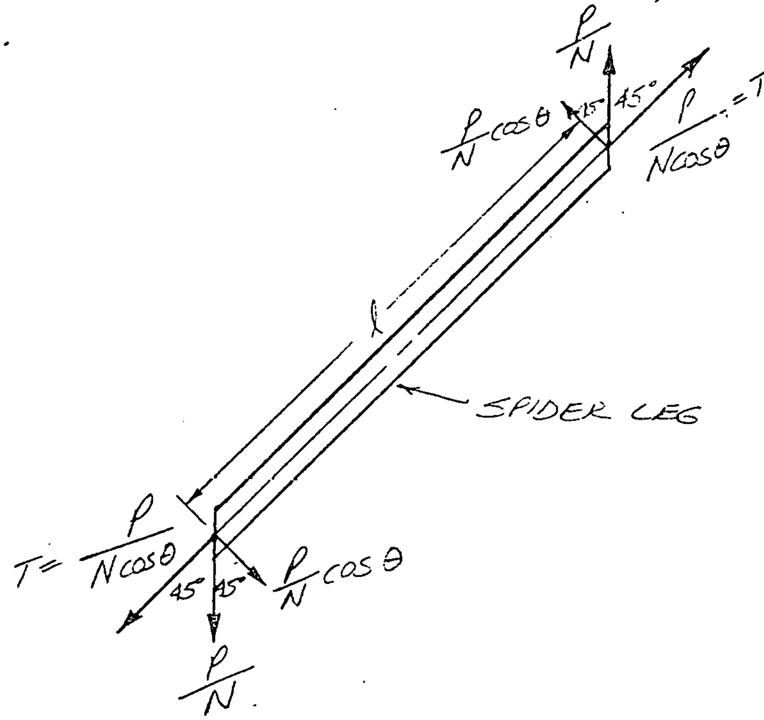
CLIENT ______ JOB NO. ER-0925

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY GWD APP'D. BY ______ DATE 31 JAN 1979

SPIDER DESIGN: USE API 5LX, GRADE X-60 PIPE TO DESIGN A SPIDER WITH "N" NUMBER OF LEGS THAT ATTACH AT A 45° ANGLE TO THE INSIDE OF THE CWP. AGAIN, LET THE SAFETY FACTOR BE 4.0.



AS BEFORE, USE FOUR DIFFERENT VALUES FOR P,

$P = 4{,}000{,}000$ LBS

$P = 6{,}000{,}000$ LBS

$P = 8{,}000{,}000$ LBS

$P = 10{,}000{,}000$ LBS

$\sigma_y = 60{,}000$ PSI

P (LBS)	N (LEG)	$\frac{P}{N}$ (LBS/LEG)
4,000,000	4	1,000,000
6,000,000	4	1,500,000
8,000,000	4	2,000,000
10,000,000	4	2,500,000
4,000,000	6	666,666
6,000,000	6	1,000,000
8,000,000	6	1,333,333
10,000,000	6	1,666,666
4,000,000	8	500,000
6,000,000	8	750,000
8,000,000	8	1,000,000
10,000,000	8	1,125,000

$$\sigma_a = \text{STRESS ALLOWABLE} = \frac{\sigma_y}{4} = \frac{60{,}000}{4} = 15{,}000 \text{ PSI}$$

$$\sigma_a = \frac{T}{A}$$

$$T = \text{TENSION IN LEG} = \frac{P}{N}\left(\frac{1}{\cos\theta}\right)$$

$$A = \frac{\pi}{4}\left(d_o^2 - d_i^2\right)$$

REWRITING:
$$15000 = \frac{\frac{P}{N}\left(\frac{1}{\cos\theta}\right)}{\frac{\pi}{4}\left(d_o^2 - d_i^2\right)}$$

$$d_i^2 = d_o^2 - \frac{\frac{P}{N}\left(\frac{1}{\cos\theta}\right)}{\frac{\pi}{4}(15{,}000)}$$

P (LBS)	N (LEGS)	d_o (IN)	d_i (IN)	t (IN)
4,000,000	4	18	14.28	1.86
		24	21.35	1.32
		30	27.93	1.04
6,000,000	4	18	12.00	3.00
		24	19.90	2.05
		30	26.83	1.58
8,000,000	4	18	10.04	3.98
		24	18.78	2.61
		30	26.01	1.99
10,000,000	4	18	6.70	5.65
		24	17.23	3.38
		30	24.92	2.54

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 7 OF 13

CLIENT ______ JOB NO. FR-0925

SUBJECT ______

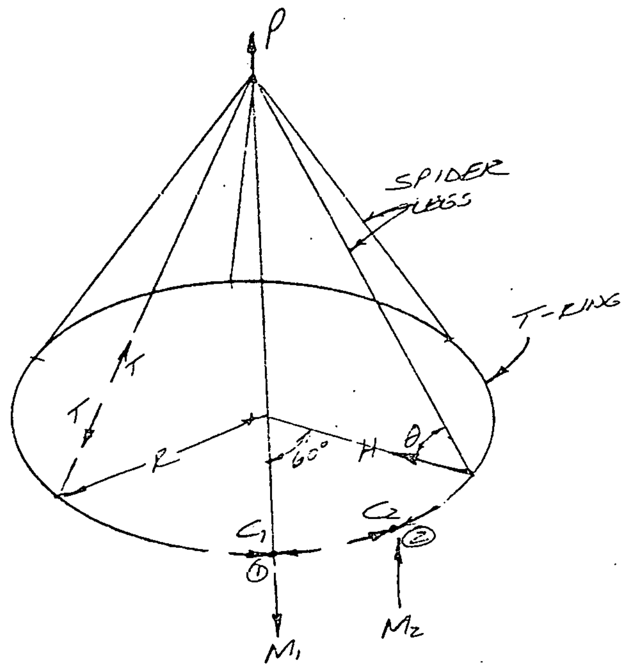
BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY GWD APP'D. BY ______ DATE 31 JAN 1979

P (LBS)	N (LEGS)	d_o (IN)	d_i (IN.)	t (IN)
4,000,000	6	18	15.80	1.10
		24	22.40	0.80
		30	28.73	0.63
6,000,000	6	18	14.28	1.86
		24	21.35	1.32
		30	27.93	1.04
8,000,000	6	18	13.23	2.38
		24	20.67	1.67
		30	27.41	1.30
10,000,000	6	18	11.75	3.13
		24	19.75	2.13
		30	26.72	1.64
4,000,000	8	18	16.38	0.81
		24	22.81	0.60
		30	29.05	0.47
6,000,000	8	18	15.50	1.25
		24	22.19	0.91
		30	28.57	0.71
8,000,000	8	18	14.28	1.86
		24	21.35	1.32
		30	27.93	1.04
10,000,000	8	18	13.58	2.21
		24	20.89	1.55
		30	27.58	1.21

CHOOSE 6 – 18" Ø PIPES TO SUPPORT 4,000,000 LBS

F.B.D. OF LEGS + RING.



TO SIZE THE RING:

@ POINT ①:

STRESS ON INSIDE OF RING

$$\sigma_{i_1} = \frac{-C_1}{A} + \frac{M_1 c}{I}$$

STRESS ON OUTSIDE OF RING

$$\sigma_{o_1} = \frac{-C_1}{A} - \frac{M_1 c}{I}$$

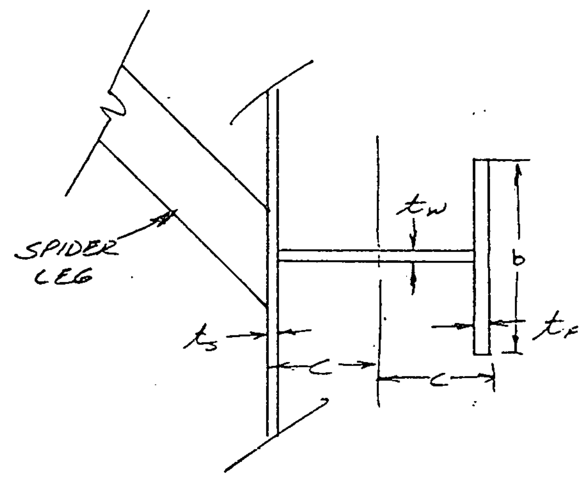
@ POINT ②:

STRESS ON INSIDE OF RING

$$\sigma_{i_2} = \frac{-C_2}{A} - \frac{M_2 c}{I}$$

STRESS ON OUTSIDE OF RING

$$\sigma_{o_2} = \frac{-C_2}{A} + \frac{M_2 c}{I}$$



DETAIL OF RING

COMPRESSION IN RING:

$$C_1 = H \sin 60° = 0.866H = 0.866\, P \cos\theta$$

$$= 0.866\left(\frac{T}{6\sin\theta}\right)\cos\theta = \left(\frac{0.866}{6}\right)\frac{T}{\tan 45}$$

$$C_2 = H = \frac{T}{6\tan\theta}$$

MOMENT IN RING: SEE ROARK (5^{th} ED.) TABLE 17, REF. 7

$$M_1 = \frac{HR}{2}\left(\frac{1}{\theta} - \frac{\cos\theta}{\sin\theta}\right) = 0.089\, HR = \frac{0.089}{6}\,\frac{TR}{\tan\theta}$$

$\theta = 30°$

$$M_2 = \frac{HR}{2}\left(\frac{1}{\sin\theta} - \frac{1}{\theta}\right) = 0.045\, HR = \frac{0.045}{6}\,\frac{TR}{\tan\theta}$$

STRESS IN RING:

$$\sigma_1 = -\frac{0.866}{6\tan\theta}\left(\frac{T}{A}\right) \pm \frac{0.089\, TRc}{6I\tan\theta}$$

$$\sigma_2' = -\frac{0.866}{6\tan\theta}\left(\frac{T}{A}\right) \pm \frac{0.045\, TRc}{6I\tan\theta}$$

NOTE:

$$T = \frac{P}{\cos 45°} = 1.41P$$

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 10 OF 13

CLIENT ______ JOB NO. ER-0925

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY GWD APP'D. BY ______ DATE 31 JAN 1979

TO SIZE RING, LET $b = 12$ IN (BOTH FLANGE + SHELL; TREAT AS A WF BEAM)

$c = 6$ IN

$t_W = 1$ IN

$t_F = 1$ IN

$t_S = 1$ IN

$$R = 180\text{ IN} + 6\text{ IN} = 186\text{ IN}$$

$$A = 2(12\text{ IN})(1\text{ IN}) + (11\text{ IN})(1\text{ IN}) = 35\text{ IN}^2$$

$$I = \frac{(12\text{ IN})(12\text{ IN})^3}{12} - \frac{(11\text{ IN})(11\text{ IN})^3}{12} = 397\text{ IN}^4$$

$$\sigma_1 = \frac{-(0.866)}{6}\left(\frac{5{,}656{,}855\text{ LBS}}{35\text{ IN}^2}\right) \pm \frac{(0.089)(5{,}656{,}855\text{ LBS})(186\text{ IN})(6\text{ IN})}{(6)\,397\text{ IN}^4}$$

$$\sigma_1 = +212{,}300\text{ PSI},\ -258{,}950\text{ PSI}$$

INCREASE THE FOLLOWING PARAMETERS:

$b = 24$ IN

$c = 12$ IN

$t_W = 1.5$ IN

$t_F = 2.0$ IN

$t_S = 2.0$ IN

$$R = 180\text{ IN} + 12\text{ IN} = 192\text{ IN}$$

$$I = \frac{(24\text{ IN})(24\text{ IN})^3}{12} - \frac{(22.5\text{ IN})(20\text{ IN})^3}{12} = 12{,}648\text{ IN}^4$$

CLIENT ______ JOB NO. EP-0925

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY GWD APP'D. BY ______ DATE 31 JAN 1979

$$A = 2(24\ \text{IN})(2\ \text{IN}) + (1.5\ \text{IN})(20\ \text{IN}) = 126\ \text{IN}^2$$

$$\sigma_1 = -\left(\frac{0.866}{6}\right)\left(\frac{5{,}656{,}855\ \text{LBS}}{126\ \text{IN}}\right) \pm \frac{(0.089)(5{,}656{,}855\ \text{LBS})(192\ \text{IN})(12\ \text{IN})}{6(12{,}648\ \text{IN}^4)}$$

$\sigma_1 = +8800$ PSI TENSION ON INSIDE OF RING

$\sigma_1 = -21{,}750$ PSI COMPRESSION ON OUTSIDE OF RING

$$\sigma_2 = -\left(\frac{0.866}{6}\right)\left(\frac{5{,}656{,}855\ \text{LBS}}{126\ \text{IN}}\right) \pm \frac{(0.045)(5{,}656{,}855\ \text{LBS})(192\ \text{IN})(12\ \text{IN})}{6(12{,}648\ \text{IN}^4)}$$

$\sigma_2 = +1260$ PSI TENSION ON OUTSIDE OF RING

$\sigma_2 = -14{,}220$ PSI COMPRESSION ON INSIDE OF RING

ALL STRESSES ABOVE ARE ACCEPTABLE. $\sigma_a = 0.6\sigma_y = 21{,}600$ PSI

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 12 OF 13

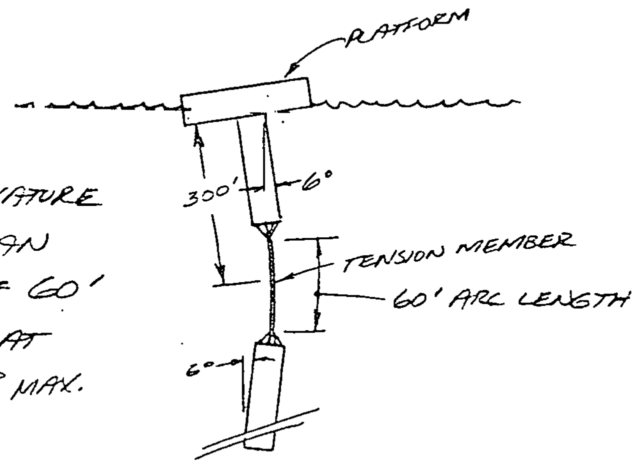
CLIENT ______ JOB NO. EJ2-0925

SUBJECT OTEC - CWP TENSION MEMBER JOINT CONCEPT SUMMARY

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY GWD APP'D. BY ______ DATE 31 JAN 1979

WORST CASE IS WHEN PLATFORM AND CWP ARE OUT OF PHASE 180° AS SHOWN BELOW:



RADIUS OF CURVATURE IS BASED ON AN ARC LENGTH OF 60' AND AN ANGLE AT EACH END OF 6° MAX.

USING AN AISC 4340 STEEL BAR AS THE TENSION MEMBER REQUIRED SLIGHTLY OVER 17"Ø TO SUPPORT A 4,000,000 LB LOAD WITH A SAFETY FACTOR OF 4.0. HOWEVER, DUE TO THE RADIUS OF CURVATURE INVOLVED, MAXIMUM DIAMETER TO PREVENT OVERSTRESSING WOULD BE 4.0 IN. THEREFORE, A SOLID STEEL BAR WILL NOT WORK.

A WIRE ROPE CONSISTING OF 54 - 2"Ø STAINLESS STEEL ROPES WOULD SUPPORT THE REQUIRED LOAD AT THE SAME SAFETY FACTOR AS ABOVE. AND BENDING WOULD BE NO PROBLEM WITH A CABLE EITHER.

SIX SPIDER LEGS ARE NECESSARY TO SUPPORT THE LOAD USING 18"Ø PIPE WITH A 1.1" WALL THICKNESS. THEY TIE INTO AN I-BEAM WITH THE FOLLOWING DIMENSIONS:

DEPTH = 24 IN
FLANGE WIDTH = 24 IN
FLANGE t = 2 IN
WEB t = 1.5 IN

BROWN & ROOT, INC.
ENGINEERING DIVISION

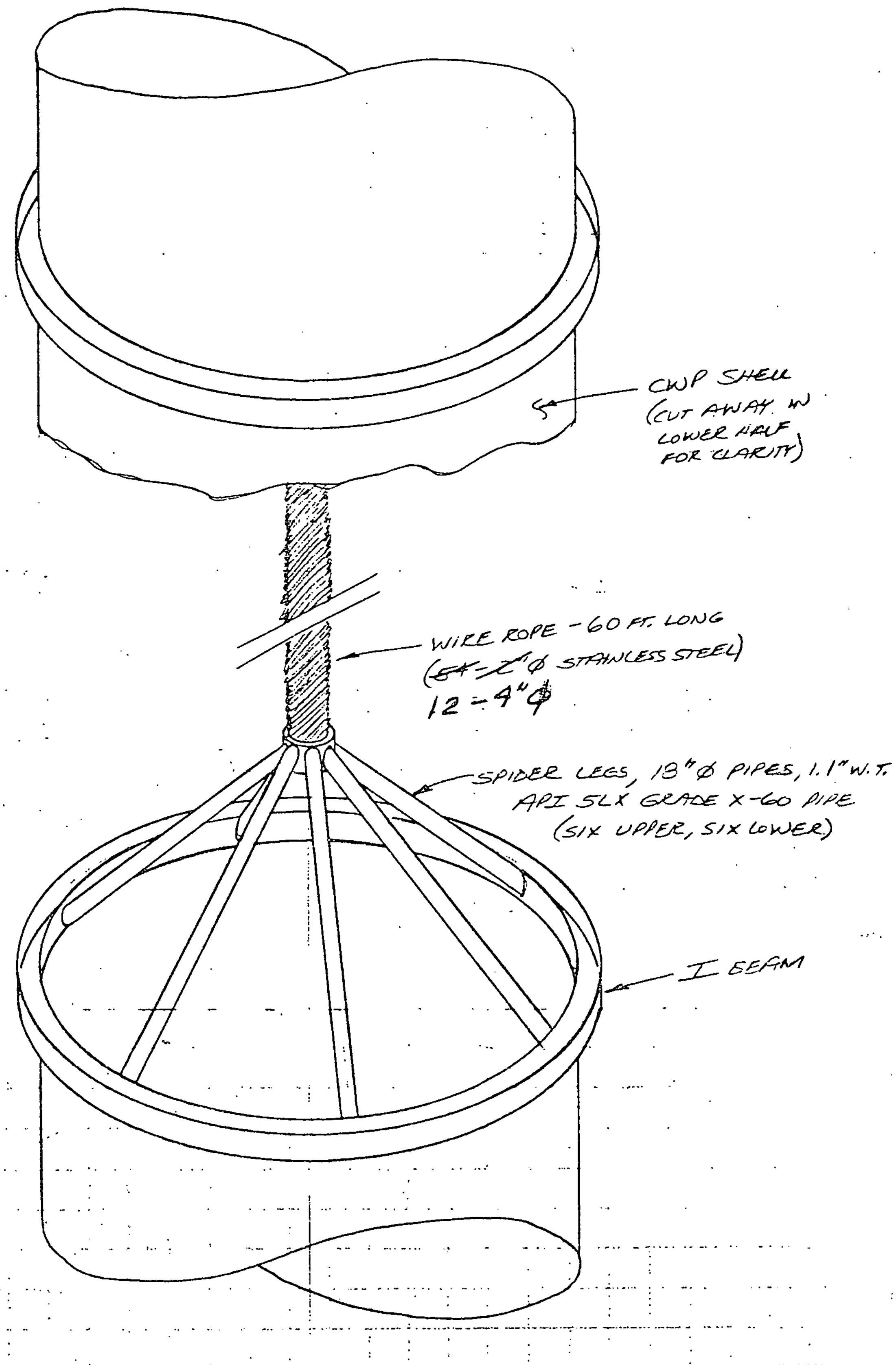
SHEET NO. 13 OF 13

CLIENT ______ JOB NO. ER-0925

SUBJECT FIGURE 5.2.10

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY GWD APP'D. BY ______ DATE 31 JAN 1979



BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 1 OF 2

CLIENT NOAA/SAI JOB NO.

SUBJECT OTEC

BASED ON FLEXIBLE TENSION MEMBER JOINT CONCEPT DRAWING NO.

COMPUTER DENISON CHK'D. BY APP'D. BY DATE 2/23 1972

GEOMETRY: FLEXIBLE MEMBER (APPROX. 30'-60') CONSISTS OF 12 - 4" DIAM CABLES ENCAPSULATED IN SYNTHETIC MAT'L. EACH END HELD BY SOCKETS WHICH ARE ATTACHED TO STRUCTURAL SPIDERS. THESE ARE IN TURN ATTACHED TO TIE-IN RING ON EACH END OF CWP. A FLEXIBLE REINFORCED ELASTOMER SEAL WILL ENCLOSE THIS CONNECTION

MATERIAL: CABLE - IMPROVED PLOW STEEL

TIE-IN RING - A-36 STEEL

SPIDER - API 5LX 60 PIPE

SOCKET - CAST AND MACHINE FROM 50 KSI STEEL.

WEIGHT:

12 CABLES (30 Ft/CABLE)(30 #/Ft)	=	10,800 lbs.
SOCKETS 2 X 9000 lb	=	18,000 lbs.
ENCAPSULANT	≈	4,000 lbs.
TIE-IN RING (2 X 2400 lb/ea)		4,800 lbs
6(2)(17.32' Lg)(203 lb/Ft)	=	42,193 lbs
COVER RUBBER		6,300 lbs
DRY WT - ≈ 43 TONS	—	86,093 lbs

WET WT. - ≈ 38.15 TONS - 76,304 lbs

BUOYANCY: NEGATIVE

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 2 OF 2

CLIENT NOAA/SAI JOB NO.

SUBJECT OTEC

BASED ON FLEXIBLE TENSION MEMBER JT. DRAWING NO.

COMPUTER DENSON CHK'D. BY APP'D. BY DATE 2/23 1979

CONSTRUCTION:

SOCKET - CASTING
SPIDER +
TIE-IN RING - WELDED STRUCTURAL

DESIGN PARAMETER:

30 YR - DESIGN LIFE OF CABLE WILL DEPEND NO OF CYCLES IN THIS DESIGN LIFE

PRIMARY ADVANTAGES:

1) INEXPENSIVE
2) SIMPLE
3) FLEXIBLE - GOOD IN FATIGUE LOADING.

PRIMARY DISADVANTAGES:

1) FATIGUE LIFE WILL HAVE TO BE DETERMINED.
2) FAILURE WILL RESULT IN LOSS OF ATTACHED CWP SECTION.

COST:

CABLE (ENCAPSULATED) WITH SOCKETS	— 300,000
TIE-IN RINGS ($1 1/2 lb X 4800 lb)	— 7200
SPIDERS ($1 1/2 X 42,193 lb)	— 63,289
RUBBER ($2 1/2 /lb X 86,093 lbs)	— 215,232

COST — $585,721

SAI

CWP PIPE LOADING 1/5

2/79

CWP STRESS RESULTANTS DUE TO ASSYMETRIC LOADING:

$$\boxed{P(\theta) = \sum_{0}^{\infty} P(n) \cos n\theta}$$

ASSUME THE LOADING (ASSYMETRIC COMP.)

$$\boxed{\frac{P(\theta)}{P_o} \approx -0.95 + 0.40 \cos\theta + 1.30 \cos 2\theta + 0.50 \cos 3\theta - 0.25 \cos 4\theta - 0.10 \cos 5\theta + 0.10 \cos 6\theta}$$

$$\frac{dP(\theta)}{d\theta} = -P_o \left[.40 \sin\theta + 2.60 \sin 2\theta + 1.5 \sin 3\theta - 1.0 \sin 4\theta - .5 \sin 5\theta + .6 \sin 6\theta \right]$$

@ $\theta = 0°$

$$\boxed{P(0) = 1 P_o}$$

@ $\theta = 180°$

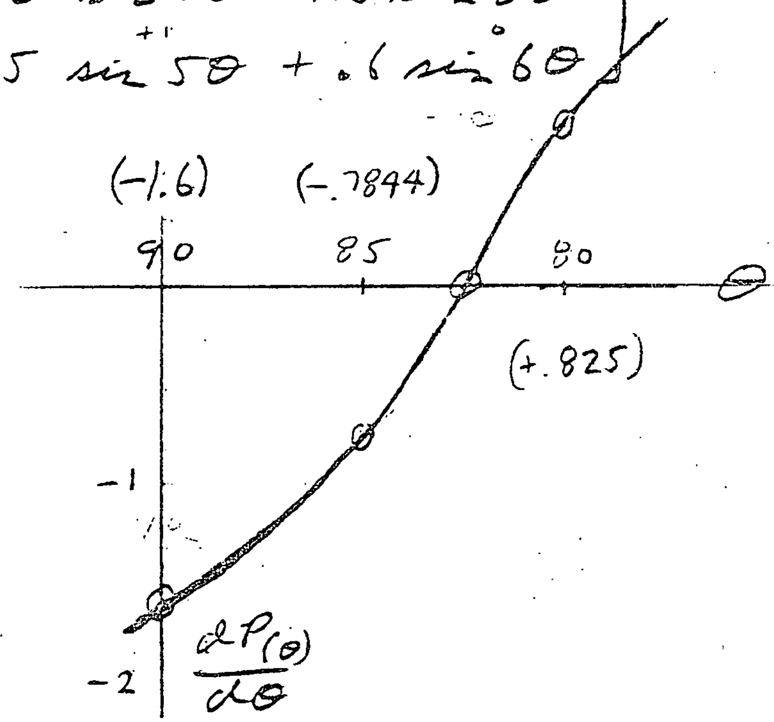
$$\boxed{P(180) = -.60 P_o}$$

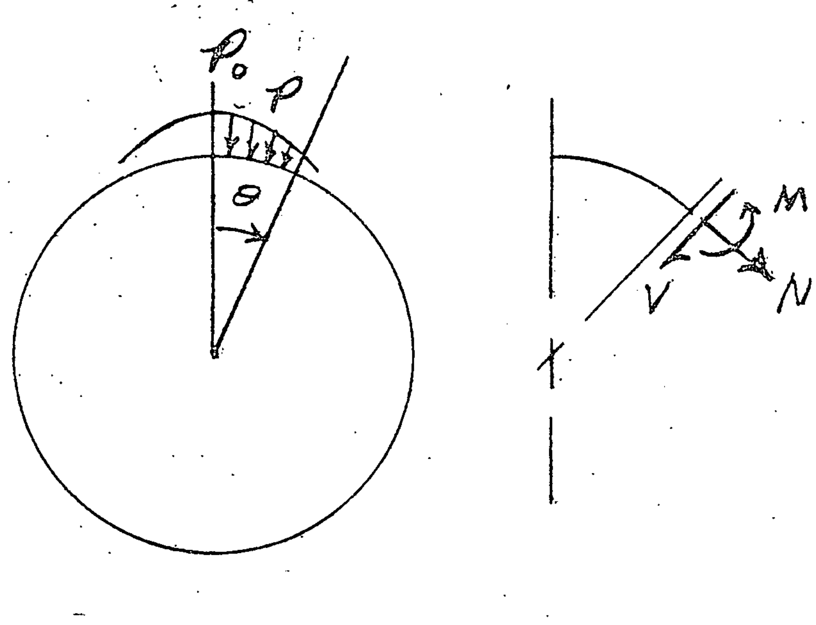
@ $\theta = 90°$

$$P(90) = -2.60 P_o$$

SAY, MAX @ SIDES @ $\theta = 82.5°$

$$\boxed{P_{82.5°} = -2.69 P_o}$$





SAI

CPL 2/5

2/79

CIRCUMFERENTIAL BENDING MOMENTS

$$\boxed{M_{(\theta)} = +R^2 \sum_{n=2}^{\infty} P_{(n)} \left(\frac{1}{n^2-1}\right) \cos n\theta}$$

180 / 90

$$\frac{M_{(\theta)}}{P_o R^2} \approx \frac{1.3}{3} \cos 2\theta + \frac{.5}{8} \cos 3\theta - \frac{.25}{15} \cos 4\theta - \frac{.1}{24} \cos 5\theta + \frac{.1}{35} \cos 6\theta$$

$$\frac{d M_{(\theta)}}{d\theta} = -P_o R^2 \left[\frac{2.6}{3} \sin 2\theta + \frac{1.5}{8} \sin 3\theta - \frac{1}{15} \sin 4\theta - \frac{.5}{24} \sin 5\theta + \frac{.6}{35} \sin 6\theta\right]$$

90

@ $\theta = 0°$

$$\boxed{M_{(0)} = +0.48^- P_o R^2}$$

@ $\theta = 180°$

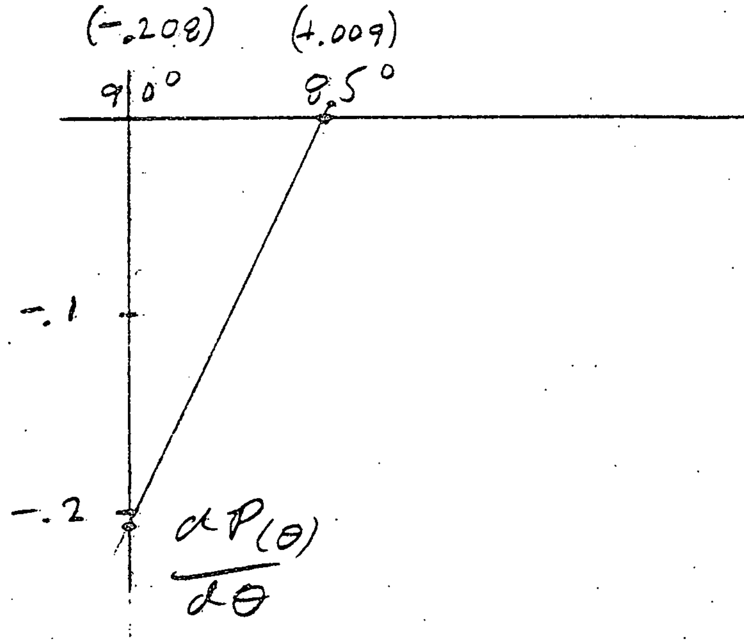
$$\boxed{M_{(180)} = +0.36\, P_o R^2}$$

@ $\theta = 90°$

$$M_{(90)} = -0.45^+ P_o R^2$$

SAY MAX @ SIDES @ $\theta = 85°$

$$\boxed{M_{(85°)} = -0.46^+ P_o R^2}$$



SAI

CPL 3/5

2/79

CIRCUMFERENTIAL TENSION

$$\boxed{N_\theta = +R \sum_{n=2}^{\infty} P_n \left(\frac{1}{n^2-1}\right) \cos n\theta}$$

$$\boxed{\frac{N(\theta)}{P_o R} \approx \frac{1.3}{3}\cos 2\theta + \frac{.5}{8}\cos 3\theta - \frac{.25}{15}\cos 4\theta - \frac{.1}{24}\cos 5\theta + \frac{.1}{35}\cos 6\theta}$$

BY SIMILARITY TO MOMENT EQUATIONS

@ $\theta = 0$

$$\boxed{N(0) = +0.48\, P_o R}$$

@ $\theta = 180$

$$\boxed{N(180) = +0.36\, P_o R}$$

@ $\theta = 90$

$$N(90) = -0.45\, P_o R$$

@ $\theta = 85°$

$$\boxed{N(85) = -0.46\, P_o R}$$

SAI

CPL 4/5

2/79

TRANSVERSE SHEAR

$$\boxed{V(\theta) = +R \sum_{n=2}^{\infty} P_n \left(\frac{n}{n^2-1}\right) \sin n\theta}$$

90 / 45 / 135

$$\boxed{\frac{V(\theta)}{P_o R} \approx \frac{2.6}{3}\sin 2\theta + \frac{1.5}{8}\sin 3\theta - \frac{1}{15}\sin 4\theta - \frac{.5}{24}\sin 5\theta + \frac{.6}{35}\sin 6\theta}$$

(values above terms: 0, −1, 0, +1, 0; below terms: ±1, +.707 / +.707, 0 / 0, −.707 / −.707, −1 / +1)

135 / 45

$$\frac{dV(\theta)}{d\theta} = P_o R\left[\frac{5.2}{3}\cos 2\theta + \frac{4.5}{8}\cos 3\theta - \frac{4}{15}\cos 4\theta - \frac{2.5}{24}\cos 5\theta + \frac{3.6}{35}\cos 6\theta\right]$$

(values above terms: 0, +.707, −1, +.707, 0; below terms: 0, −.707, −1, −.707, 0)

@ $\theta = 0°$ & $180°$

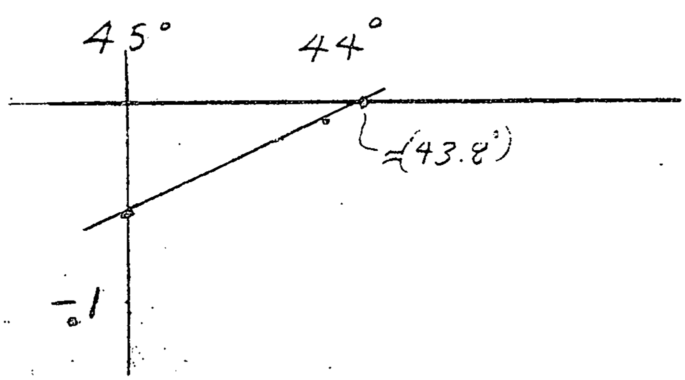
$V(0,180) = 0$

@ 90°

$V(90) = -.208\ P_o R$

@ 45°

$V(45) = 1.00^-\ P_o R$



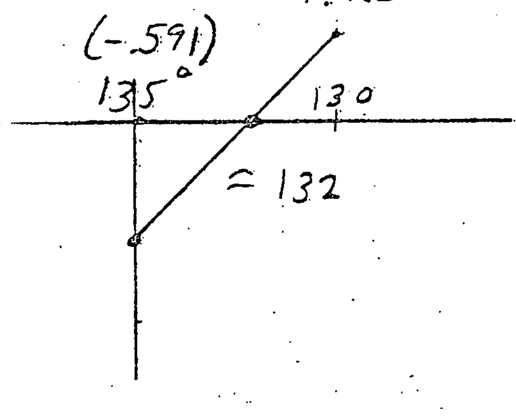
SAY MAX @ SIDES @

$\theta = 44°$

$$\boxed{V(44) = 1.00\ P_o R}$$

@ 135°

$V(135) = -.70^+\ P_o R$



SAY 2nd MAX @ SIDES @

$\theta = 132°$

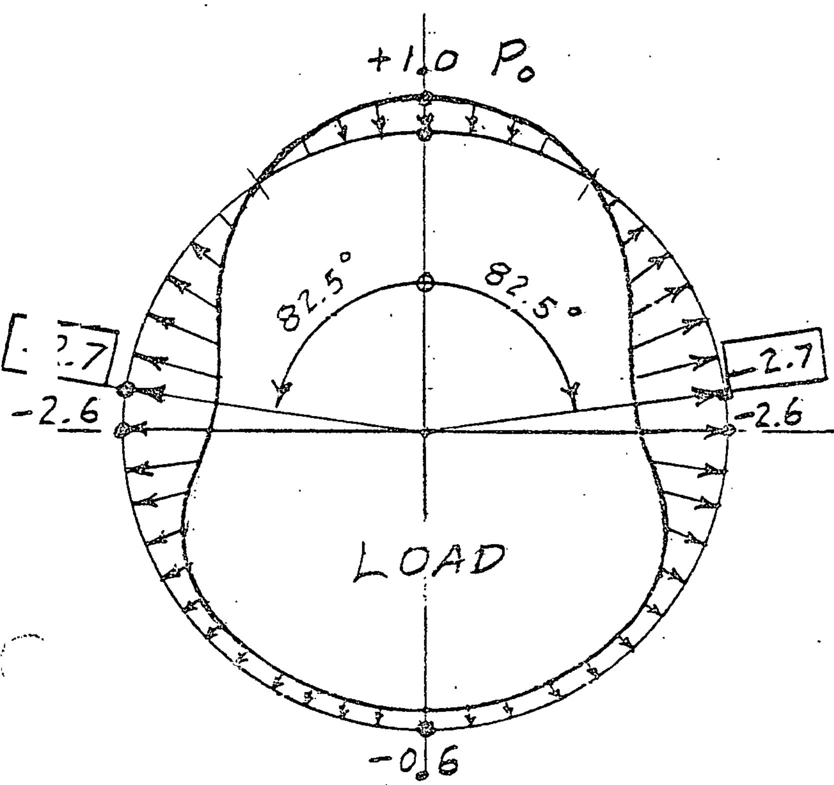
$$\boxed{V(132) = -.73\ P_o R}$$

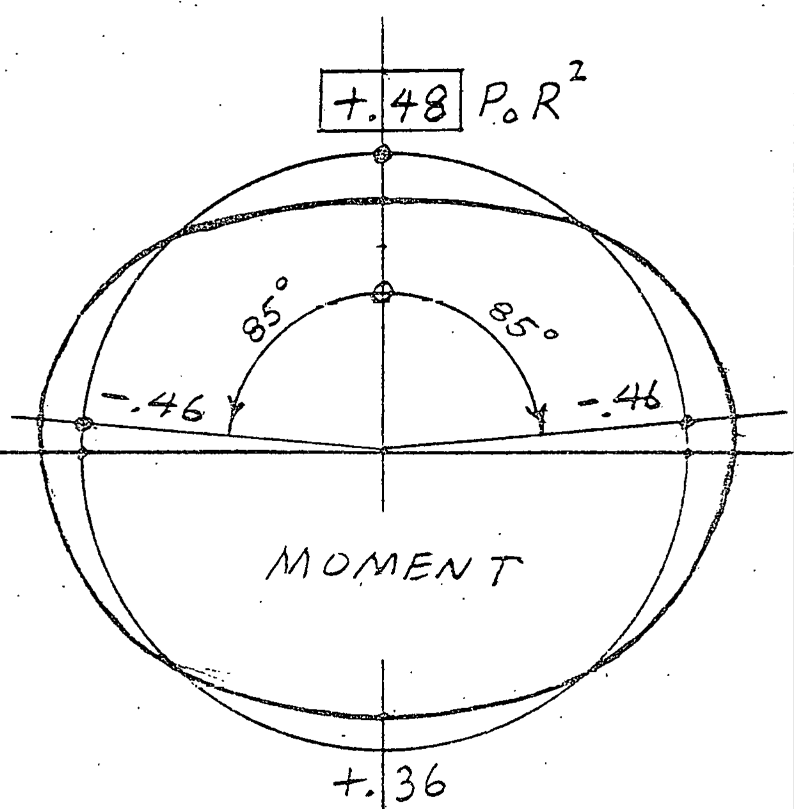
SAI

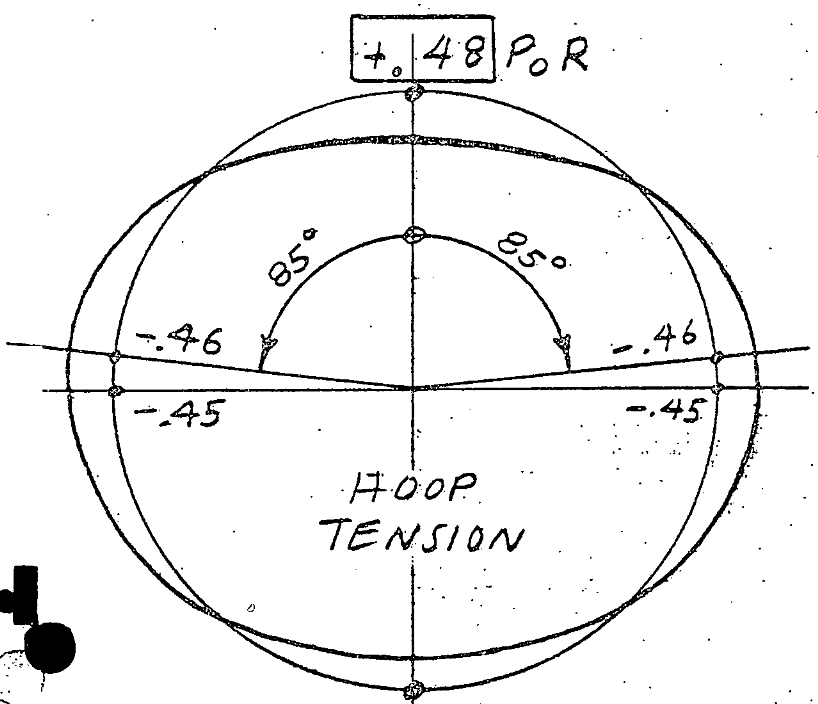
CPL 5/5

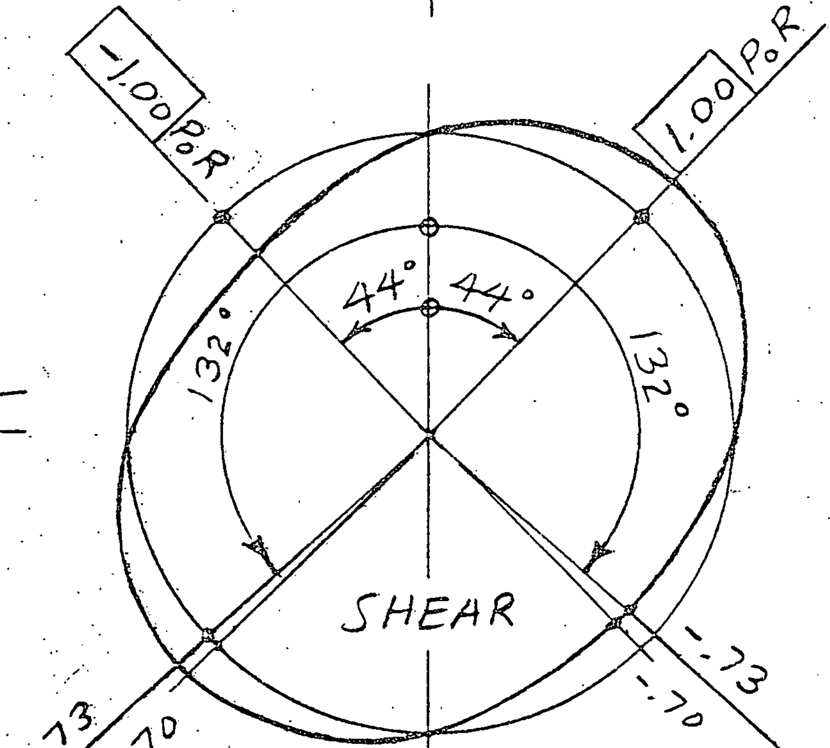
2/79

SUMMARY OF ASSYMETRIC LOADING & STRESS RESULTANTS





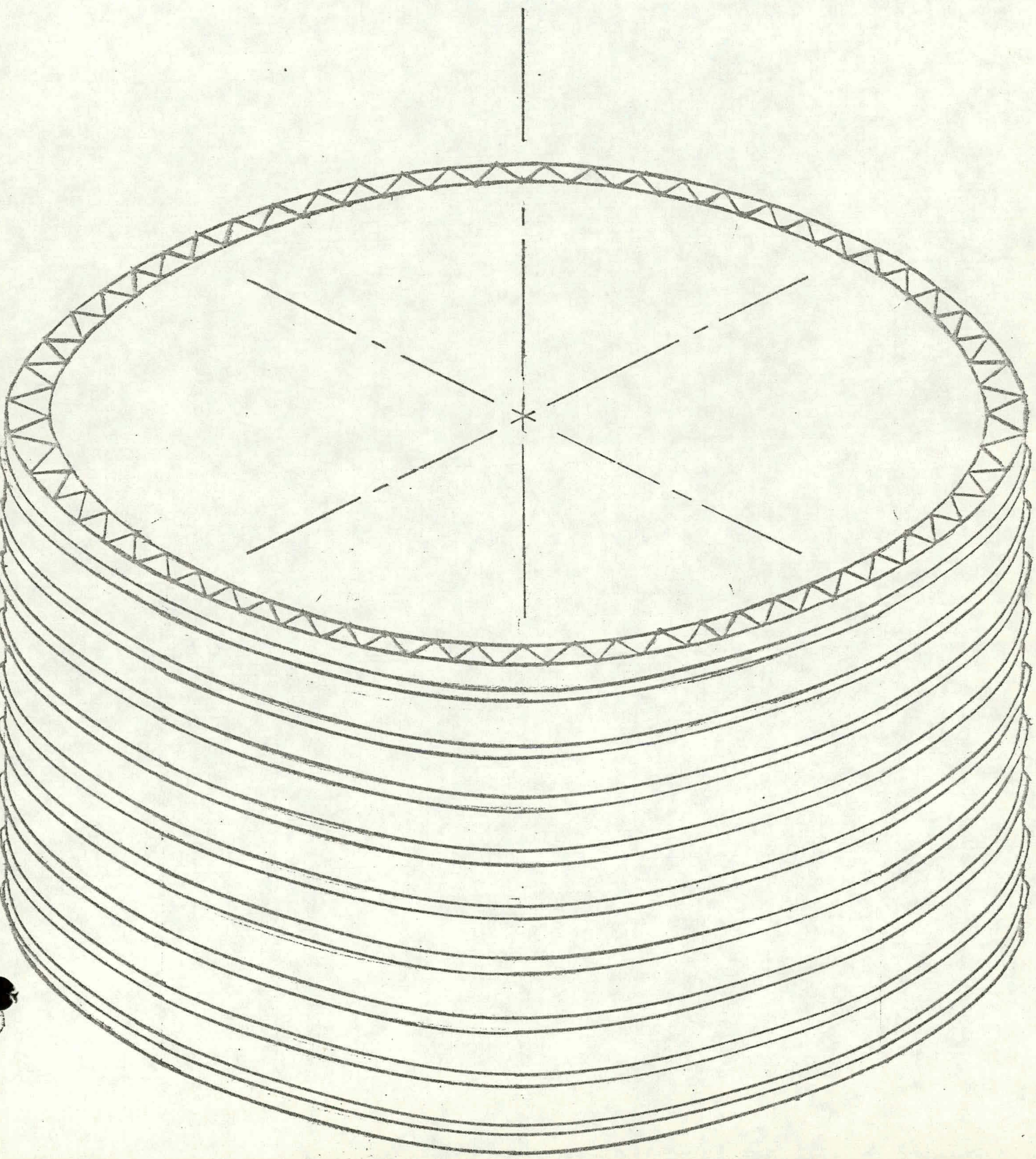




SAI
FIBERGLASS CWP,
LONGITUDINAL CORREGATED
STIFFENERS 1/16

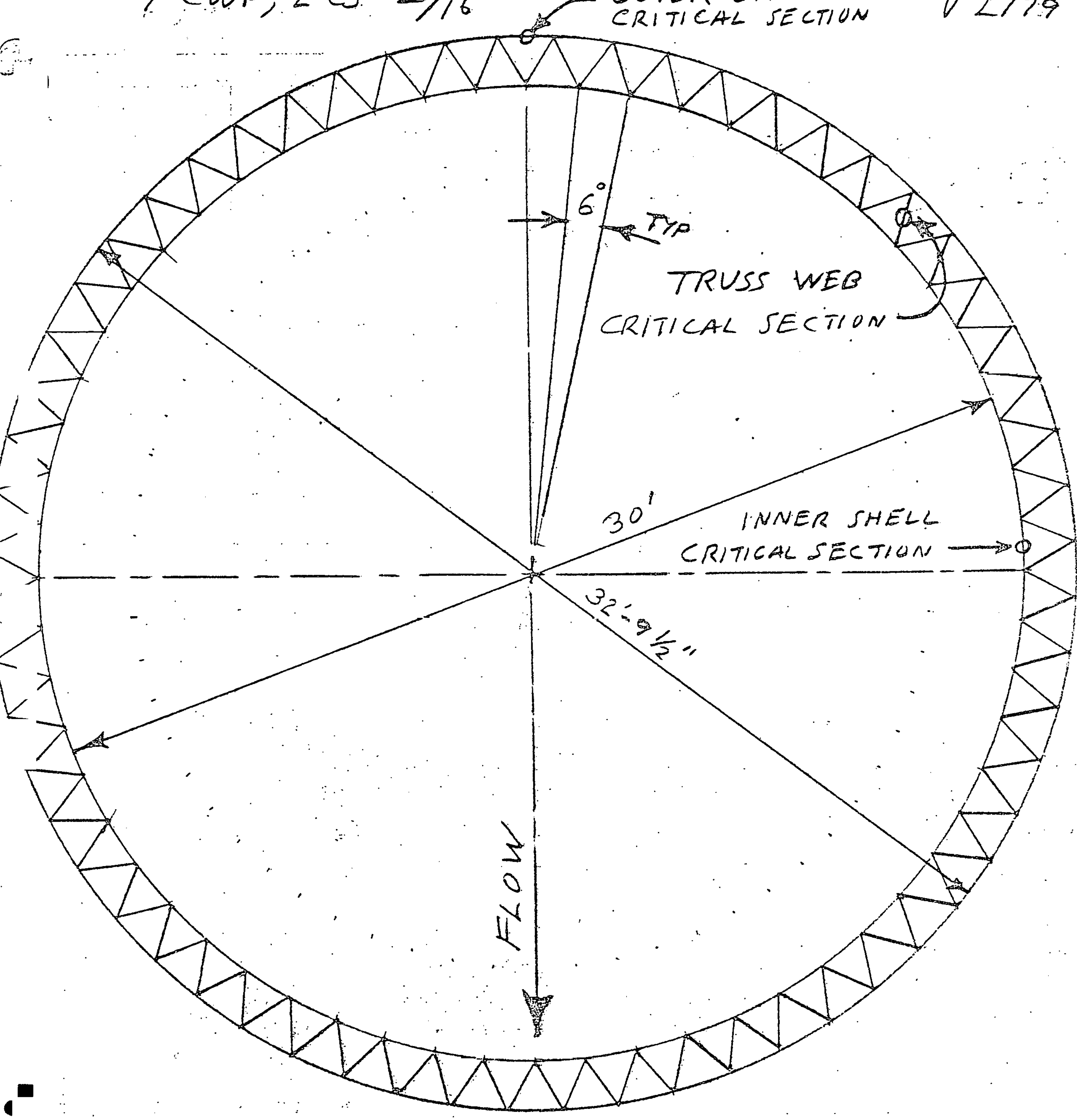
JB
2/79

TYPICAL SECTION

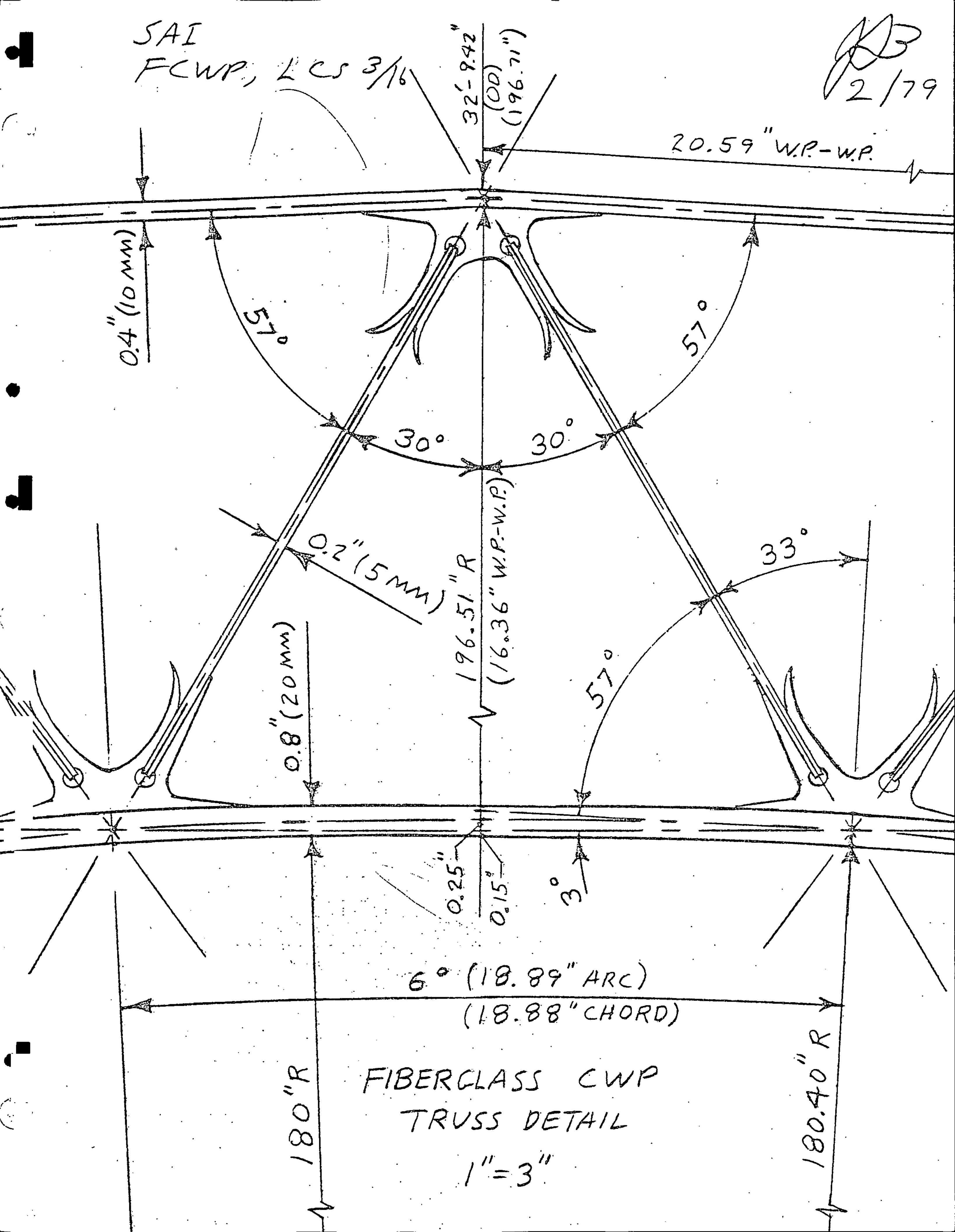


SAI
FCWP, LCS 2/16

JB
2/79



LONGITUDINALLY STIFFENED FIBERGLASS CWP
TYPICAL CROSS SECTION
&
CRITICAL DESIGN LOCATIONS


SAI
FCWP, LCS 3/16
2/79
32'-9.42"
(OD)
(196.71")
20.59" W.P.-W.P.
0.4" (10MM)
57°
57°
30°
30°
0.2" (5MM)
196.51" R
(16.36" W.P.-W.P.)
33°
57°
0.8" (20MM)
0.25"
0.15"
3°
6° (18.89" ARC)
(18.88" CHORD)
180" R
180.40" R
FIBERGLASS CWP
TRUSS DETAIL
1"=3"

SAI

F. CWP, LCS 4/16

2/79

FOR PRELIMINARY SIZING CONSIDER A CWP OF UNIFORM CROSS-SECTION

(BECAUSE OF CONSTRUCTION, TRANSPORTATION, & INSTALLATION LOADS, AS WELL AS OPERATIONAL LOADS

<u>IN THE CALCULATIONS ASSUME THAT:</u>

THE SYMMETRIC UNIFORM PRESSURE IS,

$P_u = 3$ psi	EXTERNAL	$= 30$ PSI	INTERNAL

THE ASSYMETRIC STAGNATION PRESSURE IS,

$\boxed{P_0 = 0.3 \text{ psi}}$

(RATHER THAN USING UNIT LOADS, THUS OTHER CONDITIONS CAN BE READILY PRORATED, YET BASIC CALCULATIONS SIMULATE OPERATIONAL LOADS)

FOR UNIFORM PRESSURE LOADING ON THE INNER SHELL ASSUME THAT THE RELATIVE STIFFNESSES ARE SUCH THAT 25% OF

($F = .25 P_u R$ & $= .25 P_u R$) THE LOAD GETS TRANSFERED TO THE OUTER SHELL AND 75% REMAINS IN THE INNER SHELL.

($= .12 P_0 R$ & $= .36 P_0 R$) FOR ASSYMETRIC PRESSURE LOADING ASSUME THE SAME DISTRIBUTION (DUE TO SHEAR LAG)

(NOTE, WITH RIGID WEBS THE DISTRIBUTION WOULD BE 33⅓% & 66.7%)

ASSUME EFFECTIVE "PLATE E" ($E^* = \frac{E}{1-\nu^2}$) OF:

FOR INNER & OUTER CYLINDERICAL SHELLS

$E_c = 3 \times 10^6$ psi	CIRCUMFERENTIALLY
$E_a = 1 \times 10^6$ psi	AXIALLY

FOR THE TRUSS WEBS

$\boxed{E_w = 2 \times 10^6 \text{ psi}}$

SAI

FCWP, LCS 5/16 2/79

PRELIMINARY CONSIDERATIONS

EQUIVALENT THICKNESS (FOR WEIGHT CALCS)

$t_{inner} = 0.8 \qquad\qquad = 0.800$

$t_{outer} = 0.4\left(\frac{20.59}{18.89}\right) = 0.436$

$t_{web} = 0.2\left(\frac{16\times 2}{18.89}\right) = \underline{0.339}$

$\qquad\qquad\qquad\qquad 1.575$

$t_{BOND\ BARS} = \qquad\qquad \underline{.4}$

$\qquad\qquad\qquad\qquad 1.975$

SAY THAT THE EQUIVALENT THICKNESS IS 2"

$\boxed{t_{eq} = 2''}$

AIR WEIGHT (1.80 SP.GR. ⇒ .065 #/in³)

$W_a = \{[.065(360\pi \times 2)]\, 12\} \times 3000$

$\{1764\ \#/Ft\} \times 3000' = 5,300,000\ \#$

SAY ADD 700,000# (13%) FOR OUTER SHELL STIFFENERS, TOLERANCES, & MISC.

$\boxed{W_a = 6 \times 10^6\ \#}$

SUBMERGED WEIGHT

$\frac{112-64}{112} = 43\%$ OF AIR WT

$W_s = .43 \times 6 \times 10^6 = 2.58 \times 10^6$

$\boxed{W_s = 2.6 \times 10^6\ \#}$

AXIAL STRESS (ASSUMING 300K INLET)

$\sigma = \frac{P}{A} = \frac{(2.6 + .3)\times 10^3}{360\pi \times 2} = 1.28$

$\boxed{\sigma \approx 1.3\ \text{KSI}}$ @ TOP

$\boxed{\sigma \approx 0.15\ \text{KSI}}$ @ BOTTOM

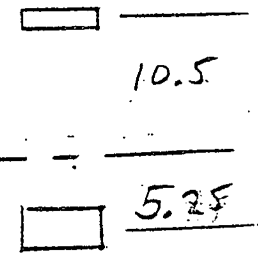
SAI

FCWP, LCS 6/16

2/79

CHECK OVERALL BUCKLING OF CYLINDER

TRUSS MOMENT OF INERTIA PER INCH



$I \approx .4 \times 10.5^2 + .8 \times 5.25^2$ (44) (22)

$\boxed{I \approx 66\ in^4/in}$

CRITICAL UNIFORM PRESSURE (NOT REALLY APPLICABLE SINCE NOT A THIN WALL TUBE)

$$P_{cr} = \frac{3EI}{R^3}$$

$$P_{cr} = \frac{3(3\times10^6)\times 66}{181 \times 185^2}$$

$P_{cr} = 96\ psi > 3\ psi$ ∴ OK THOUGH NOT APPLICABLE

CHECK LOCAL BUCKLING

FOR EFFECTIVE LENGTHS ASSUME:

L = 18" FOR INNER SHELL PANEL
L = 18" FOR OUTER SHELL PANEL
L = 9" FOR WEB PANEL

$$\sigma_{cr} = \frac{\pi^2}{12} E \left(\frac{t}{L}\right)^2$$

(THIN PANEL EULER BUCKLING ONLY PARTIALLY APPLICABLE)

FOR INNER SHELL

$*\ \sigma_{cr} = \frac{\pi^2}{12} \times 3\times10^6 \left(\frac{.8}{18}\right)^2 = 4{,}870$ ∴ $\boxed{\text{SAY } \sigma_{cr} = 4800\ psi}$

FOR OUTER SHELL

$\sigma_{cr} = \frac{\pi^2}{12} \times 3\times10^6 \left(\frac{.4}{18}\right)^2 = 1{,}220$ ∴ $\boxed{\text{SAY } \sigma_{cr} = 1200\ psi}$

FOR WEB

$\sigma_{cr} = \frac{\pi^2}{12} \times 2\times10^6 \left(\frac{.2}{9}\right)^2 = 810$ ∴ $\boxed{\text{SAY } \sigma_{cr} = 800\ psi}$

* NOTE THAT FOR A CHECK; ($n = \frac{60\ \text{NODES}}{2} = 30$ WAVES):

$\sigma_{cr} = \frac{(n^2-1)}{}\left(\frac{E}{}\right)\left(\frac{t}{R}\right)^2 = \left(\frac{30^2-1}{}\right)(3\times10^6)\left(\frac{.8}{180}\right)^2 = 4{,}440\ psi$ ∴ OK

SAI

FCWP, LCS 7/16

2/79

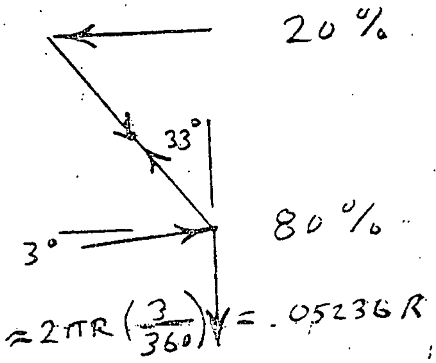
UNIFORM LOADING LOADS (@ 3 PSI LOADING)

COMPRESSION IN OUTER SHELL

$C_o = -.25 P_u R$	$= -45 P_u$	$= -135$ #/in

COMPRESSION IN INNER SHELL

$C_i = -.75 P_u R$	$= -135 P_u$	$= -405$ #/in



TENSION IN WEB

$$T_w = \frac{.25 \left[2\pi R\left(\frac{3}{360}\right)\right] P_u}{\cos 33} = .0156\, P_u R$$

$T_w = +.0156 P_u R$	$= +2.8 P_u$	$= +8.4$ #/in

UNIFORM LOADING STRESSES (@ 3 PSI EXTERNAL)

COMPRESSION IN OUTER SHELL

$\sigma_o = \frac{C_o}{.4} = \frac{-45}{.4} P_u =$	$-113 P_u =$	-338 psi

COMPRESSION IN INNER SHELL

$\sigma_i = \frac{C_i}{.8} = \frac{-135 P_u}{.8} =$	$-169 P_u =$	-507 psi

TENSION IN WEB

$\sigma_w = \frac{T_w}{.2} = \frac{2.8 P_u}{.2} =$	$+14 P_u =$	$+42$ psi

NOTE: 30 PSI INTERNAL PRESSURE FOR UPENDING DURING DEPLOYMENT IS SIMPLY 10 TIMES THESE STRESSES AND OPPOSITE IN SENSE.

SAI

FCWP, LCS 8/16 2/79

ASSYMETRIC LOADING (@ $P_0 = .3$ psi)

AT NOSE OF PIPE

MOMENT INDUCED FORCES IN SHELLS (OUTER & INNER)

$$F = \frac{M}{d} = \frac{.48 P_0 R^2}{d} = \frac{.48(185 \times 196)P_0}{15.75} = \pm 1105 P_0 = \pm 331 \text{ \#/in}$$

$F_o = -1105 P_0$	$= -331$ #/in	COMP
$F_i = +1105 P_0$	$= +331$ #/in	TEN

BENDING INDUCED STRESSES IN SHELL (OUTER & INNER)

$\sigma_o = \frac{-1105 P_0}{.4} = -2762 P_0$	$= -828$ psi	C	$\sigma_o = \frac{Mc}{I} = \left\{\frac{.48(185 \times 196).3}{66}\right\} 10.5 = -83[illegible]$
$\sigma_i = \frac{1105 P_0}{.8} = +1381 P_0$	$= +414$ psi	T	CHECK $\sigma_i = \{ \quad \} 5.25 = +415$

DIRECT HOOP FORCES IN SHELLS (OUTER & INNER)

$$F = N = .48 P_0 R = .48(196)P_0 = 94 P_0 = 28 \text{ \#/in (TENSION)}$$

$F_o = .25 N =$	$+24 P_0$	$= +7$ #/in	T
$F_i = .75 N =$	$+70.5 P_0$	$= +21$ #/in	T

DIRECT HOOP LOAD STRESSES IN SHELLS

$\sigma_o = \frac{23.5 P_0}{.4}$	$= +59 P_0$	$= +18$ #/in	T
$\sigma_i = \frac{70.5 P_0}{.8}$	$= +88 P_0$	$= +27$ #/in	T

AT THE SIDES (85° FROM NOSE) THE FORCES ARE

$\left(\frac{.46}{.48}\right) = 96\%$ OF THE MAGNITUDES AT THE NOSE, BUT REVERSED IN SENSE

SAI

FCWP, LCS 9/16

2/79

AT THE LEADING QUARTER POINTS (@ 44°)

THE "SHEAR INDUCED FORCE" IN THE DIAGONAL WEBS

$$F = \frac{V}{\cos\phi} = \frac{1.00 P_o R}{\cos\phi} = \frac{1.00(188) P_o}{\cos 31.5} = \pm 220\, P_o = \pm 66\ \#/in$$

$F =$	$\pm 220\, P_o$	$= \pm 66\ \#/in$

T & C

SHEAR INDUCED STRESSES IN THE DIAGONAL WEBS

$\sigma_w = \dfrac{\pm 220\, P_o}{.2}$	$= \pm 1100\, P_o$	$= \pm 330\ psi$

T & C

SAI

FCWP, LCS 10/16

JB 2/79

(#/IN)

		FORCES		STRESSES		
COMP.	V	$-220P_o$	-66	$-1100P_o$	-330	↘(330
	U	$+3P_u$	$+8$	$+14P_u$	$+42$	-420
	TOTAL		$\boxed{-58}$	—	$\boxed{-288}$	↘(23
TENS.	V	$+220P_o$	$+66$	$+1100P_o$	$+330$	
	U	$+3P_u$	$+8$	$+14P_u$	$+42$	-420
	TOTAL		$+74$	—	$+372$	

$\boxed{-459\ \#/in \quad (-1148\ psi)}$

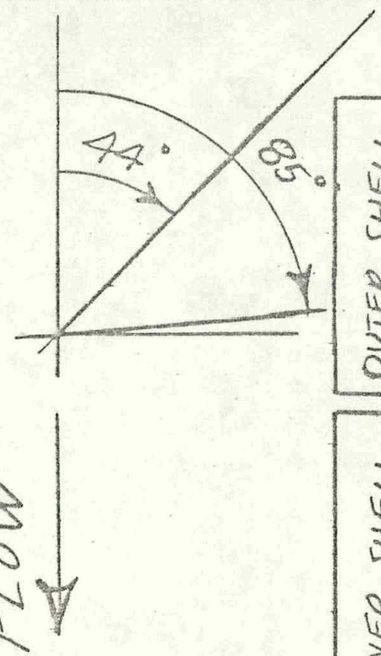
$-53\ \#/in \quad (-66\ psi)$

$\boxed{-58\ \#/IN \quad -288\ psi}$

$+74\ \#/IN \quad (+372\ psi)$

(#/IN)

		FORCES		STRESSES		
OUTER SHELL	M	$-1105P_o$	-331	$-2762P_o$	-828	
	N	$+24P_o$	$+7$	$+59P_o$	$+18$	
	Σ	$-1081P_o$	-324	$-2703P_o$	-810	
	U	$-45P_u$	-135	$-113P_u$	-338	$+3380$ ↘(2704)
	TOTAL		$\boxed{-459}$	—	$\boxed{-1148}$	↘(918)
INNER SHELL	M	$+1105P_o$	$+331$	$+1381P_o$	$+414$	
	N	$+71P_o$	$+21$	$+88P_o$	$+27$	
	Σ	$+1176P_o$	$+352$	$+1469P_o$	$+441$	
	U	$-135P_u$	-405	$-169P_u$	-507	$+5070$ ↘(4056)
	TOTAL		-53	—	-66	



(#/IN)

		FORCES		STRESSES		
OUTER SHELL	M	$+1059P_o$	$+317$	$+2647P_o$	$+793$	
	N	$-23P_o$	-7	$-57P_o$	-17	
	Σ	$+1036P_o$	$+310$	$+2590P_o$	$+776$	
	U	$-45P_u$	-135	$-113P_u$	-338	$+3380$
	TOTAL		$+175$	—	$+438$	
INNER SHELL	M	$-1059P_o$	-317	$-1323P_o$	-397	
	N	$-68P_o$	-21	$-84P_o$	-25	
	Σ	$-1127P_o$	-338	$-1408P_o$	-422	
	U	$-135P_u$	-405	$-169P_u$	-507	$+5070$ ↘(4056)
	TOTAL		$\boxed{-743}$	—	$\boxed{-929}$	↘(743)

$\boxed{-743\ \#/IN \quad -929\ psi}$

$+175\ \#/IN \quad +438\ psi$

SAI

F.CWP, LCS 11/16

JB 2/79

INNER SHELL (CRITICAL @ SIDE (85°))

$F.S. = \frac{4800}{929} = 5.2$	≈ 5	∴ OK

WEB (CRITICAL @ LEAD QUARTER POINT (44°))

$F.S. = \frac{800}{288} = 2.8$	≈ 3	HOWEVER $= \frac{800}{420} = 1.9 \approx 2$ (FOR UPENDING UNIFORM PRESSURE

OUTER SHELL (CRITICAL @ NOSE)

$FS = \frac{1200}{1148} = 1.0$	≈ 1	∴ REQUIRES STIFFENERS

(RECOMMEND INCREASING WALL THICKNESSES

(STAYING WITHIN WEIGHT CONSTRAINT OF 3,300 K SUBMERGED WEIGHT; SAY USE = 1", 1/2", & 1/4" INSTEAD OF .8, .4, & .2)

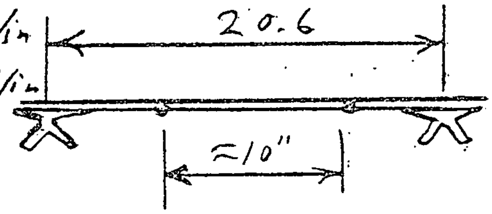
SAI

FCWP, LCS 12/16 2/79

LOCAL STRESSES IN OUTER SHELL PANEL DUE TO EXTERNAL PRESSURE ON PANEL

"ONE WAY" FLEXURAL STRESS (ULTRA CONSERVATIVE)

$$\sigma = \frac{M}{S} = \frac{\frac{w\ell^2}{8}}{\frac{t^2}{6}} = \frac{\frac{.3 \times 10^2}{8}}{\frac{.4^2}{6}} = \frac{3.75 \text{ in-lb/in}}{.0267 \text{ in}^3/\text{in}}$$



$$\boxed{\sigma = \pm 140 \text{ psi}}$$

NOTE THAT THIS WILL BE GREATLY REDUCED (SAY BY ONE HALF) BY "TWO WAY" PLATE ACTION AND SECONDARY MEMBRANE ACTION. HOWEVER SECONDARY MEMBRANE ACTION DEFLECTION IS DETRIMENTAL TO BUCKLING RESISTANCE.

SAI

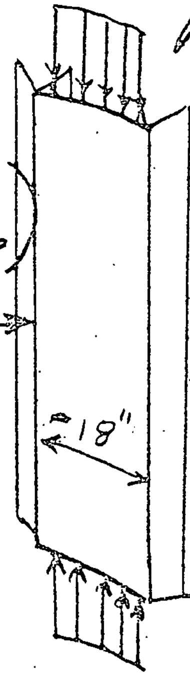
FCWP, LCS 13/16

LONGITUDINAL BUCKLING

2/29

$$\sigma_{cr} = \text{"}4\text{"}\left(\frac{\pi^2}{12}\right)\left(\frac{E}{1-\nu^2}\right)\left(\frac{t}{b}\right)^2$$

("4", IF S.S.
"7", IF CLAMPED)
ALONG EDGES



INNER SHELL

$$\sigma_{cr} = 4\left(\frac{\pi^2}{12}\right)(2\times10^6)\left(\frac{.8}{18}\right)^2$$

$\sigma_{cr} = 13,000$ psi IF SS.

$= 22,750$ psi IF CLAMPED

ALTERNATE (ROARK P351 – K) (SS.)

$$\sigma_{cr} = \frac{1}{6}\left(\frac{E}{1-\nu^2}\right)\left[\sqrt{12(1-\nu^2)\left(\frac{t}{R}\right)^2 + \left(\frac{\pi t}{b}\right)^4} + \left(\frac{\pi t}{b}\right)^2\right]$$

$$\sigma_{cr} = \frac{1}{6}(2\times10^6)\left[\sqrt{12(.9)\left(\frac{.8}{180}\right)^2 + \left(\frac{\pi\times.8}{18}\right)^4} + \left(\frac{\pi\times.8}{18}\right)^2\right]$$

(NOTE THAT THESE ARE IDENTICAL IF $R \to \infty$)

$\sigma_{cr} = 14,618$ psi (S.S.) (A 12% INCREASE DUE TO CURVATURE)

$\boxed{\text{SAY USE } \sigma = 15,000 \text{ psi FOR INNER SHELL}}$

(NOTE THAT THERE IS STILL A LOT OF RESERVE LOAD CARRYING CAPACITY REMAINING EVEN AFTER THIS BUCKLING STRESS IS REACHED LOCALLY NEAR THE CENTER OF THE PANEL.)

OUTER SHELL

$$\sigma_{cr} = 4\left(\frac{\pi^2}{12}\right)(2\times10^6)\left(\frac{.4}{18}\right)^2$$

$\sigma_{cr} = 3250$ psi IF SS.

$\sigma_{cr} = 5700$ psi IF CLAMPED

$\boxed{\text{SAY USE } \sigma = 4,000 \text{ psi FOR OUTER SHELL}}$

(NOTE THAT A LARGE RESERVE REMAINS)

WEB

$$\sigma_{cr} = 4\left(\frac{\pi^2}{12}\right)(2\times10^6)\left(\frac{.2}{9}\right)^2$$

$\sigma_{cr} = 3,250$ psi IF SS

$\boxed{\text{SAY USE } \sigma = 4,000 \text{ psi FOR WEB}}$

NOTE: BASE PIPE BENDING MOMENT CAPACITY ON 12,000 psi ON GROSS AREA

SAI

FCWP, LCS 14/16

EFFECTIVE AXIAL STIFFNESS (EA)

$EA = (1\times10^6)(360\pi\times2) = 2.26\times10^9$ #

$EA_{CWP} = 2.25\times10^9$ #	$= 2.25\times10^6$ K

CHECK LONGITUDINAL VIBRATION

$T = \frac{2L}{(n-\frac{1}{2})}\sqrt{\frac{m}{EA}}$ ← PERIOD

FOR A UNIFORM FIBERGLASS PIPE

$\frac{m}{A} = \frac{0.065}{386} \quad \frac{\#/in/in^2}{in/sec^2}$ (IN AIR)

$\frac{m}{A} = \frac{0.065}{386}(1+\eta) \quad \frac{\#\ sec^2}{in^4}$ (IN SEAWATER WHERE η IS THE ADDED MASS FACTOR

ADDED MASS FACTOR

η OUTER SKIN RING STIFFENERS ≈ 0.16

η SEA WATER ≈ 0.83

$\boxed{1.0 \approx \eta}$

SO PERIOD IS

$T = \frac{2(3\cancel{000}\times12)}{(n-\frac{1}{2})}\sqrt{\frac{.065(1+1)}{386\times1\times\cancel{10^6}}} = 2.64$ SEC

$\boxed{T \approx 2.67 \text{ SEC}}$ ← PERIOD OF FIRST NATURAL FREQ.

SAI

FCWP, LCS 15/16

2/79

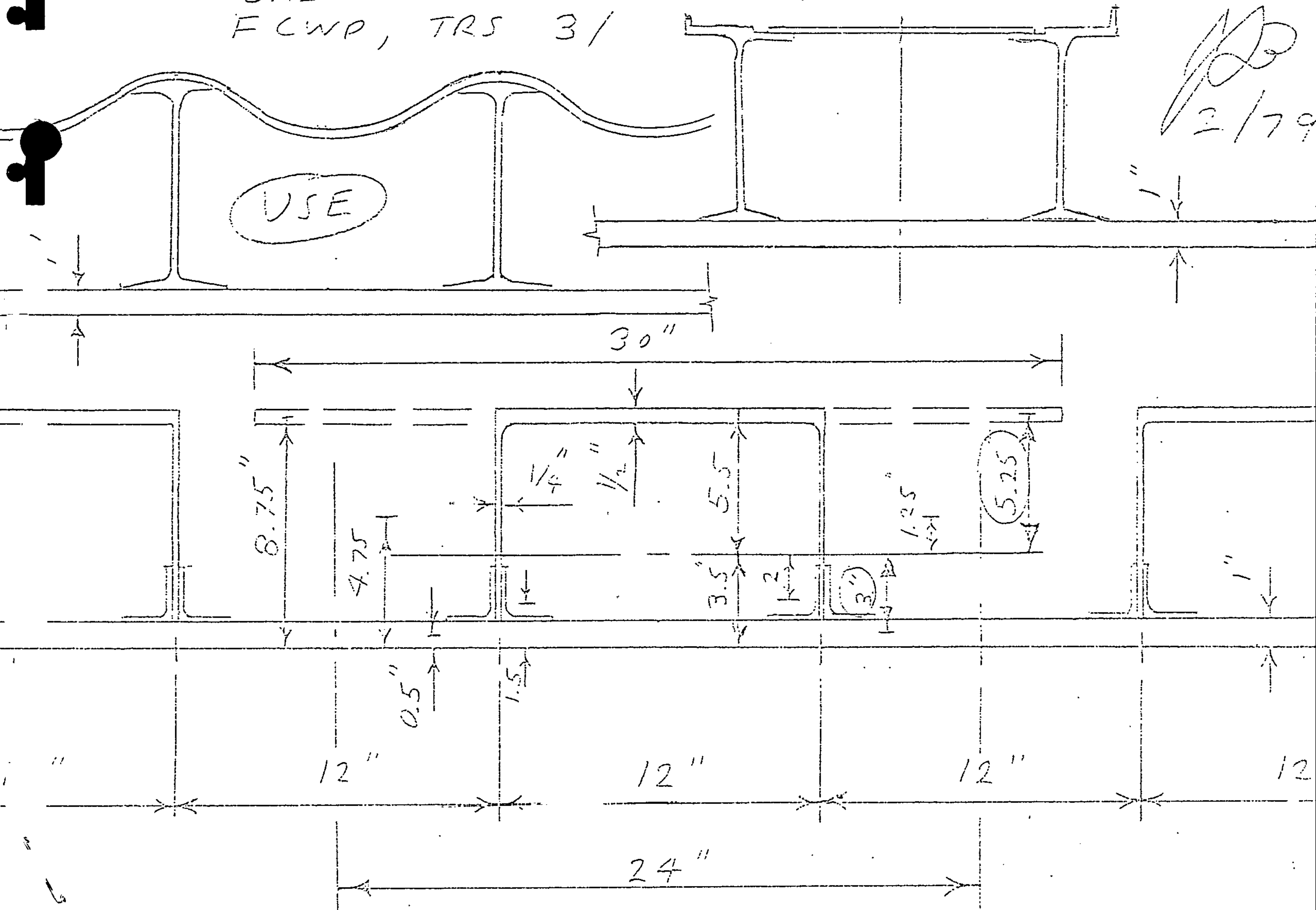
EFFECTIVE FLEXURAL STIFFNESS EI

$EI = E(\pi r^3 t) = 1\times10^6 (\pi\ 184^3 \times 2) = 3.9\times10^{13}\ \#\ in^2$

$\boxed{EI_{cwp} = 3.9\times10^{13}\ \#\ in^2 = 3.9\times10^{10}\ K\ in^2}$

SAI
FCWP, TRS 31

2/79



LOCATE THE NA

$$\bar{y} = \frac{\sum y_i A_i}{\sum A_i} = \frac{.5(24) + 8.75(15) + 4.75(3.75) + 1.5(4)}{(24 \times 1) + (30 \times 1/2) + (7.5 \times 1/2) + (4)} = \frac{167}{46.75}$$

9 + 6

$= 3.57$

SAY $\bar{y} = 3.5"$

$I \approx I_{FLANGES} + 6\%$

$$I = [24(3.5)^2 + 15(5.25)^2](1 + .06)$$
$$= [294 + 413](1.06) = 750 / 24" \text{ SPAN}$$

CIRCUMFERENTIAL MOMENT OF INERTIA OF RING

$I = 750$ IN^4/24" SPAN	(TRANSFORMED SECTION)

CIRCUMFERENTIAL AREA OF RING

$A = 47$ IN^2/24" SPAN	(TRANSFORMED AREA FOR STRESS CALCULATIONS)
$A = 38$ IN^2/24" SPAN	(ACTUAL AREA FOR WEIGHT CALCULATIONS)

SAI

FCWP, TRS 4/

12/79

CRITICAL UNIFORM PRESSURE

$$P_{cr} = \frac{3\,EI}{R^3}$$

$$P_{cr} = \frac{3\,(2\times10^6)\,750}{180.5\,(183.5)^2\,[24]} = 30.9\ psi$$

$\boxed{P_{cr} = 31\ psi}$ ← OVERALL BUCKLING PRESSURE

STRESSES DUE TO ASSYMETRIC LOADING (@ 0.3 PSI)

$M = 0.48\ P_o\ R^2$ (IN#/IN)

$M = 0.48 \times 180.5^2 \times P_o = 15,640\ P_o = 4691$ IN#/IN

$M = +15,640\ P_o$	$= +4690$ IN#/IN	@ NOSE
$M = +375,300\ P_o$	$= +112,560$ IN#/24"	

$M = -14,990\ P_o$	$= -4496$ IN#/IN	@ SIDES
$M = -359,690\ P_o$	$= -107,900$ IN#/24"	$\left(-\frac{.46}{.48}\right.$ of NOSE)

BENDING STRESS IN RING

MAIN SHELL

$$\sigma = \frac{Mc}{I} = \frac{375,300\ P_o \times 3.5}{750} = +1752\ P_o = +525\ Psi$$

$\sigma = +1752\ P_o$	$= +525$ Psi	TENSION @ NOSE
$\sigma = -1679\ P_o$	$= -504$ Psi	COMPRESSION @ SIDES

RING FLANGE

$$\sigma_{RF} = \frac{Mc}{I} = \left(\frac{5}{2}\right)\left(\frac{5.5}{3.5}\right)\sigma_{RS}$$

$\sigma = -6881\ P_o$	$= -2064$ Psi	COMPRESSION @ NOSE
$\sigma =$ [illegible]	$=$ [illegible] Psi	TENSION @ SIDES

SAI

FCWP, TRS 5/

2/79

ASSYMETRIC HOOP LOAD IN RING

$F = N = 0.48\,P_0 R = 0.48 \times 180.5\,P_0 = 87\,P_0 = 26$ #/IN

$F = +87\,P_0$	$= +26$ #/IN	
$F = +2079\,P_0$	$= +624$ #/24 IN	TENSION @ NOSE

$F = -83\,P_0$	$= -25$ #/IN	
$F = -1993\,P_0$	$= -598$ #/24 IN	COMPRESSION @ SIDES

ASSYMETRIC HOOP STRESSES IN RING

$\sigma = \frac{P}{A} = \frac{+2079\,P_0}{47} = 44\,P_0 = 13$ #/IN

$\sigma = +44\,P_0$	$= +13$ PSI	TENSION @ NOSE
$\sigma = -43\,P_0$	$= .13$ PSI	COMPRESSION @ SIDES

RING FLANGE

$\sigma_{RF} = \left(\frac{5}{2}\right)\sigma_{MS}$

$\sigma = +111\,P_0$	$= +33$ PSI	TENSION @ NOSE
$\sigma = -107\,P_0$	$= -32$ PSI	COMPRESSION @ SIDES

ASSYMETRIC SHEAR LOADING @ LEADING QUARTER

$V = 1.00\,P_0 R = 1.00 \times 180.5\,P_0 = 181\,P_0 = 54$ #/IN

$V = 181\,P_0$	$= 54$ #/IN	@ LEADING QUARTER
$V = 4332\,P_0$	$= 1300$ #/24 IN	

SHEAR STRESS DUE TO ASSYMETRIC LOADING

$\tau = \frac{\pm V}{A} = \frac{4332\,P_0}{2(.25 \times 9)} = 963\,P_0 = 289$ PSI

$\tau = \pm 963\,P_0$	$= \pm 289$ PSI	@ LEADING QUARTER

SAI

FCWP, TRS 6/

UNIFORM LOADING LOADS (@ 3 PSI)

RING COMPRESSIVE FORCE

$C_o = -P_m R = -180.5\, P_m = -542$ #/IN

$C_o = -181\, P_m$	$= -542$ #/IN
$C_o = -4332\, P_m$	$= -13{,}000$ #/24" RING

RING COMPRESSIVE STRESS

$$\sigma = \frac{C_o}{A} = \frac{-4332\, P_m}{.47} = -92\, P_m = -277 \text{ PSI}$$

RING STRESS IN SHELL & WEB

$\sigma = -92\, P_m$	$= -277$ PSI

COMPRESSION IN SHELL & WEB

RING STRESS IN FLANGE ($5/2 \times$ STRESS IN SHELL)

$\sigma = -230\, P_m$	$= -691$ PSI

SAI

FCWP, TRS 7/ 2/79

EQUIVALENT THICKNESS FOR WEIGHT CALCULATIO.

$t_{eq} = \left(\frac{183}{180}\right)\left(\frac{39}{24}\right) = 1.652$ INCHES

SAY THAT THE EQUIVALENT THICKNESS IS 1.67

$\boxed{t_{eq} = 1.67''}$

AIR WEIGHT (1.80 SP. GR. → .065 #/IN³)

$W_a = \left\{\left[.065(360\pi \times 1.67)\right]12\right\}3000'$

$\left\{1473\ \#/FT\right\}3000' = 4,420,000\#$

SAY ADD 330,000# (7½ % FOR JOINTS TOLERANCES ETC)

$\boxed{W_a = 4,750,000\#}$

SUBMERGED WEIGHT

$\frac{112-64}{112} = 43\ \%$ OF AIR WEIGHT

$W_s = .43 \times 4.75\times10^6 = 2.04\times10^6$

$\boxed{W_s = 2\times10^6\#}$

AXIAL STRESS (ASSUMING 300K INLET)

$\sigma = \frac{P}{A} = \frac{(2+.3)\times10^3}{360\pi\times1.0} = 2.03$

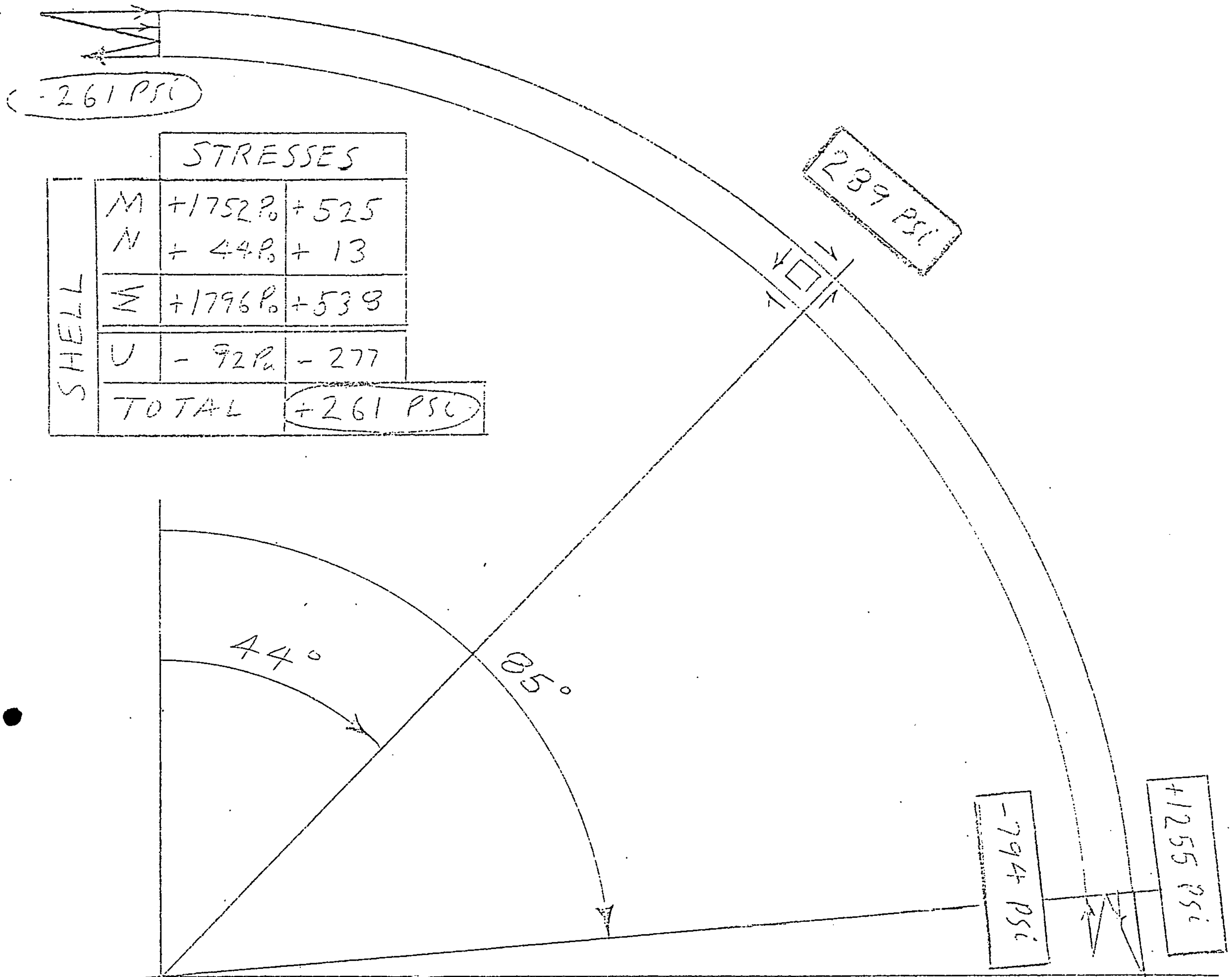
$\sigma = 2.0$ KSI	@ TOP
$\sigma = 0.27$ KSI	@ BOTTOM

SAI

FCWT, TRS 8/

JB
2/79

FLANGE	STRESSES	
M	$-6881 P_o$	-2064
N	$+111 P_o$	$+33$
Σ	$-6770 P_o$	-2031
U	$-230 P_u$	-691
TOTAL		-2722 PSI



SHELL	STRESSES	
M	$+1752 P_o$	$+525$
N	$+44 P_o$	$+13$
Σ	$+1796 P_o$	$+538$
U	$-92 P_u$	-277
TOTAL		$+261$ PSI

SHELL	STRESSES	
M	$-1679 P_o$	-504
N	$-43 P_o$	-13
Σ	$-1722 P_o$	-517
U	$-92 P_u$	-277

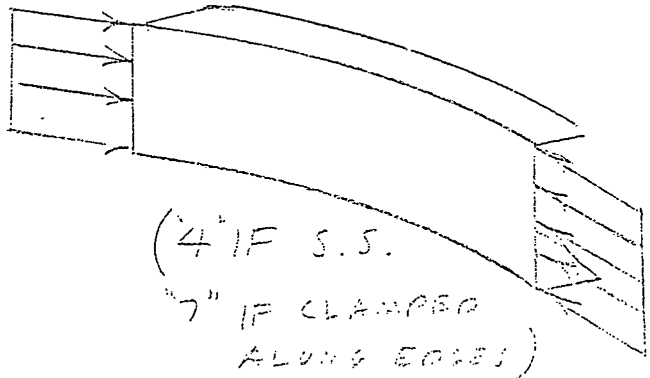
FLANGE	STRESSES	
M	$+6,594 P_o$	$+1973$
N	$-107 P_o$	-32
Σ	$+6487 P_o$	$+1946$
U	$-230 P_u$	-691

SAI

FCWP, TRS 9/

LOCAL CIRCUMFERENTIAL BUCKLING

IN SHELL WALL



$$\sigma_{cr} = \text{"}4\text{"}\left(\frac{\pi^2}{12}\right)\left(\frac{E}{1-\nu^2}\right)\left(\frac{t}{b}\right)^2$$

$$\sigma_{cr} = \text{"}4\text{"}\left(\frac{\pi^2}{12}\right)\left(2\times10^6\right)\left(\frac{1}{12}\right)^2$$

$$\boxed{\sigma_{cr} = 45{,}700 \text{ psi}}$$

("4" IF S.S.
"7" IF CLAMPED ALONG EDGES)

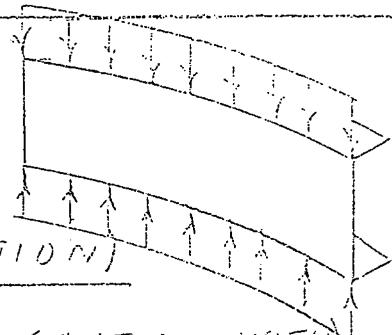
IN RING FLANGE

$$\sigma_{cr} = 4\left(\frac{\pi^2}{12}\right)\left(3\times10^6\right)\left(\frac{.5}{12}\right)^2$$

$$\boxed{\sigma_{cr} = 5450 \text{ PSI}}$$

(CAUTION)

LOCAL LONGITUDINAL BUCKLING IN SHELL WALL



$$\sigma_{cr} = \text{"}1\text{"}\left(\frac{\pi^2}{12}\right)\left(\frac{E}{1-\nu^2}\right)\left(\frac{t}{b}\right)^2$$

$$\sigma_{cr} = \text{"}1\text{"}\left(\frac{\pi^2}{12}\right)\left(2\times10^6\right)\left(\frac{1}{12}\right)^2$$

$$\boxed{\sigma_{cr} = 11{,}400 \text{ PSI}}$$

(CAUTION)

(EXTRA CAUTION WITH BIAXIAL STRESS)

RECOMMEND INCREASING WALL THICKNESSES (STAYING WITHIN WEIGHT CONSTRAINT OF 3,300 K SUBMERGED WT; SAY USE 1 1/4" WALL)

SAI

FCWP, TRS 10/

2/79

EFFECTIVE AXIAL STIFFNESS (EA)

$$EA = (2\times10^5)\times(360\,\pi\times1) = 2.26\times10^9 \ \#$$

$$\boxed{EA_{cwp} = 2.25\times10^9 \ \# = 2.25\times10^6 \ K}$$

CHECK LONGITUDINAL VIBRATION

$$T = \frac{2L}{(n-\frac{1}{2})}\sqrt{\frac{\mu}{AE}}$$ ← PERIOD

FOR A UNIFORM FIBERGLASS PIPE

$$\frac{\mu}{A} = \frac{0.065}{386} \ \frac{\#/in/in^2}{in/sec^2}$$ (IN AIR)

$$\frac{\mu}{A} = \frac{.065}{386}(1+\eta) \ \frac{\#\,SEC^2}{IN^4}$$ (IN SEAWATER WHERE η IS THE ADDED MASS FACTOR

ADDED MASS FACTOR

$$\eta_{(RIBS \,\&\, RING\ FLANGE)} = 1.67 - 1 = .67$$

$$\eta\,(SEA\ WATER\ ENTRAINED) \approx \frac{6}{\frac{1}{1.8}} = \ = 3.33$$

$$\boxed{4.0 \approx \eta}$$

∴ PERIOD IS:

$$T = \frac{2\,(3\cancel{000}\times12)}{(n-\frac{1}{2})}\sqrt{\frac{0.065\,(1+4)}{386\times2\cancel{\times10^6}}} = 2.95 \ SEC$$

$$\boxed{T \approx 3 \ SEC}$$ ← PERIOD OF FIRST NATURAL FREQ.

SAI

FCWP, TRS 11/

JB 2/79

EFFECTIVE FLEXURAL STIFFNESS EI

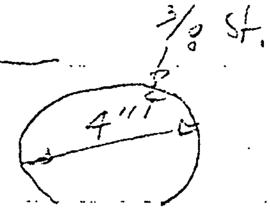
$$EI = E(\pi r^3 t) = 2\times10^6(\pi\, 180.5^3 \times 1) = 3.7\times10^{13}\ \#\,in^2$$

$EI_{cwp} = 3.7\times10^{13}\ \#/in^2$	$= 3.7\times10^{10}\ K\,in^2$

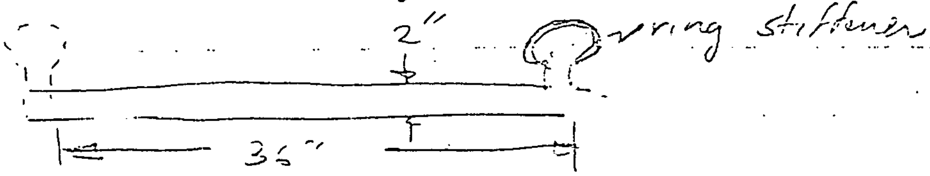
Thick Wall Polyethylene Pipe

Pressure loads –

	Sym ΔP Due to Long. Flow (psi)	Assym ΔP due to transverse Flow (psi)
Top 1000′	4.5	.3
Lower 2000′	1.5	.1

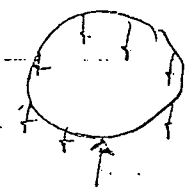


Assume the following sections



Fabrication load –

$$M_{max} = \frac{3}{2} wR^2$$



$$w = \frac{.95(62.4)}{1728}(2'' \text{ thk}) = .034(2'') = .069 \ \frac{lb}{in/in}$$

Assume 75% increase due to ring stiffeners

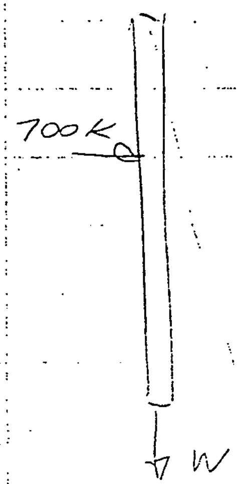
$$w = 1.75(.069) = .121 \ lb/in/in.$$

$$M_{max} = \frac{3}{2}(.121)180^2 = 5868 \ \frac{in\ lb}{in}$$

Assume that the total fabrication moment is carried by the steel reinforcing ring.

$$Z_{fab} = \frac{M_{max}}{\sigma_a} = \frac{5868}{30\,000} = .196 \ in^3/in.$$

Tension load requirements.



$$700\,\frac{\cancel{\delta}}{3} - W\,\cancel{\delta}\,\phi = 0$$

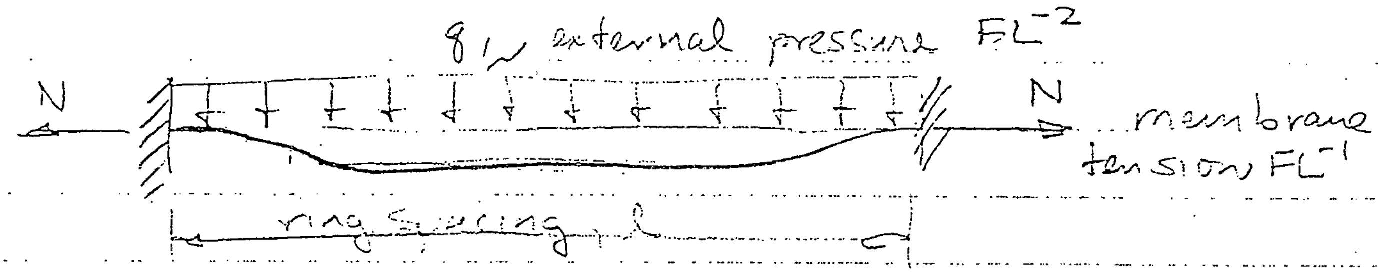
$$W = \frac{700}{3\phi} = \frac{700}{3(.175)} = 1.34\cdot 10^{6}\ \text{lb}$$

ϕ = 10°

This requirement can be reduced somewhat by considering the weight of steel in the ring stiffeners.

Membrane Effect

The question arises, is there as an axisymmetric shell shape which eliminates or reverses the compressive circumferential stresses which arise from external pressure. Consider a beam on an elastic foundation



The differential equation governing deflection of the pipe wall is

$$EI\, y_1^{(4)} - N y_1^{(2)} + K y_1 = q + y_2'' N \qquad (1)$$

where $y_2(x)$ is the initial shape of the pipe wall and $y_1(x)$ is the deflection relative to the initial undeformed shape.

If we wish the deflection due to the external pressure to be zero, then we require

$$q + y_2'' N = 0 \qquad (2)$$

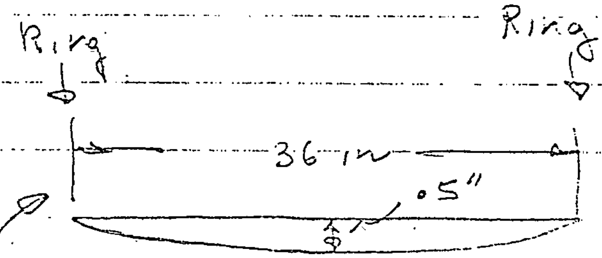
$$y_2'' = -\frac{q}{N} \qquad y_2 = 0 \text{ @ } x = 0, l$$

Integrating twice and simplifying —

$$y_2 = \frac{q\ell^2}{2N}\left(\frac{x}{\ell} - \left(\frac{x}{\ell}\right)^2\right) \quad \text{parabolic}$$

$$N \approx \frac{1.45 \cdot 10^6}{\pi \cdot 360} = 1282 \ \frac{lb}{in} \quad \text{Grazing}$$

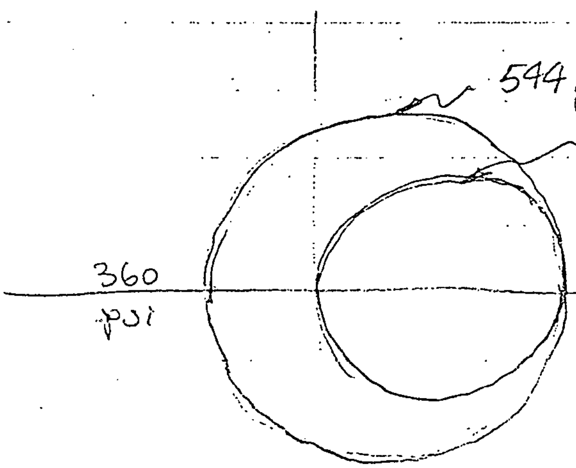
ring spacing, $\ell = 36''$



$q = 4$ psi

$$y_2\Big|_{x=\frac{\ell}{2}} = \frac{q\ell^2}{8N} = \frac{4\,(36)^2}{8\,(1282)} = .51 \text{ in. Use } .5 \text{ in.}$$

Effect on Maximum shear —



544 psi max shear without camber

364 psi max shear with camber

33% reduction in maximum shear.

Ring Stiffener Requirements

Based on fabrication $Z_{fab}/_{in} = .196 \frac{in^3}{in}$

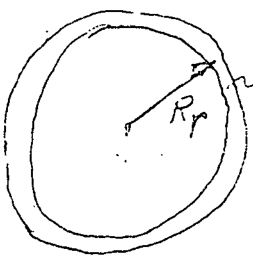
$l = 36$ $\quad Z_{fab} = 7.06\ in^3$ $\quad t = .375\ in$

Based on collapse pressure, 4 psi. $\quad R_r = \sqrt{\frac{7.06}{.375\pi}}$

$= 2.45\ in.$

$$l P_{cr} = \frac{3EI}{R^3}$$

$$I = \frac{R^3 P_{cr}}{3E} = \frac{180^3 \cdot P_{cr}}{3(30)\cdot 10^6} = .065\ P_{cr}\, l$$



$I = \pi R_r^3 t$

$Z = \pi R_r^2 t$

$I = Z R_r$

Using ring based on fab loads

$I = 7.06(2.45) = 17.3\ in^4$

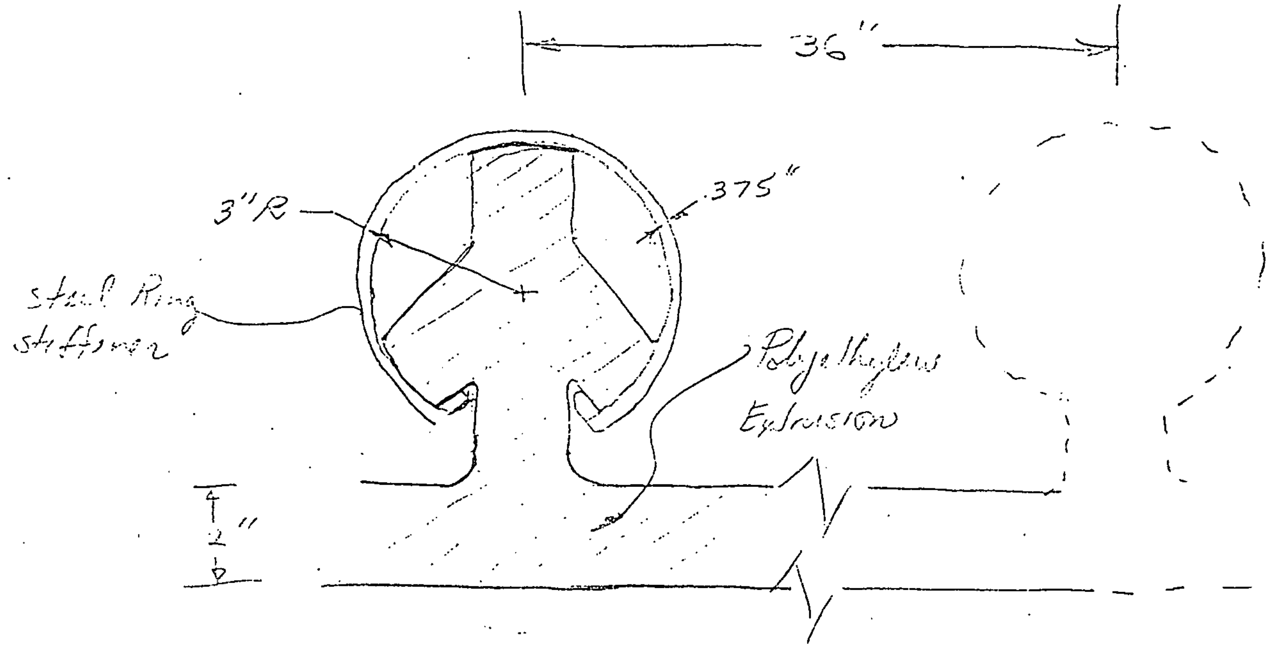
$$P_{cr} = \frac{I}{.065 l} = \frac{17.3}{.065(36)} = 7.39\ psi$$

Increase R_r to 3 in.

$I = \pi R_r^3 t = \pi (3)^3 (.375) = 32\ in^4$

$$P_{cr} = \frac{I}{.065 l} = \frac{32}{.065(36)} \doteq 13.68\ psi$$

$\therefore$ External pressure is more significant than fab loads in upper pipe section in establishing reinforcement requirements. Rings should be 6" diameter, .375" thick, on 36" ctrs.



weight

for a 36" Draft

wt Ring $= 2\pi R(\pi D_r t \gamma_s) = 2\pi^2 R D_r t \gamma_s$

$= 2\pi^2 180(6)\frac{3}{8}(.27) = 2158$ lb.

wt of polyethylene $= \dfrac{(2(36)+20).2(180)\pi(.95)62.4}{1728}$

$= 3569$ lb. (+ wt of Ring) $= 5727$

$w/ft = 1909$ (in air)

Volume $= \dfrac{1}{3}\left(\dfrac{2158}{.27(1728)} + \dfrac{3569}{.95(62.4)}\right) = 21.61\ ft^3/ft$

weight in water $= 1909 - 21.61(62.4) = 560$ lb/ft

$I = \pi R^3 t = \pi(15^3)\frac{1}{6} = 1767\ in^4$ $E = 5.76 \cdot 10^6$ lb/in² $EI = 1.02 \cdot 10^{10}$

[illegible] Natural Frequencies in Heave

$$\omega_n = \frac{\pi}{2l}\sqrt{\frac{Eg}{\gamma}},\ \frac{3\pi}{2l}\sqrt{\frac{Eg}{\gamma}},\ \frac{5\pi}{2l}\sqrt{\frac{Eg}{\gamma}}$$

$l = 3000\ ft$

$E = 10^5\ psi = 1.44 \cdot 10^7\ lb/ft^2$

$g = 32.2\ ft/sec^2$

$\gamma \geq \frac{1909}{A}\ \frac{lb/ft}{ft^2} \quad A = 22.62\ in^2 = 15.71\ ft^2$

$\geq 121.5\ \frac{lb}{ft^3}$

$$\omega_n \leq \frac{\pi}{2(3000)}\sqrt{\frac{1.44 \cdot 10^7\,(32.2)}{121.5}} = 1.02\ Rd/sec.$$

$= .163\ cps$

6 sec. period.

Approximate natural frequency in lateral vibration of polyethylene pipe wall. (8)

$$\omega_1 = (4.73)^2 \sqrt{\frac{EI}{m l^4}}$$

Can wall snap thru when tension oscillations are applied?

$E = 100000$ psi

$I = \frac{2^3}{12} = .67 \text{ in}^4$

$m = 1,776 \cdot 10^{-6} \frac{\text{lb sec}^2}{\text{in}}$

$l = 36$ in.

$$\frac{EI}{m l^4} = \frac{10^5 (.67)}{1.776 \cdot 10^{-6} (36)^4} = 22460.$$

$\omega_1 = 3353$ Rd/sec. It's unlikely wall could snap through.

PW 5/79

Polyethylene Cost Notes

10 F/C/I facilities/Equipment	$1000	Range $1000.
Extrusion die	100	75 – 200
Cutting Table	~~150~~ 75	50 – 100
Fabrication Fixture	200	100 – 300
Section Assembly Equipt.	1000	500 – 1500
Trench – flotation	3000	500 – 5000
	3375	$\underbrace{\hspace{3em}}_{1750\ -\ 6500}$

3.3.3 CWO Hull/Transition

Bearing

Seal

[illegible] Cont'd.

3.3 Cold water pipe system.

	$1000
Polyethylene	$ 3000
Extrusion	$ 1000
Transportation-on land	$ 90
Section Fab. ($600/section) (1 hr/section; 12 men)	200
Assembly. Butt fusion $600/section 1 hr/section 12 men	200.
Steel rings $2000 each*	2000.
Steel split rings. = $1800 each ** 1000 required	1800.
	8090.

3.3.4 Bio-Corrosion control

Cathodic protection

1000 tons = $165000.

* includes trimming, straightening, ~~and~~ set-up, and welding
** Includes material and welding

Costs, Cont'd.

Acceptance Testing

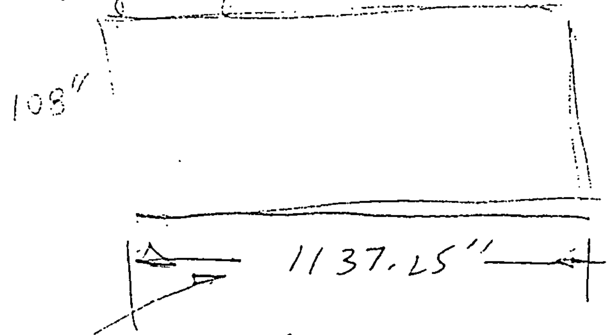
Assume 2 hrs - 2 men - each joint

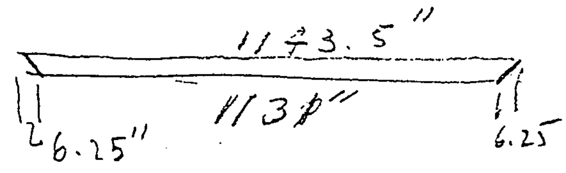
4 mhrs @ $25 = $100 / joint

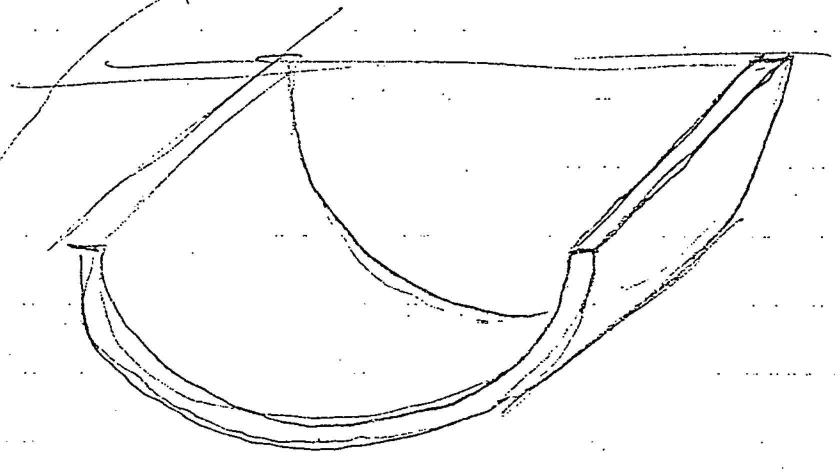
330 longitudinal } 660 joints. = 66 ($10
330 transverse } @ $100

Fusion equipment verification/testing 500 ($10

Polyethylene fabrication. PB 3/79 (1)







$$\frac{M}{EI} = \frac{1}{R}$$

$$M = \frac{EI}{R}$$

If fabrication is begun with 108" X 1137.25" flat sheets, when these are curve the compress/elongation in the inner and outer fibers is 6.32". Which will result in a parallel interface. However, residual strains will be retained of .0055 in/in or approx. 1/6 of allowable strain. This problem can be eliminated by one of two methods - curve the sheet in an approximate 180" radius as it is extruded; *anneal the pipe in a hot oil bath.

$$\sigma = \frac{M}{Z}$$

$$\sigma = \frac{EI}{RZ}$$

$$\epsilon = \frac{\sigma}{E} = \frac{I}{RZ}$$

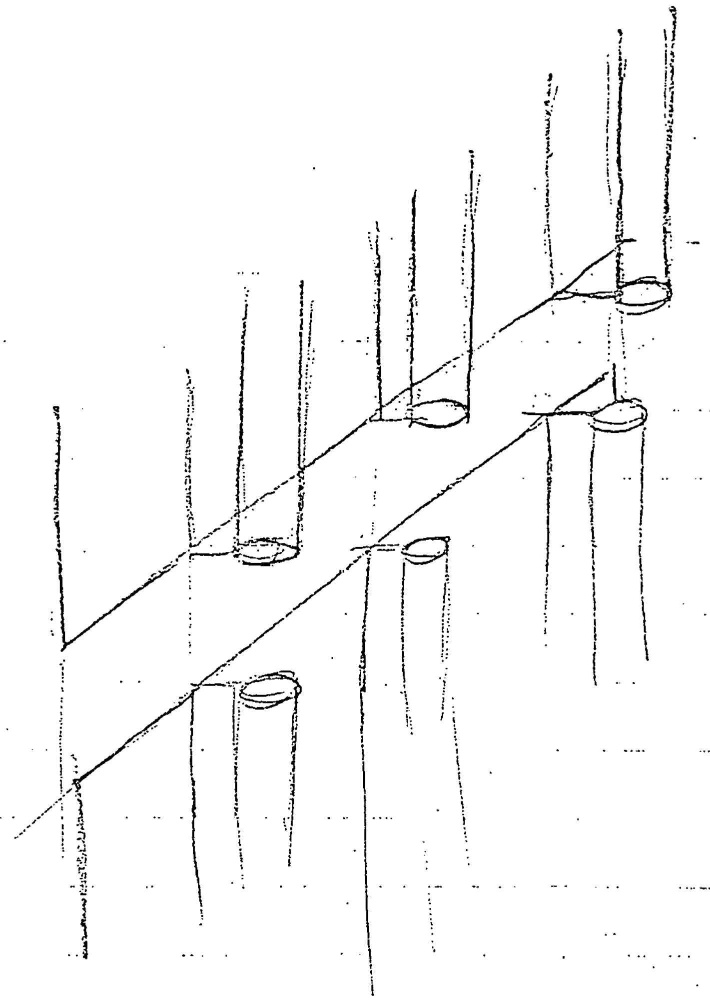
$$Z = \frac{I}{C} \qquad \epsilon = \frac{C}{R}$$

$$C = 1 \qquad R = 180$$

$$\epsilon = \frac{1}{180}$$

$$\epsilon(1137.25) = 6.32"$$

PD 3/79 (2)



PY 3/79 (3)

Area = 92 in^2

Fusion Pressure = 70 psi

Fusion Force = 70(92) = 6440 lb./36 in Section

Clamping force $\underbrace{}$ = 19320

① - Can be developed through friction

② - local deformation at the edge of the clamp.

① is more disirable. ② defines an allowable clamping pressure and design of edges of the clamp.

Assume < 3% strain p < .03(100000)

t .06" < 30000 psi

< .001 in. defl. p_c < 100 psi

This defines width of clamp when total force is Know. = f_c clamp force / unit length.

Assume μ = .05

force/in r=8"

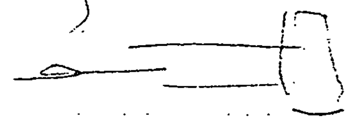
$$f_c = \frac{6440(3)}{(108-6)\mu} = \frac{189}{\mu} = 3788 \frac{lb}{in}$$

Total clamp force width of ring stubs

$$F_{CT} = 102 f_c = 386400 \text{ lb.}$$

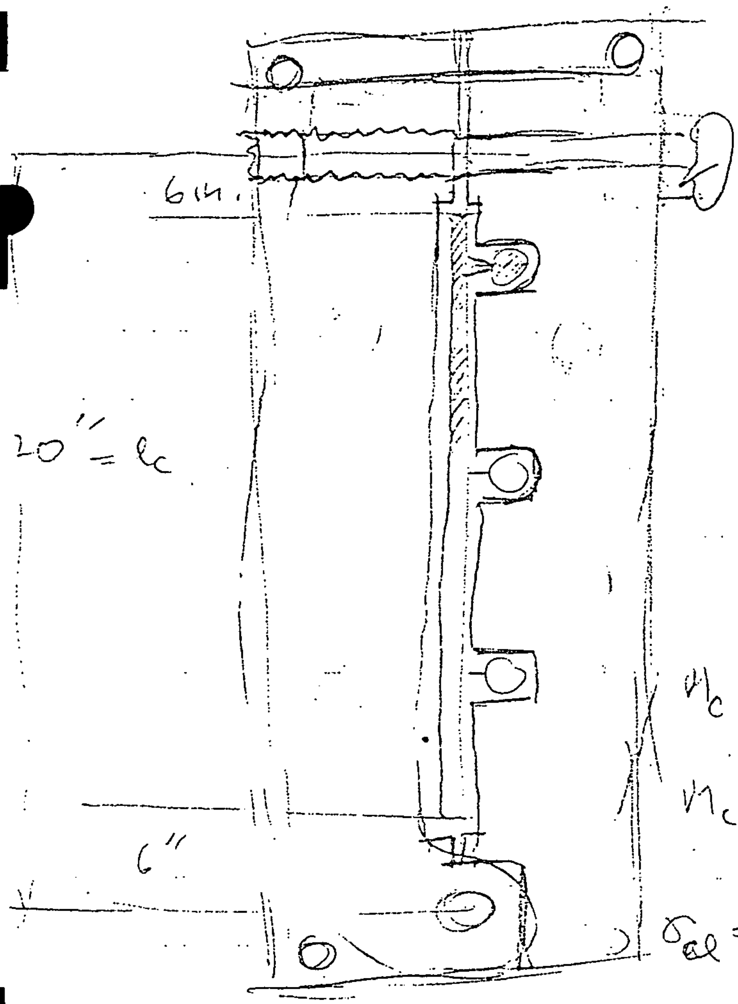
PH 3179 (7)

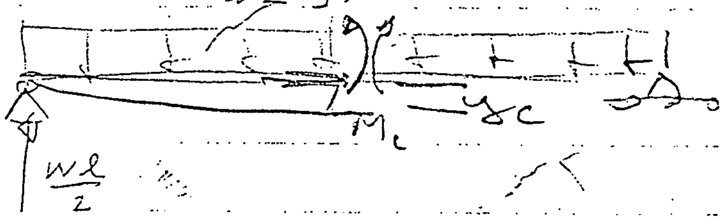
386400 lb. @ 30000 psi



$A_{req} = 12.88 \text{ in}^2$

$D_{req} = 4 \text{ in.}$





$$M_c = w\frac{l_c}{2}\left(\frac{l_c}{2}\right) - \frac{wl_c}{2}\left(\frac{l_c}{4}\right) = \frac{wl_c^2}{8}$$

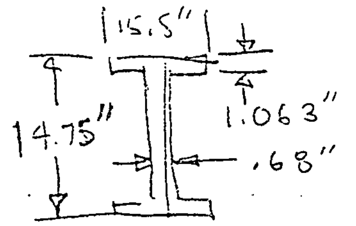
$$M_c = \frac{3788(120)^2}{8} = 6.8 \cdot 10^6 \text{ in lb.}$$

$$\sigma_{al} = \frac{M_c}{Z} \qquad Z_{req} = \frac{M_c}{\sigma_{al}}$$

$$Z_{req} = \frac{6.8 \cdot 10^6}{30000} = 227 \text{ in}^3$$

$$I = \frac{227(14.75)}{2} = 1674.$$

This can be supplied by a WF 14"x16"



$$y_c = \frac{5}{384}\frac{wl_c^3}{EI}$$

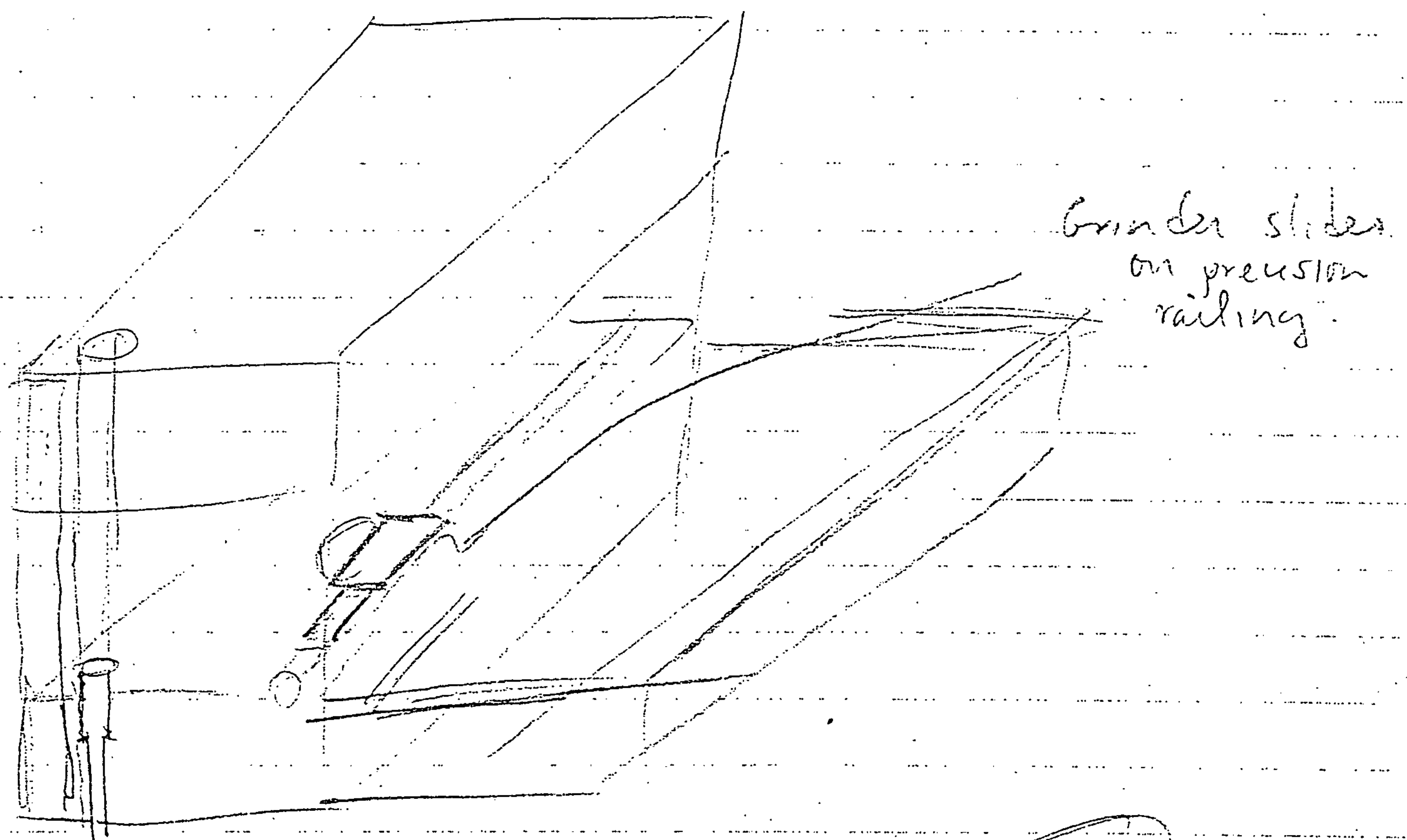
$$= \frac{5}{384}\frac{3788(120)^3}{30 \cdot 10^6 (1674)} = 1.7 \cdot 10^{-3} \text{ in.}$$

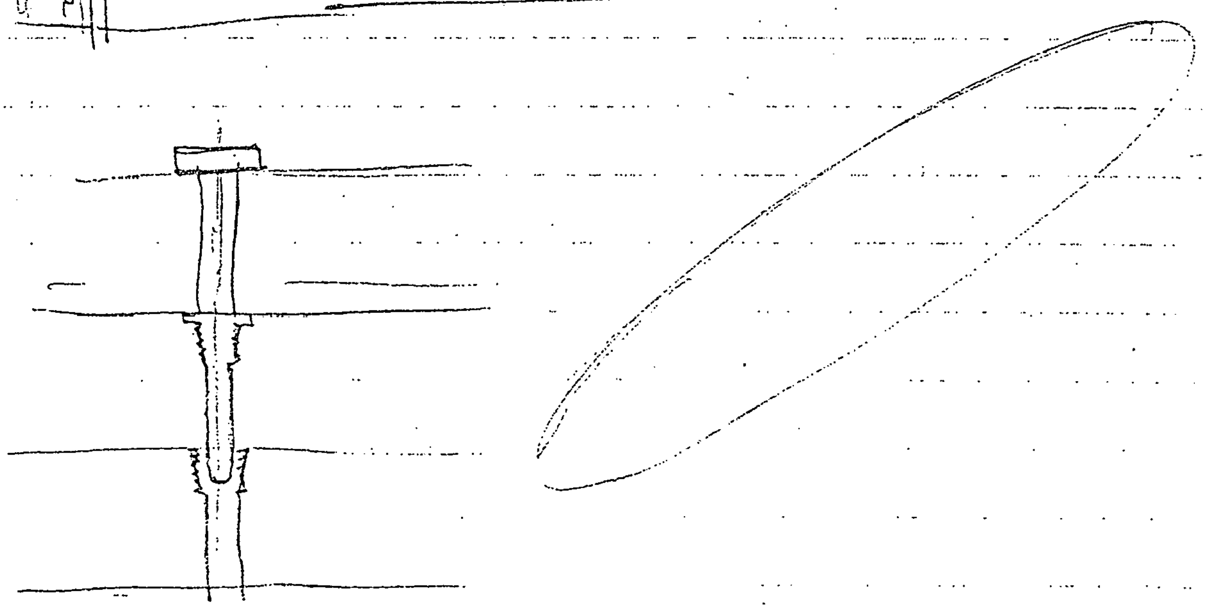
Clamping pressure

$$= \frac{3788}{15.5} = 244 \text{ psi}$$

PM 3/79 (5)

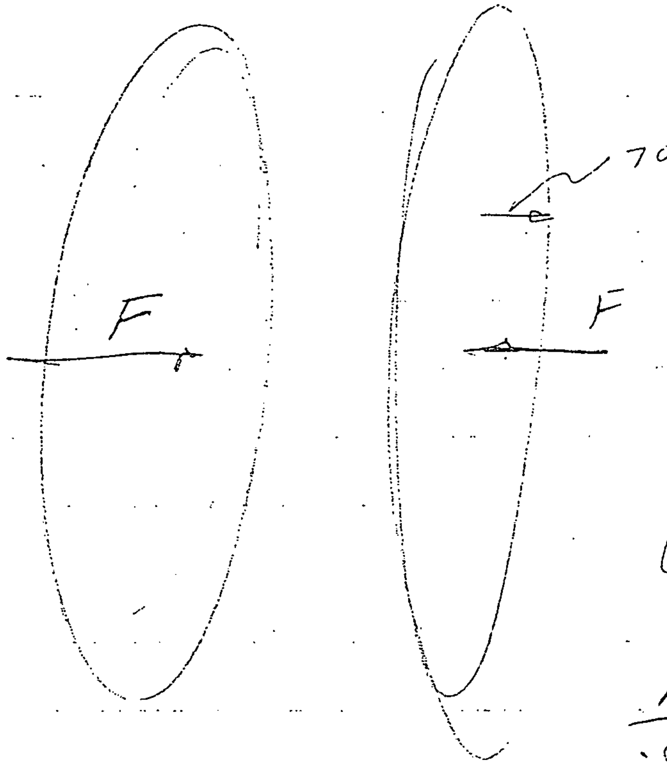
Fusion Force is 19320 lb., Four 1" diameter screws should carry this easily.





Cylinder Fusion:

PQ 3/79



$F = 2262(70)$
$= 158000$ lb.

Clamping Force

$\frac{F}{.05} = 3.17 \cdot 10^6$ lb.

Radial clamping force per in of circumference

$f_c = 2800 \frac{lb}{in}$

Internal / External ring compression / tension respectively

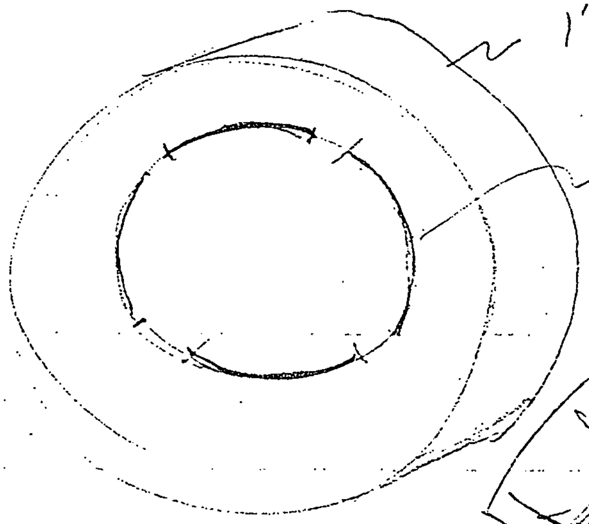
$f_r = 504000$ lb.

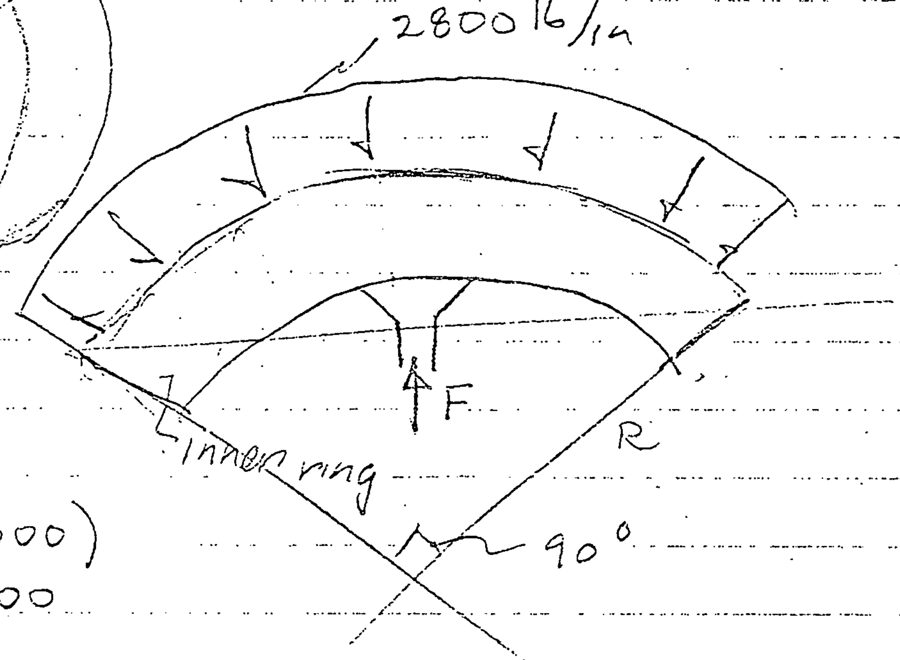
$\frac{f_r}{A} = \sigma_{al} = 30000$ psi

$A_{req} = \frac{f_r}{\sigma_{al}} = \frac{504000}{30000} = 16.8 \text{ in}^2$

1" thk & 17" wide yields a clamping pressure of 165 psi

1" thick 17" wide   PV 3/79   7



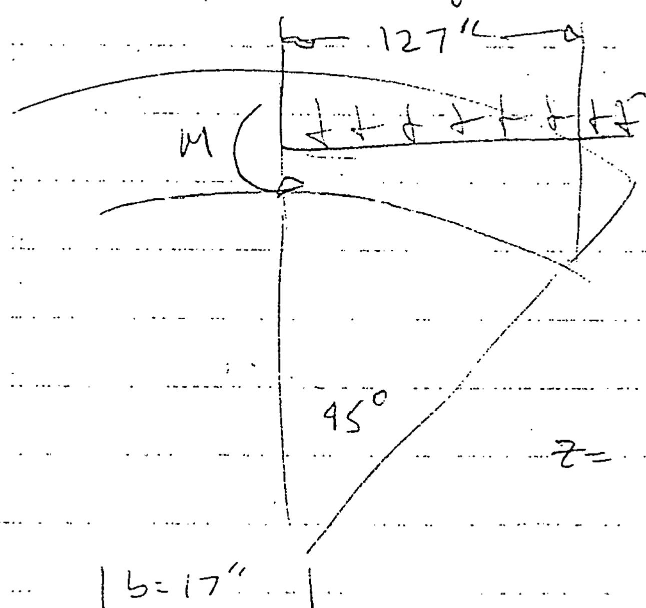


$F = 2R\sin 45^\circ (2800)$

$= \cancel{2}(180)\frac{\sqrt{2}}{\cancel{2}}\, 2800$

$= 713000 \text{ lb}.$

Approx. ring section requirements.

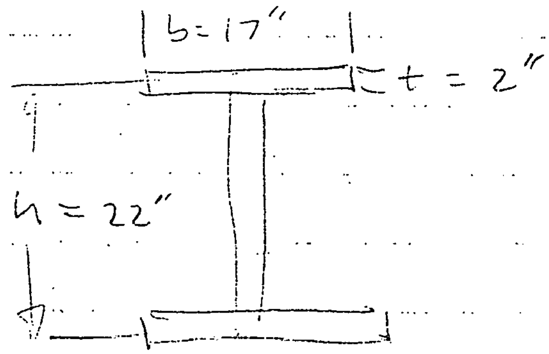


$M = \dfrac{2800(127)(127)}{2}$

$= 22.6 \cdot 10^6 \text{ in lb}.$

$Z = \dfrac{M}{\sigma_{al}}$, $\sigma_{al} = 30000$ psi

$Z_{req} = 753 \text{ in}^3$



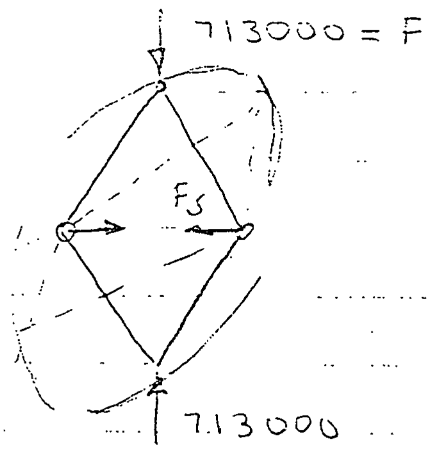
$I \approx 2\left(\frac{h}{2}\right)^2 bt = \dfrac{h^2bt}{2}$

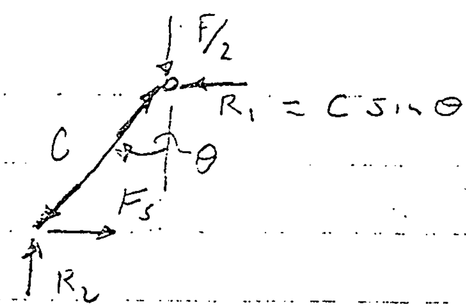
$Z \approx \dfrac{2I}{h} = hbt$

if $b = 17$ $ht = \dfrac{753}{17} = 44$

$t = 2$ $h = 22$ in.

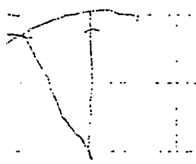
Assume 2 pair of scissors jacks are used as shown





$C \cos\theta = F/2$

We would like to make θ small to shorten the length of the compression members. Assume ~~min~~ final $\theta_f = 10°$ to accommodate members at the end of stroke. Assume that 4 in of radial space is required to insert fixture. Then the initial θ_i is



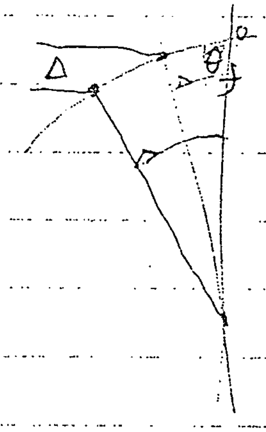
$R(1-\cos\theta) = \Delta$

$\left(1 - \frac{\Delta}{R}\right) = \cos\theta$

$\Delta = 4$

$R = 180$

$\theta = 12°$



$\Delta_f = R(1-\cos\theta_f)$

$\Delta_i = R(1-\cos\theta_i)$

$\Delta_i - \Delta_f = 4 \text{ in.}$

$4 = R(1-\cos\theta_i) - R(1-\cos\theta_f)$

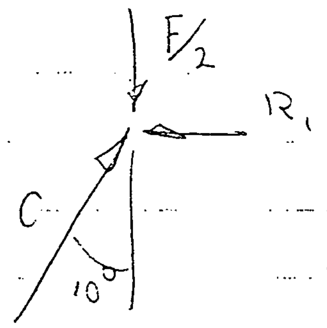
$= R(\cos\theta_f - \cos\theta_i)$

$$\theta_i = \cos^{-1}\left\{\frac{\overset{\Delta_i-\Delta_f}{-4} + R\cos\theta_f}{+R}\right\}$$

$R = 180 \quad \theta_f = 10°$

$$\theta_i = \cos^{-1}\left\{\frac{180\cos 10° - 4}{180}\right\} = 15.72°$$

PA 3/79 (4)



$$C\cos 10^\circ = \frac{F}{2}$$

$$C = \frac{F}{2\cos 10^\circ} = \frac{7.13\cdot 10^5}{2\cos 10^\circ} = 3.62\cdot 10^5$$

$$R_1 = C\sin 10^\circ = 6.3\cdot 10^4 \text{ lb}$$

$$R_2 = 3.565\cdot 10^5$$

$$F_s = 6.3\cdot 10^4 \text{ lb}.$$

Buckling of scissors member.

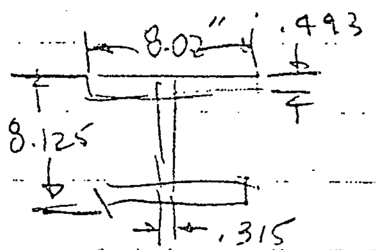
$$C = P_{cr} = \frac{\pi^2 EI}{l^2}$$

$$l < \frac{180}{\cos 10^\circ} = 183 \text{ in.}$$

$$I_{cr} = \frac{l^2 C}{\pi^2 E} = \frac{183^2(3.62)10^5}{\pi^2\, 30\cdot 10^6} = 40.94$$

Use $I = 3 I_{cr} = 123 \text{ in}^4$

WF 8X8



Assuming tubes to obtain I

$$I = \pi R^3 t$$

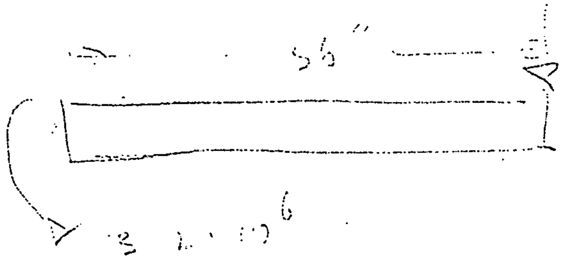
$$t = \frac{I}{\pi R^3}$$

$I = 123 \text{ in}^4$

	R	t
	4 in	.61
Use ⇒	3 in	1.45
	5 in	.313 Use 10" D 5/16" wall

Shaft sizing:

$4\frac{1}{3}$ 300. 624



33000 = Estimated total weight of apparatus.

$I = \frac{1}{4}\pi R^4$

$$Z = \frac{I}{c} = \frac{\pi R^3}{4}$$

$$\frac{M}{Z} = \sigma_{al} \qquad Z = \frac{M}{\sigma_{al}}$$

$$R_{req.} = \sqrt[3]{\frac{4}{\pi}\frac{M}{\sigma_{al}}} = \sqrt[3]{\frac{4(3.2)\cdot 10^6}{\pi(30000)}} = 5.1''$$

Use 12 in. diameter shaft

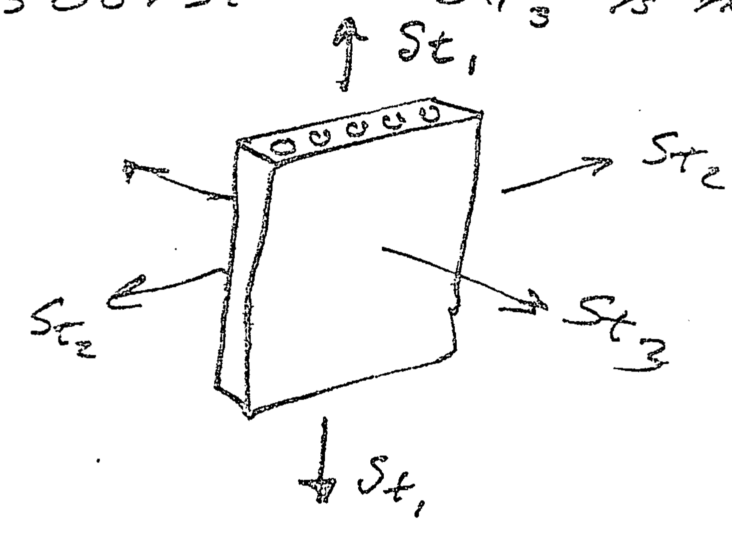
ENGINEERING PIPE SIZING CALCULATIONS

1.0 RUBBER COMPOSITE

THE MATERIAL IS RUBBER REINFORCED WITH NYLON FIBRES. EACH LAYER OF FIBRES IS .040 THICK AND HAS A UNIAXIAL TENSILE STRENGTH = S_{t_1} = 1500 LBS/INCH

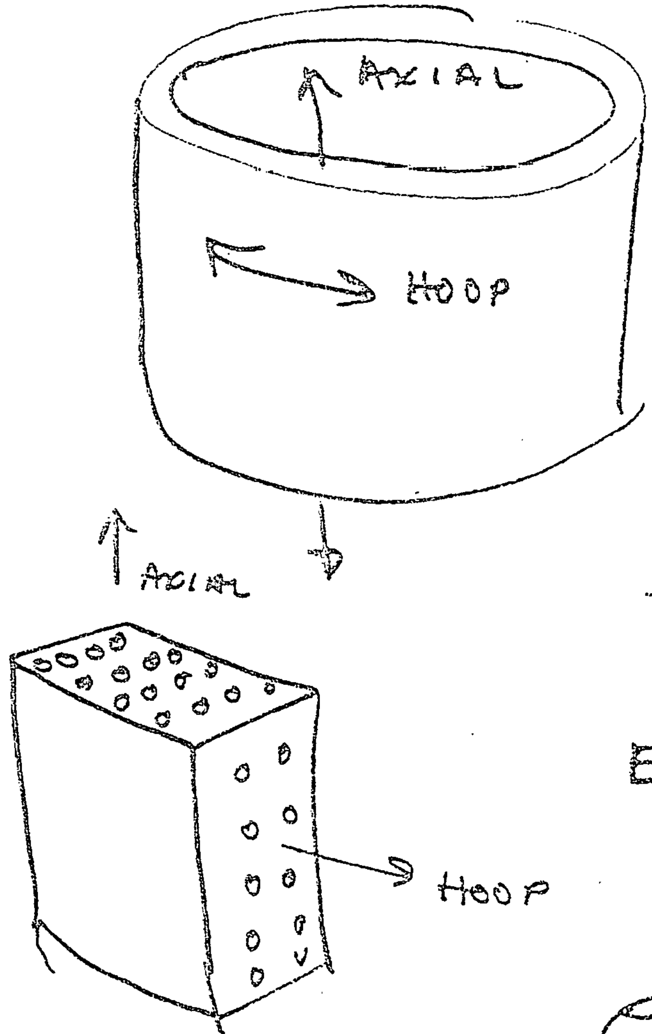
S_{t_1} IN ORDINARY TERMS = $\frac{1500}{.040}$ = 37,500 PSI

S_{t_2} IN THE OTHER DIRECTION IS VERY LOW - THE TENSILE STRENGTH OF THE RUBBER - ABOUT 1500 PSI. S_{t_3} IS THE SAME.



TO MAKE A COMPOSITE, THE .040 THICK LAYERS ARE BONDED (VULCANIZED) TOGETHER WITH LAYERS ARRANGED TO GIVE DESIRED PROPERTIES.

FOR THE PIPE, THE ASSUMED PROPORTIONS ARE 2-1 WITH TWICE AS MUCH FIBER IN THE AXIAL DIRECTION AS IN THE HOOP DIRECTION.



S_t MAX

AXIAL	25000 PSI
HOOP	12500 PSI

E, PSI

AXIAL	100,000 PSI
HOOP	50,000 PSI

$\rho = 1.25 \times 62.4 = 78$ LB/FT^3

NORMALLY A FACTOR OF SAFETY = 4.0 IS USED IN DESIGN.

∴ ALLOWABLE STRESSES ARE:

$$S_f \text{ AXIAL} = \frac{25000}{4} = \underline{6250 \text{ PSI}}$$

$$S_f \text{ HOOP} = \frac{12500}{4} = \underline{3125 \text{ PSI}}.$$

ALSO STEEL WIRE CAN BE USED TO INCREASE STRENGTH - IF REQUIRED ALTHOUGH THE NYLON FILAMENTS ARE VERY STRONG.
S_f NYLON = 117,000 PSI

POISSON'S RATIO FOR THE COMPOSITE $\cong$ 0.45

PIPE SIZING

PIPE SIZING IS DONE SEVERAL DIFFERENT WAYS.

(1) THE FIRST WAY - PRESSURE RESISTANT PIPE. FIRST ORDER APPROACH

THE RUBBER PIPE WAS SIZED TO WITHSTAND EXTERNAL PRESSURE DUE TO (STATIC) FLOW AND EXTERNAL CURRENT. BENDING WAS NOT CONSIDERED. THE FOLLOWING ASSUMPTIONS WERE MADE BASED ON GOODRICH DATA:

(a) S.F. = 4

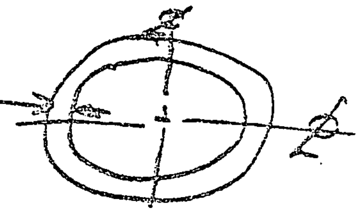
(b) E AXIAL = 72000 PSI
E HOOP = 50,000 PSI

(c) RING SPACING = 3 FT.
(d) S_t = 1500 LB/IN
(e) ρ = 1.25 × 62.4 = 78 LB/FT^3

FROM ROARK -
A PIPE HELD CIRCULAR BY RINGS COLLAPSES AT

$$P' = \frac{0.807\, E t^2}{l r} \sqrt[4]{\left(\frac{1}{1-\nu^2}\right)^3 t^2}$$

$r = 180 + \frac{t}{2}$



$l = 36$, $d = 360''$

WEIGHT OF PIPE = $\left[\pi\left(\frac{d}{2}+t\right)^2 - \pi\left(\frac{d}{2}\right)^2\right] l \rho$

WEIGHT IN WATER = −64 + 78 = 14 LB/FT^3

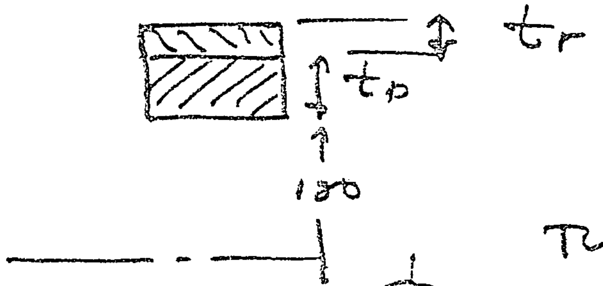
TENSILE STRESS = $\frac{W}{AREA} = \frac{W}{\pi\left[\left(\frac{d}{2}+t\right)^2 - \left(\frac{d}{2}\right)^2\right]}$

ORIGINAL RINGS WERE CONSIDERED TO BE STEEL "CABLE" WITH E = 19 × 10^6 PSI
SOLID STEEL RINGS E = 29.4 × 10^6 PSI

FROM ROARK - COLLAPSE PRESSURE = P'

$$P' = \frac{3EI}{r^3}$$

$$r = 180 + t_p + \frac{t_R}{2}$$



TWO TYPES OF RINGS

CIRCULAR + SQUARE
CROSS SECTION

AS FIRST GUESS -

FIRST PRESSURE TYPE PIPE

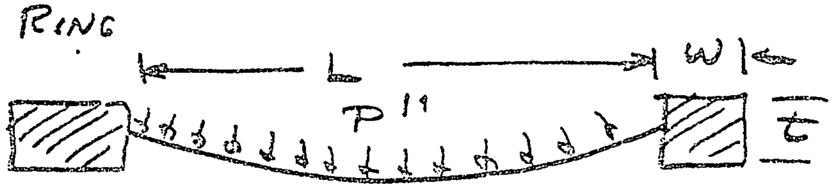
STA	L'	P'_{psi}	t''	WEIGHT, LBS AIR	WATER	t_R	$W^{\#}_{RA}$	$W^{\#}_{R\,H_2O}$	ΣW_{H_2O}	S_t PST
1	150	2.25	3.25	602,200	108,200	1.8	105,600	91,900	1,177K	317
2	450	1.54	2.77	512,600	92,100	1.5	73,200	63,600	977K	309
3	750	1.11	2.40	443,600	79,700	1.26	51,500	44800	821K	300
4	1050	.82	2.11	389,700	70,000	1.07	37,100	32,300	697K	290
5	1350	.605	1.87	345,210	62,000	.92	26,200	22,800	59.4K	280
6	1650	.52	1.75	322,700	58000	.85	23,400	20,300	509K	256
7	1950	.5	1.72	317,300	57,000	.82	21,700	18,900	431K	219
8	2250	.44	1.65	304,400	54,700	.77	19,200	16,700	355K	189
9	2550	.42	1.62	298,800	53,700	.75	18,200	15,800	284K	157
10	2850	.38	1.56	276,600	49,700	.72	16,800	14,600	213K	126

BALLAST → 150,000

STRESSES WERE LOW - WTS
HIGH FOR THIS DESIGN

2ND METHOD

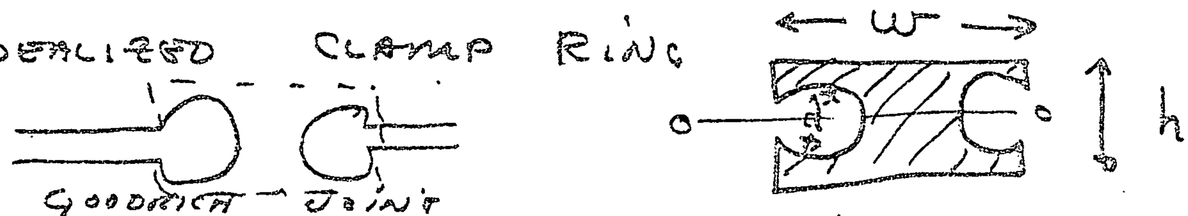
"LIMP" PIPE DESIGN ASSUMES THAT RINGS TAKE ENTIRE LOAD - PIPE IS A "LIMP" MEMBRANE THAT TRANSFERS PRESSURE LOAD -



TOTAL EXTERNAL PRESSURE P IS TRANSFERED TO RINGS

P effective on ring $= \frac{P'' L}{W}$ and $\frac{L}{W} = K'$

IDEALIZED CLAMP RING



d"	W	h	I_{oo}	K' (5' SPACING)	P'/4 psi *	WEIGHT, LBS AIR	WEIGHT, LBS H_2O
2.0	6	4	30.43	10	11.50	5690	4950
1.5	5	3.5	17.37	12	5.47	4490	3900
1.0	4	3.0	8.90	15	2.24	3350	2910
.75	3.5	2.75	6.03	17.14	1.33	2810	2440

* FACTOR OF SAFETY = 4.0

NEW RUBBER PIPE DESIGN
GOODRICH DATA -
PLIES OF .040 INCH THICK 1500 lb/in
COMPOSITE - NYLON REINFORCED.
STEEL RINGS ON 10' CENTERS -

RUBBER IS "LIMP" - TENSILE MEMBRANE

DEPTH (FT)	COMPOSITE THICKNESS INCHES	WEIGHT, LBS AIR	SUBMERGED	RING WEIGHT LBS. (10' CENTERS) AIR	SUBMERGED
0-300	4.0	743,000	133,000	171,000	149,000
300-500	1.5	185,000	33,000	90,000	78,000
500-1000	1.0	307,000	55,000	168,000	146,000
1000-2500	0.75	921,000	165,000	421,000	366,000
SCREEN	——	172,000	150000		

TOTAL WTS.	RUBBER	AIR	2,156,000
		SUBMERGED	386,000
	RINGS	AIR	850,000
		SUBMERGED	739,000

TOTAL DEPLOYED WEIGHT - PIPE + SCREEN + RINGS

AIR	SUBMERGED
3,178,000 LBS	1,275,000 LBS
1589 TONS	638 TONS

TENSILE LOAD DEVELOPED ON EACH SECTION - DUE TO WT. ONLY - NOT PRESSURE

SECTION DEPTH	ΣW 1000 LBS.	A IN^2	S_t * PSI	S_t ALLOW.	SF *
1000'	681	850	801	25000	31.
500'	882	1134	778	|	32
300'	993	1704	583	|	43
0	1275	4574	279	25000	90

* NO BENDING OR PRESSURE LOADS INCLUDED

$$A = \pi\left((R+t)^2 - R^2\right)$$
$$= \pi\left((180+t)^2 - 180^2\right)$$

S_t ALLOWED $= \frac{1500 \times \cancel{t}}{(1)(\cancel{t})\ .040} \times 2/3 = \underline{25000 \text{ PSI}}$

BASED ON .040 LAMINAE @ 1500 LB/IN ON 1-2 SPACING (2 VERTICAL — 1 HOOP)

THESE STRESSES MUST BE COMBINED WITH EXTERNAL PRESSURE INDUCED STRESSES AND BENDING STRESSES.

RUBBER CWP

Material

Nylon reinforced rubber
longitudinal E = 100,000 psi
circumferential E = 50,000 psi
specific gravity = 1.25

Geometry (Case 1)

cwp length = 3000 ft
steel ring spacing = 5 ft
screen weight = 150,000 lbs
inner diameter = 30 ft

ring 5" wide 3" thick

wall thickness and weights

Depth (ft)	Rubber thickness inch	fabric weight (10^6 lbs)		ring weight (10^6 lbs)		individual dry ring weight (lbs)
		dry	wet	dry	wet	
0 - 300	3.0	.56	.10	.34	.30	5690
300 - 500	1.5	.19	.03	.18	.16	4490
500 - 1000	1.0	.31	.06	.34	.29	3350
1000 - 3000	.75	.92	.17	1.12	1.0	2810
Total		1.98	.36	1.98	1.75	

Case 2 : Same as Case 1 except increasing the screen weight to 30,000 lbs.

Case 3 : Same as Case 2 except using heavier rings (3350 lbs each) in the last 2000 ft section.

<u>Loadings</u>

Current Load : Basic extreme condition from Reference 1

Circumferential pressure load : mean value from Reference 1

<u>Static Beam Response</u>

Results from CUPELX runs are plotted as shown in Figures 1 and 2.

<u>Ring Statics</u>

The circumferential rigidity of rubber pipe is small compared to that of steel ring. The ratio is

$$\frac{E_S I_S}{E_R I_R} \times \frac{w}{l} = \frac{30\times10^6 \times 3^3/12 \times 5}{50{,}000 \times 3^3/12 \times 12\times5} = 50$$

Thus all loads are taken by rings.

Hoop stress $\sigma_{hoop} = \Delta p \, \frac{l}{w} \, \frac{R}{t} = 4 psi \times \frac{5\times12}{6} \times \frac{15\times12}{3}$

$= 2.4$ ksi

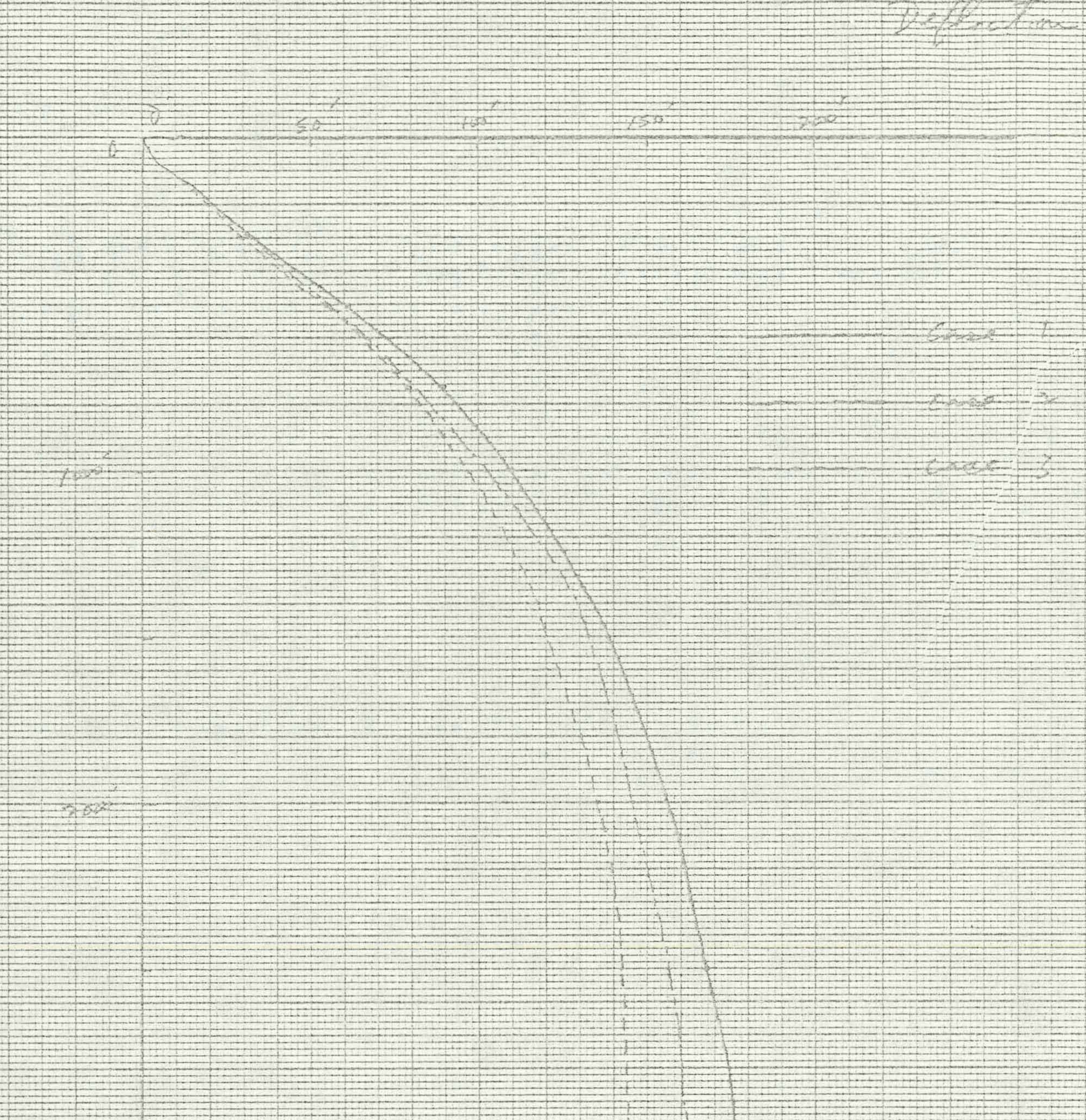


Figure 1 Deflection

shear or

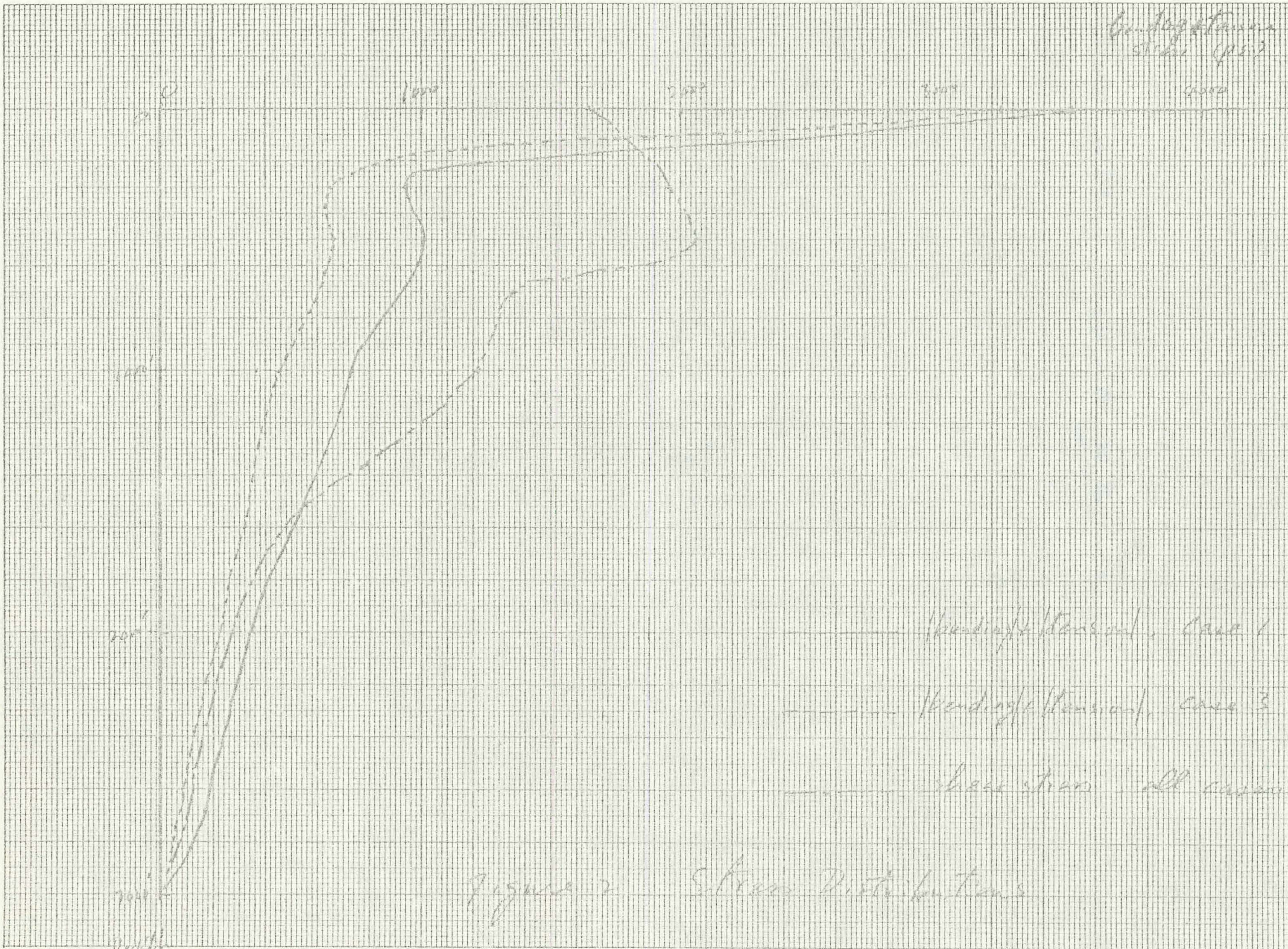
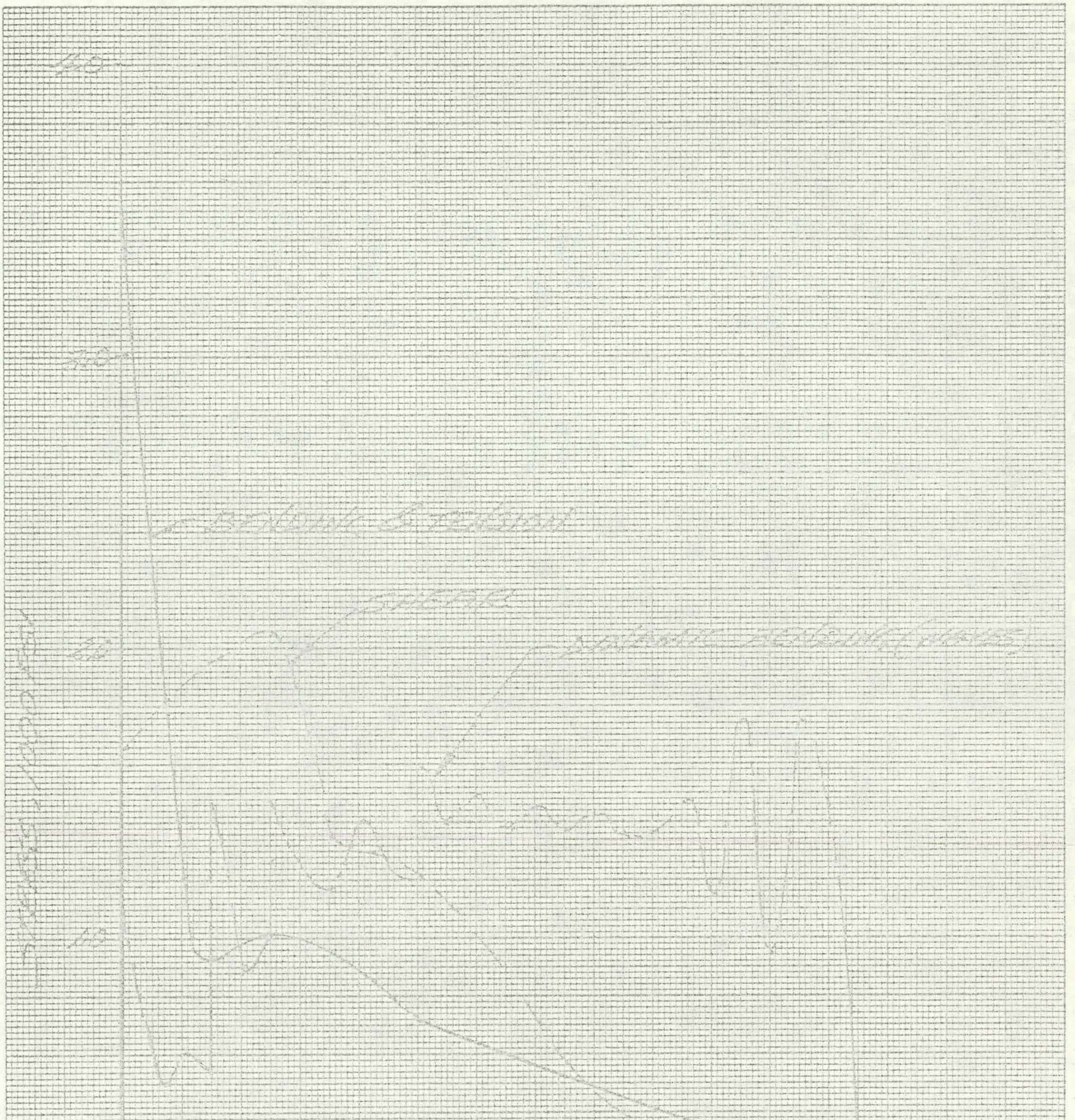


Figure 2 Stress Distributions


STRESS, 1000 PSI
40
30
20
10
0
1000
2000
3000
DEPTH, FT
BENDING & TENSION
DYNAMIC BENDING (WAVES)

Ref. 2

The bending stress due to ovalization pressure distribution

$$\sigma_{bending} = .0094 \left(\frac{PD}{t} \right)^{2} \frac{1}{[illegible]} = .0094 \left(\frac{[illegible]}{[illegible]} \right)^{2} \frac{[illegible]}{2}$$

$= 173$ psi

<u>[illegible]</u>

The effective thickness is computed per Ref. 2

$$\left(\frac{[illegible]}{[illegible]}\right)^{3} = [illegible] \left(\frac{[illegible]}{[illegible]}\right) \left(\frac{[illegible]}{[illegible]}\right)^{[illegible]}$$

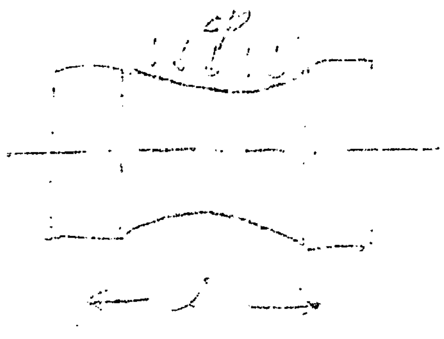
[illegible]

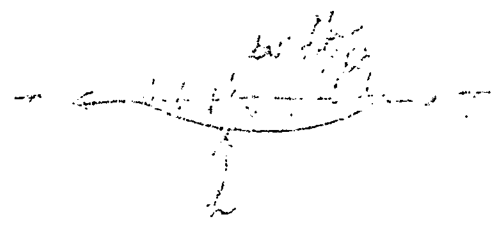
The bending stress due to static [illegible] (Ref. 2)

$$\sigma_{bending} = .0094 \left(\frac{[illegible]}{[illegible]} \right)^{2} = 100 \text{ psi}$$

<u>[illegible] Pipe Local Deflection</u>

Local static deflection can be found by approximating the pipe section between rings by fixed ends subject to uniform load.





Ref. 3 gives the maximum deflection as

$$\delta = \frac{T}{w}\left[\cosh\left(\frac{w}{T}\cdot\frac{l}{2}\right) - 1\right]$$

$T =$ [illegible] $= 2.26 \times 10^{?}$ lb.

$l = 5$ ft

$w =$ [illegible]

$$\delta = \frac{\text{[illegible]}}{\text{[illegible]}}\left[\cosh\left(\frac{\text{[illegible]}}{\text{[illegible]}}\right) - 1\right] = \text{[illegible]}$$

Thus the local deflection is small due to high tension force.

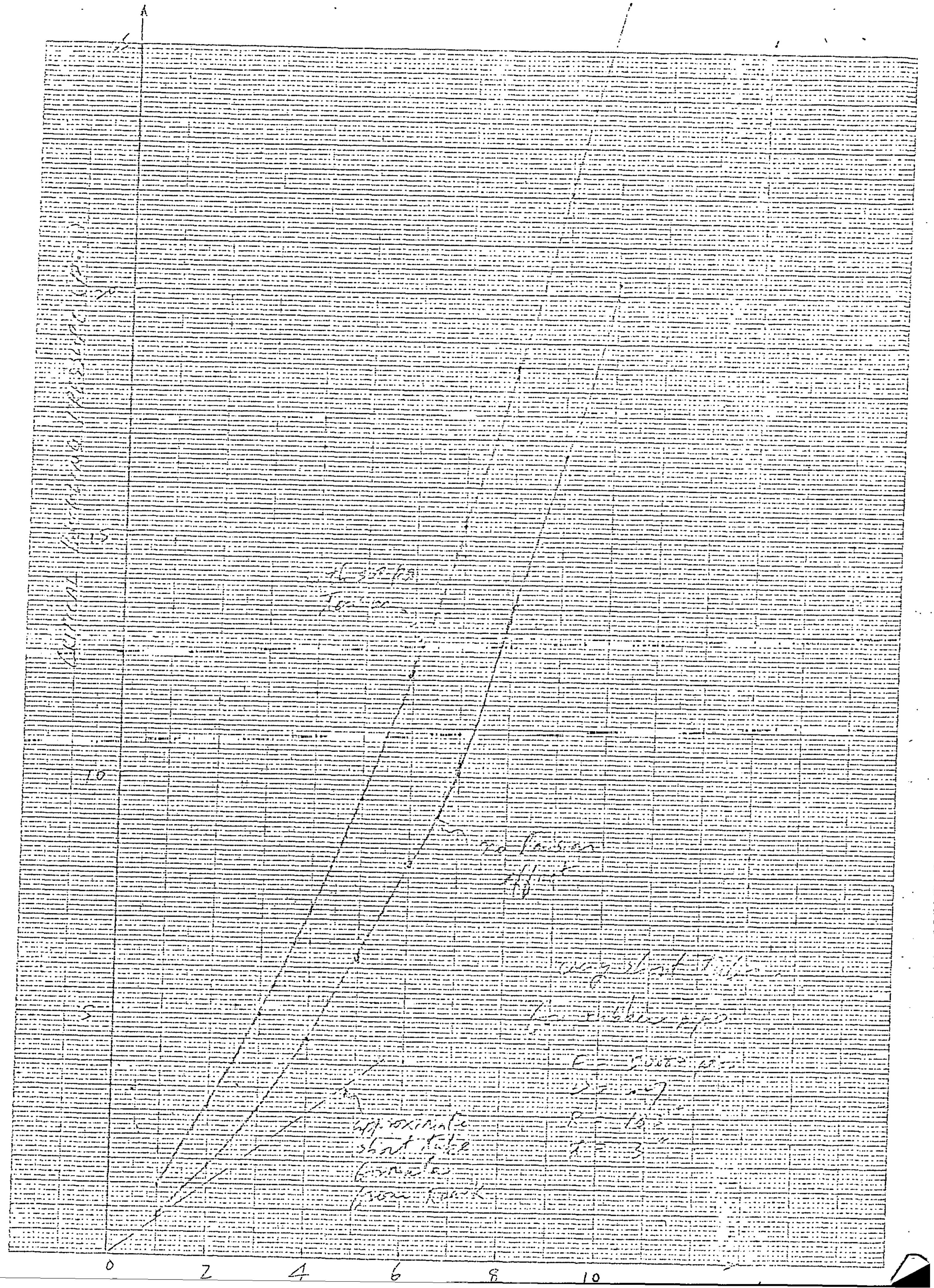
Initial Buckling Load (Consider torsion and rings)

Ref. 2 gives the ~~...~~ buckling load of a cylindrical shell under combined axial and uniform lateral pressure. The corresponding result to the present design is plotted in Figure 3.

For $R/t = 30$, $\frac{l}{R} = 6$ and $T_{tension} = 500$ psi the critical buckling load is found to be 12 psi.

The buckling shape corresponds to $m = 1$ and $n = 10$ where m and n define the displacements

$$u = A \sin n\theta \cos\frac{m\pi x}{l}$$
$$v = B \cos n\theta \sin\frac{m\pi x}{l}$$
$$w = C \sin n\theta \sin\frac{m\pi x}{l}$$


10
0
2
4
6
8
10

References

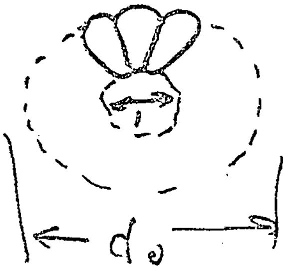
1. [illegible]
2. [illegible]
3. Housner, G. W., *[illegible]*
4. Timoshenko and [illegible], *[illegible]*

(1)

3/6/79

INFLATED PIPE. - CONCEPT 4.3

BELL AEROSYSTEM DESIGN.



$d_i = 30'$
$d_o = 50'$
L PRESSURIZED = $\underline{2500'}$

THE BELL AEROSYSTEM DESIGN IS A "LIMP" PIPE COMPOSED OF AN INNER AND OUTER "PIPE" JOINED BY 40 RADIAL WEBS. NOMINALLY, O.D. = 50', I.D = 30' web length = 10'

The pipe is stabilized by internal pressure in the annulus and by a sizable ballast weight.

INTERNAL PRESSURE RIGIDIZES THE PIPE AND PROVIDES AN END LOAD IN TENSION

P TENSION = P(PRESSURE, PSI) × ANNULAR AREA

$= P \times \frac{\pi}{4}(50^2 - 30^2) \times 144 = \underline{P \times 181000 \text{ LBS}}$.

THUS INFLATION TENSION = 181,000 P

$\Delta P = 16.50$ PSI

$\therefore$ INFLATION TENSION = 2,986,000 LBS.

TO THIS STATIC TENSILE LOAD MUST BE ADDED THE WEIGHT OF THE PIPE WALLS WEIGHT OF THE RINGS (FLANGES) AND BALLAST.

MAX STATIC TENSILE LOAD:

PRESSURE	2,986,000 LBS.	
(RINGS (15)(FULL)	1,440,000	LBS (AIR))
" "	1,252,000	LBS SUBMERGED
BALLAST	1,300,000	" "
(FABRIC. (DRY)	1.600,000	" AIR)
FABRIC.	.290,000	SUBMERGED

TOTAL DEAD WT. + TENSION (STATIC) ACTING ON UPPER FABRIC = 5,828,000 LBS.

FABRIC LENGTH = AS FOLLOWS

OUTER LENGTH (π50') = 50π = 157'

40 Webs @ 10' 400'

INNER LENGTH = 30π 94'

Σ L = 651'

L = 651' = 7816"

AREA = 7816 × .15 = 1172 sq"

$$\#/\text{IN} = \frac{5,828,000}{7816} = 746 \text{ LB/IN}$$

WITH 1500 LB/IN MIN.. SF = ONLY 2

THIS IS TOO LOW —

NORMALLY NEED SF = 4 FOR FATIGUE LIFE

$$PSI = \frac{5,828,000}{1172} = \underline{\underline{4973\ PSI}}$$

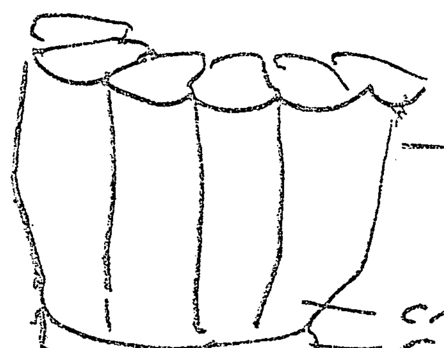
FAIRLY HIGH

STRENGTH OF CLOTH = $\frac{3000}{.15}$ = $\underline{\underline{20,000\ PSI}}$

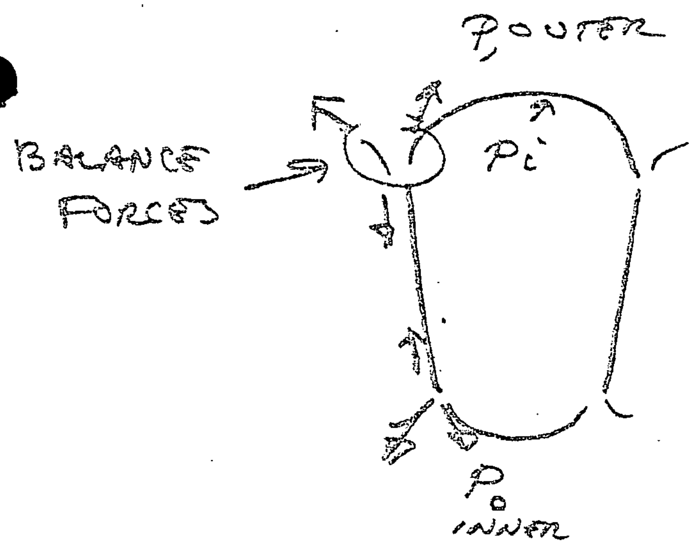
IDEAL IF 50% OF FIBERS WERE AXIAL

$$S = \frac{Pr}{t} = \frac{(16.5)(300)}{.15} = \underline{\underline{33000\ PSI}}$$

NOT SAFE NEAR THE RINGS WHERE THE SECTION IS CIRCULAR - WILL BE A TROUBLE AREA - TO BE LOOKED INTO, WILL REQUIRE AT LEAST DOUBLE THICKNESS THERE - ALSO LOOK AT TRANSITION SEAMS -



A BRIEF ANALYSIS OF THE INFLATED PIPE WAS PERFORMED. GEOMETRY AND STRESSES ARE DETERMINED BY BALANCING FORCE DIAGRAMS.



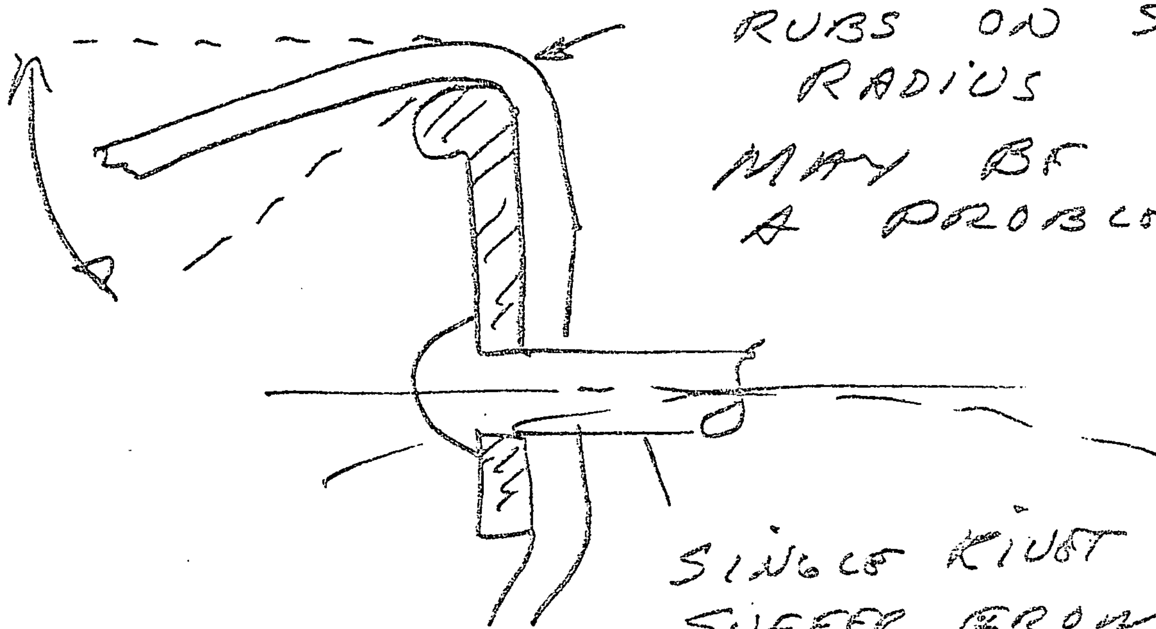
NOTE THAT GEOMETRY OF PIPE CHANGES AS P_{OUTER} + P_{INNER} CHANGE WITH P_i

IN SOME CASES PIPE MOVES IN OR OUT AS SHOWN.

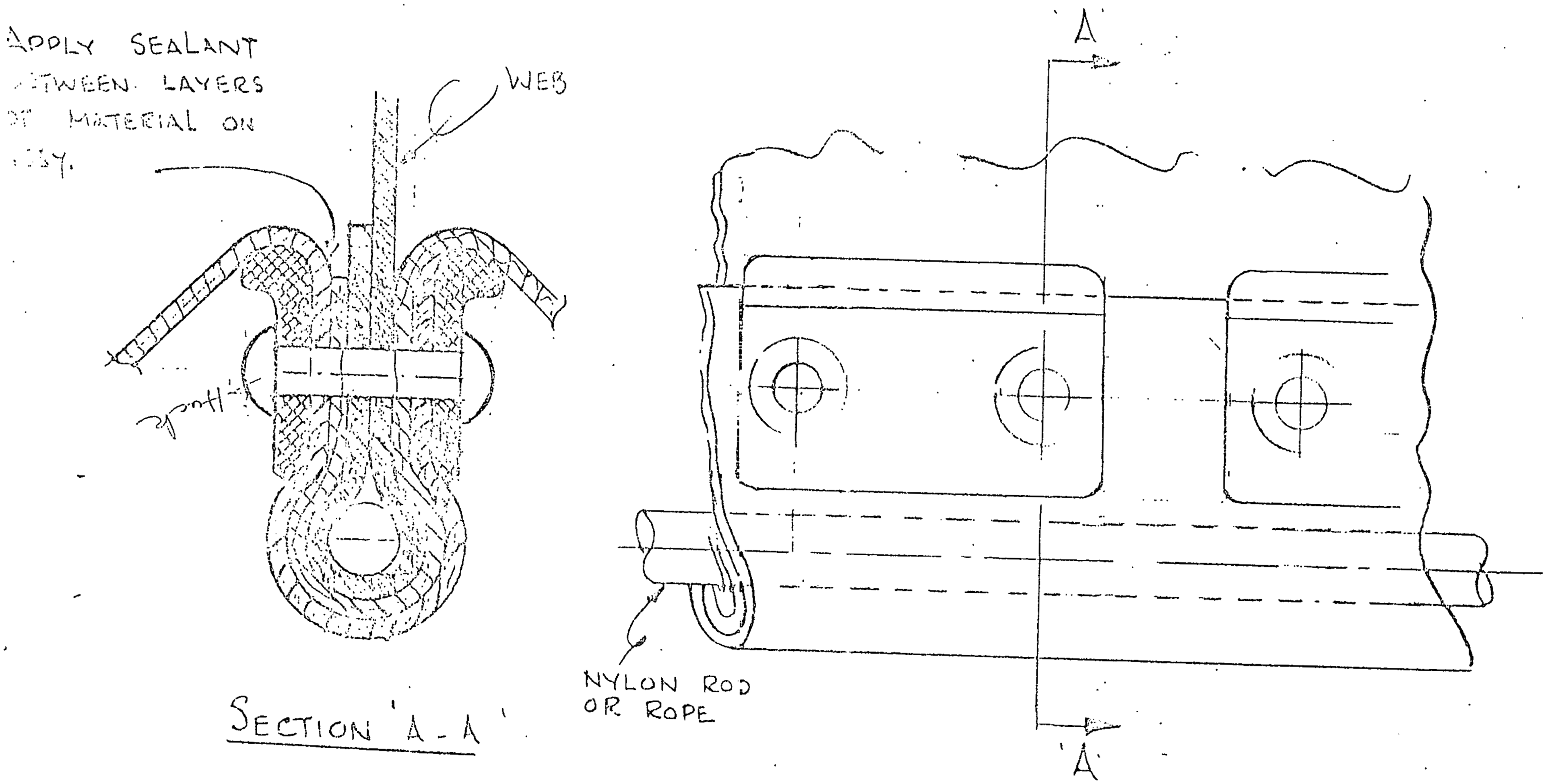
THE COMPUTER PRINTOUTS SHOWN ARE FROM BELL AEROSYSTEMS. THE NOMINAL DESIGN IS FOR THE BRAZIL PIPE.

THE BELL AEROSYSTEMS JOINT DESIGN IS SHOWN ON PAGE 6. NOTE THAT IT IS A "REVERSE" JOINT TENDING TO PUT THE RIVET IN TENSION AND BENDING AND SUBJECT TO ABRASION AND BENDING AROUND A SMALL RADIUS.

CLOTH MOVES CONTINUALLY AND FATIGUES OR RUBS ON SMALL RADIUS MAY BE A PROBLEM.



SINGLE RIVET MAY SUFFER FROM FATIGUE IN BENDING



OTEC COLDWATER PIPE CANDIDATE JOINT

BELL AEROSYSTEMS JOINT

A SIMPLIFIED ANALYSIS OF THE CLOTH CONSTRUCTION IS SHOWN ON THE FOLLOWING PAGES - THE FORCES WERE BALANCED FOR PRESSURES SHOWN.

OTEC – SCWP   J. GLASSCO, 12-2-[illegible]

ASSUMPTIONS

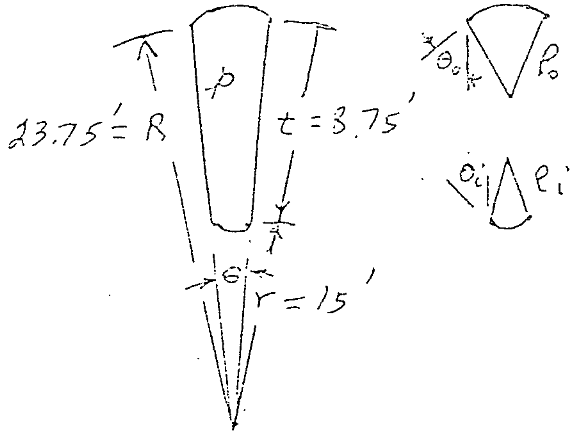
n = 30 LOBES   F.S. = 4 p = 9.7 psi (GAGE)

I.D. = 30 FT , t = 8.75 FT (O.D. = 47.5 FT)

θ_i = 66° (θ_o = 64.4°) W_B = 250,000 LBS (BALLAST) (IN SEA WATER)

θ = 12° ρ_o = 5.75 FT. ρ_i = 3.85 FT

LENGTH OF PERIPHERY



l_o = 154 FT. (OUTER)

l_i = 96.8 FT (INNER)

l_w = 262.5 FT (WEBS)

513.3 FT

AREA OF ANNULUS

A = 1135 FT²

DESIGN LOADING (4 × LOAD)

LONG.   1192 LBS/IN

HOOP.   2677 LBS/IN (OUTER)

          1796 LBS/IN (INNER)

COST

$17 /YD (54 IN MAT.)   550 LBS/IN (STRENGTH)

735,733 SQ. YDS.   3,180,000 LBS OF MATERIAL

$ 8,338,000 (MATERIAL)
5,338,000 (LABOR)

[illegible]676,000 TOTAL PLUS JOINTS ($.27/LB) cost

$154 \times 5 \times 3000 = 2,310,000\ FT^2 = 256,667\ YD.^2$ (COVER)

$(262.5 + 96.8)\ 4 \times 3000 = 4,311,600\ FT^2 = 479,067\ YD.^2$ (WEDGING)

$735,733\ YD^2$ (TOTAL)

$17/yd 54" MAT (1.5 YD)

$$\frac{17}{1 \times 1.5} = \$11.33/YD^2$$

$11.33 \times 735,733 = \$8,338,311$ (MATERIAL)

$8,338,311$ (LABOR)

$\$16,676,622$

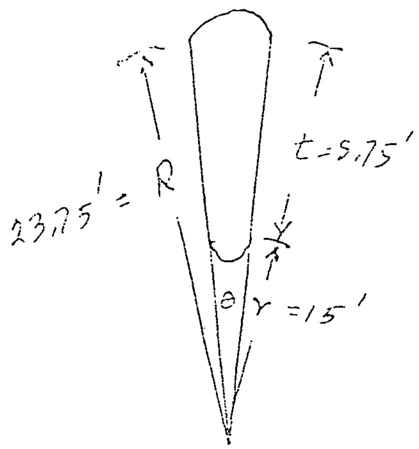
3,150,000 # OF MAT.

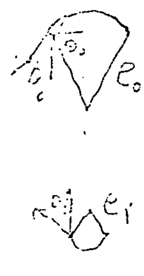
PLUS JOINTS

ASSUME 30 LOBES $\qquad$ ID = 30 FT

ASSUME OD = 47.5 FT $\qquad$ ASSUME $\theta_i = 66°$

ASSUME $\theta_o = 64.4°$ $\qquad$ $t = 8.75$ FT





$$\theta = \frac{360°}{30} = 12°$$

$$R \sin\frac{\theta}{2} = \rho_o \sin(90°-\theta_o)$$

$$\frac{D}{2}\sin\frac{\theta}{2} = \rho_o \cos\theta_o$$

$$\rho_o = \frac{D}{2}\,\frac{\sin\theta/2}{\cos\theta_o} = \frac{47.5}{2}\,\frac{\sin 6°}{\cos 64.4°}$$

$$\rho_o = 5.75 \text{ FT}$$

$$r \sin\frac{\theta}{2} = \rho_i \cos\theta_i$$

$$\rho_i = \frac{d}{2}\,\frac{\sin\theta/2}{\cos\theta_i} = \frac{30}{2}\,\frac{\sin 6°}{\cos 66°} = 3.85 \text{ FT}$$

LENGTH OF PERIPHERY

$$l_o = m\,\rho_o\,2(90°-\theta_o)\frac{\pi}{180°} = 30\times 2(\overset{25.6°}{90°-64.4°})\frac{\pi}{180}\,5.75 = 154 \text{ FT. (OUTER)}$$

$$l_i = m\,\rho_i\,2(90°-\theta_i)\pi/180 = 30\times 2(\overset{24°}{90°-66°})(\pi/180°)\,3.85 = 96.8 \text{ FT. (INNER}$$

$$l_w = m\,t = m(R-r) = m\left(\frac{D}{2}-\frac{d}{2}\right) = 30\left(\frac{47.5}{2}-\frac{30}{2}\right) = \underline{262.5 \text{ FT.}} \text{ (WEBS)}$$

Total $\qquad$ 513.3 FT.

AREA OF ANNULUS

$$A = \left\{(R^2-r^2)\frac{\sin\theta}{2} + \rho_o^2\left[(90°-\theta_o)\frac{\pi}{180°} - \frac{\sin 2\theta_o}{2}\right] + \rho_i^2\left[(90°-\theta_i)\frac{\pi}{180°} - \frac{\sin 2\theta_i}{2}\right]\right\} m$$

$$A = \left\{(\overline{23.75}^2 - \overline{15}^2)\frac{\sin 12°}{2} + \overline{5.75}^2\left[(\overset{25.6°}{90°-64.4°})\frac{\pi}{180°} - \frac{\sin 2\times 64.4°}{2}\right]\right.$$

$$\left. + \overline{3.85}^2\left[(\overset{24°}{90°-66°})\frac{\pi}{180°} - \frac{\sin 2\times 66°}{2}\right]\right\} 30 = 1135 \text{ FT}^2$$

ASSUME ANNULUS PRESSURE = 9.70 psi (GAGE)

ASSUME BALLAST LOAD = 250,000 LBS

$$\text{WEB LOAD} = \frac{P}{L} = \frac{P_B + pA + W_p A \Delta l}{L}$$

For bottom of pipe $\Delta l = 0$

$$\text{WEB LOAD} = \frac{P_B + pA}{L} = \frac{250{,}000 + 1396.8 \times 1135}{513.3}$$

[illegible] LBS/IN

$$\text{DESIGN LOAD (WEB)} = 4 \times \overset{298}{\cancel{282}} = 11\overset{92}{\cancel{28}} \text{ LBS/IN}$$

MATERIAL STRENGTH = 550 LBS/IN

USE 2 THICKNESSES $550 \times 2 = 1100$ LBS/IN

Hoop stress

OUTER MATERIAL

$$T_o = p\,P_o = 1396.8 \times 5.75 = 8032 \text{ LBS/FT} = 669.3 \text{ LBS/IN.}$$

INNER

$$T_i = p\,P_i = 1396.8 \times 3.85 = 5378 \text{ LBS/FT} = 448 \text{ LBS/IN}$$

$$T_W^{\,WEB} = 2T_o \cos\left(\theta_o + \frac{\theta}{2}\right) = 2 \times 669.3 \cos\left(64.4 + \frac{12}{2}\right) = 449 \text{ LBS/IN}$$

$$T_W = 2T_i \cos\left(\theta_i - \frac{\theta}{2}\right) = 2 \times 448 \cos\left(66 - \frac{12}{2}\right) = 448 \text{ LBS/IN}$$

DESIGN

$$4 \times 669.3 = 2677 \text{ LBS/IN}$$

$$\frac{2677}{550} = 4.87 \sim 5 \text{ thicknesses (OUTER)}$$

$$4 \times 449 = 1796 \text{ LBS/IN}$$

$$\frac{1796}{550} = 3.27 \sim 4 \text{ thickness (WEBS AND INNER)}$$

Nylon and Elastomers

Bag - 2000 hrs, (life) on boat

TEC-1, 150 ft sections (cost effective) joints

70 oz/sq yd (top.) $17/yd 54" wide, 50% cost 50% labor

cost of facilities
Cost of deployment
Ports in ring joints

Ballast weight to resist load drag

10 - 12% strain

stability safety factor = 2
strength " " = 4
life " " 4+2

$p = 6.6$ psi

2 × 2 basket weave

3" bonded lap for 100% strength joint

Pipe 64 tons in air 5.5 tons in sea water
Ballast 66 tons in air 57
130 62.5

Test $p_A = 3 p_{corr}$ $p_{cr} = \frac{3EI}{R^3_{outside}}$
p_{corr} (crit.) = $p_{hammocks}$

5 - 6 million \$ pipe (30 ft Dia)

5086 AL
5456 AL

$\left.\begin{array}{l}5086\ \text{AL}\\5456\ \text{AL}\end{array}\right\}$ in sea water

screen wt 162,000# - 280,000#

```
.DISPLAY 01SCC0,354,361
M.0073   ACTION IN PROGRESS
L.0354   /DATA
L.0355   0.115      0.235      0.335      0.440      0.515      0.600      0.645
L.0356   0.695      0.780      1.000
L.0357   0.024      0.065      0.119      0.188      0.25)      0.334      0.384
L.0358   0.450      0.584      1.000
L.0359   0.0005     40.00      64.167     1.10       8.00       30.00      1000000.0
L.0360   3000.00    3000.00    0.40       2435.00    30.00      2000000.0  1.00
L.0361   300.00     16.50      40.00
M.0070   END
M.0072   BEGIN
/RUN
```

BRAZIL SITE

C O L D   W A T E R   P I P E   C O N F I G U R A T I O N

DATE 02/23/79

CYL. MATERIAL STRENGTH=	3000.00	PLI	WEB MATERIAL STRENGTH=	3000.00	PLI
MATERIAL ULTIMATE STRAIN=	0.40000	IN/IN	ROUGHNESS COEFF. OF PIPE MATERIAL=	0.000500	
NUMBER OF RADIAL WEBS=	40		RADIAL WEB INITIAL LENGTH=	100.70	IN
LENGTH OF OUTER LOBE (INITIAL)=	40.34	IN	LENGTH OF INNER LOBE (INITIAL)=	23.74	IN
PIPE LENGTH=	2435.00	FT	PIPE DIAMETER=	30.00	FT
COLD WATER TEMPERATURE=	40.00	DEG.F	FLOW RATE (GALLONS PER MINUTE)=	2000000.00	GPM
INFLATED OUTER RADIUS=	300.00	IN	INFLATED INNER RADIUS=	180.00	IN
ANNULUS-OUTSIDE GAGE PRESSURE=	16.50	PSI	ANNULUS-INSIDE GAGE PRESSURE=	19.25	PSI
WATER FLOW UPWARD VELOCITY=	6.30	FPS	FACTOR OF SAFETY AGAINST BUCKLING=	2.00	
PRESSURE DIFFERENCE DUE TO DRAG=	0.0	PSI	TOTAL PRESSURE DIFFERENCE=	2.750	PSI
EFFECTIVE FLEXURAL RING STIFFNESS=	0.53980 08	IN.LB	CRITICAL RADIAL PRESSURE=	8.25	PSI
LOBE AXIAL STRESS DUE TO PRESSURE=	395.31	PLI	WEB AXIAL STRESS DUE TO PRESSURE=	395.31	PLI
PIPE CROSS SECTION MAT L LENGTH=	7913.99	IN	ANNULUS CROSS SECTION AREA=	189602.56	SQ.IN.
PIPE BENDING STIFFNESS EI=	0.15177D 13	LB.IN.SQ	PIPE EXTENSIONAL STIFFNESS EA=	48119738.62	LB

I N F L A T E D   S T R U C T U R E - G E O M E T R Y   A N D   L O A D S

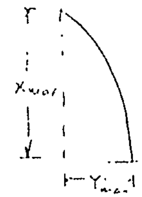
OUTER CYLINDER					INNER CYLINDER					WEB
LOBE RADIUS (IN)	HALF ANGLE (DEG)	LOBE LENGTH (IN)	HOOP LOAD (PLI)	HOOP STRAIN (IN/IN)	LOBE RADIUS (IN)	HALF ANGLE (DEG)	LOBE LENGTH (IN)	HOOP LOAD (PLI)	HOOP STRAIN (IN/IN)	RADIAL LOAD (PLI)
49.74	28.25	49.04	820.63	0.2155	41.81	19.74	28.81	804.82	0.2134	660.91

```
CPU TIME =  0  SEC
M.0070   END
M.0072   BEGIN
```

BELL AEROSYSTEMS DATA
SHEET #1

```
[illegible]
[illegible]   ZDATA
L.[illegible]36   0.50       65.00      2435.00    600.00    0.15      28.00      31470.0
L.0137   500000.0   43.00      8000.00    1083.00   1.00
M.0070   END
M.0072   BEGIN
/RUN
```

C.W.PIPE AXIS GEOMETRY AND AXIAL LOAD   DATE   02/22/77



[illegible]ZIL SITE PIPE

$Y_{max}/X_{max} = 5784.09/29220. = 0.198$

BALLAST LOAD $= 1.8 \times 10^6$ LB (WT. IN WATER)

```
CURRENT SURFACE VELOCITY=          0.50  KT
PIPE LENGTH=                    2435.00  FT
DEPTH OF PIPE TOP=                65.00  FT
PIPE OUTSIDE DIAMETER=           600.00  IN
PIPE MATERIAL THICKNESS=         0.1500  IN
PIPE WEIGHT PER L.INCH=           43.00  LB/IN
PIPE BUOYANCY PER L.INCH=         43.00  LB/IN
NUMBER OF STEEL RINGS=               28
WEIGHT OF ONE RING IN AIR=     31470.00  LB
NET BALLAST LOAD=             500000.00  LB
UPWARD RESULTANT PRESSURE=1299600.00  LB
TOTAL BALLAST LOAD=          1799600.00  LB
```

X-COORDINATES OF PIPE AXIS (ALONG DEPTH)

0.0	1461.00	2922.00	4383.00	5844.00	7305.00	8766.00
10227.00	11688.00	13149.00	14610.00	16071.00	17532.00	18993.00
20454.00	21915.00	23376.00	24837.00	26298.00	27759.00	29220.00

Y-COORDINATES OF PIPE AXIS (HORIZONTALLY)

0.0	486.03	956.15	1406.56	1837.25	2247.97	2638.84
3009.93	3361.24	3692.73	4004.31	4295.69	4566.38	4815.60
5042.24	5244.74	5420.97	5568.01	5681.80	5756.63	5784.09

ARC LENGTHS ALONG PIPE AXIS

0.0	1539.98	3074.52	4603.38	6126.55	7644.20	9156.59
10663.99	12166.65	13664.79	15158.66	16648.44	18134.32	19616.44
21094.92	22569.91	24041.52	25509.93	26975.39	28438.36	29899.70

TILT ANGLE OF PIPE AXIS (DEG.)

18.71488	18.12993	17.47802	16.78366	16.06362	15.33993	14.61511
13.88687	13.15279	12.41277	11.66186	10.89239	10.09502	9.25805
8.36658	7.40106	6.33511	5.13191	3.73797	2.07159	0.0

PIPE AXIAL TENSION (LB)

2652207.	2538008.	2423947.	2310340.	2197536.	2085779.	1975039.
1865244.	1756325.	1648240.	1540916.	1434283.	1328263.	1222866.
1117996.	1013648.	909811.	806487.	703703.	601509.	500000.

```
 CPU TIME=  97  SEC.
M.0070  END
M.0072  BEGIN
```

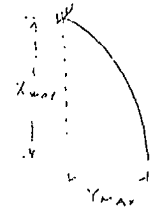
BELL AEROSYSTEMS DATA

SHEET # 2

[redacted]

```
L.0136  0.50    65.00   2435.00   600.00   0.15    28.00    31470.0
L.0137  0.00    43.00   0000.00   1083.00  1.00
M.0070  END
M.0072  BEGIN
/RUN
```

BRAZIL SITE PIPE



$Y_{MAX}/X_{MAX} = 14124.82/29220.0 = 0.483.$

BALLAST LOAD = 1.3×10^6 LB (WT IN WATER).

C.W.PIPE AXIS GEOMETRY AND AXIAL LOAD   DATE   02/22/79

```
CURRENT SURFACE VELOCITY=          0.50  KT
PIPE LENGTH=                    2435.00  FT
DEPTH OF PIPE TOP=                65.00  FT
PIPE OUTSIDE DIAMETER=           600.00  IN
PIPE MATERIAL THICKNESS=         0.1500  IN
PIPE WEIGHT PER L.INCH=           43.00  LB/IN
PIPE BUOYANCY PER L.INCH=         43.00  LB/IN
NUMBER OF STEEL    RINGS=            28
WEIGHT OF ONE RING IN AIR=     31470.00  LB
NET BALLAST LOAD=                   0.0  LB
UPWARD RESULTANT PRESSURE=   1299600.00  LB
TOTAL BALLAST LOAD=          1299600.00  LB
```

X-COORDINATES OF PIPE AXIS (ALONG DEPTH)

0.0	1461.00	2922.00	4383.00	5844.00	7305.00	8766.00
10227.00	11688.00	13149.00	14610.00	16071.00	17532.00	18993.00
20454.00	21915.00	23376.00	24837.00	26298.00	27759.00	29220.00

Y-COORDINATES OF PIPE AXIS (HORIZONTALLY)

0.0	844.37	1675.74	2492.53	3294.02	4080.17	4851.40
5608.51	6351.75	7081.77	7799.22	8504.62	9198.37	9880.70
10551.61	11210.71	11857.00	12488.33	13099.83	13678.27	14124.82

ARC LENGTHS ALONG PIPE AXIS

0.0	1687.45	3368.43	5042.26	6708.67	8367.75	10019.86
11665.35	13304.53	14937.76	16565.43	18187.81	19805.16	21417.64
23025.33	24628.12	26225.69	27817.27	29401.09	30972.48	32505.20

TILT ANGLE OF PIPE AXIS (DEG.)

30.19536	29.84366	29.43048	28.98138	28.51450	28.05548	27.60894
27.17494	26.75379	26.34941	25.96087	25.58483	25.21686	24.85070
24.47695	24.08039	23.63377	23.08097	22.27878	20.67218	0.0

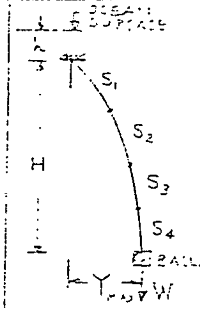
PIPE AXIAL TENSION (LB)

2293529.	2171701.	2049522.	1927716.	1806721.	1686975.	1568478.
1451144.	1334898.	1219706.	1105474.	992098.	879485.	767550.
656219.	545427.	435123.	325272.	215876.	107042.	0.

```
CPU TIME=  90  SEC.
M.0070  END
M.0072  BEGIN
```

BELL AEROSYSTEMS DATA
SHEET # 3

CHARACTERISTICS OF BRAZIL AND PUERTO RICO SITE COLD WA[illegible]



	PIPE SITE	
	BRAZIL	PUERTO RICO
h (FT)	65	225
H (FT)	2435	2775

W: BALLAST WT. IN WATER (MAT'L: STEEL)

ITEM			UNIT	BRAZIL		PUERTO RICO
		P (ANNULUS-OUTSIDE) PSI		16.50		15.00
		BALLAST WEIGHT, W LB $\times 10^{-6}$		1.3 ✓	1.8	1.6
1		Y_{MAX}	FT	1177.07	43[illegible].01	111.27
2		ARC LENGTH (PRESSURIZED)	FT	2708.77	2491.64	2778.50
3		Y_{MAX}/H		0.435	0.173	0.040
4		WEB RADIAL LOAD	PLI	661.	661.	501.
5		LOBE MAX. HOOP LOAD	PLI	921.	371.	746.
6	ARC S_1	AXIAL TENSION	PLI	385.	730.	653.
7		MEAN MAT'L STRENGTH (1)	PLI	3011.	3102.	2798.
8		FREE LENGTH (2)	FT	563.	518.	578.
9		FREE AREA (2)	FT^2	371358.	341591.	380918
10		WEIGHT	LB	333 518.	312 452.	337 221.
11	ARC S_2	AXIAL TENSION	PLI	594.	645.	564.
12		MEAN MAT'L STRENGTH (1)	PLI	2928.	2931.	2619.
13		FREE LENGTH (2)	FT	563.	518.	578.
14		FREE AREA (1)	FT^2	371358.	341591.	380918
15		WEIGHT	LB	321665.	301 753.	314771.
16	ARC S_3	AXIAL TENSION	PLI	521.	577.	491.
17		MEAN MAT'L STRENGTH (1)	PLI	2683.	2794.	2473.
18		FREE LENGTH (2)	FT	563.	518.	578.
19		FREE AREA (2)	FT^2	371358.	341591.	380918.
20		WEIGHT	LB	311167.	293 210.	304583.
21	ARC S_4	AXIAL TENSION	PLI	450.	510.	418.
22		MEAN MAT'L STRENGTH (1)	PLI	2542.	2662.	2327.
23		FREE LENGTH (2)	FT	563.	518.	578.
24		FREE AREA (2)	FT^2	371358.	341591.	380918.
25		WEIGHT	LB	301601.	284925.	294419.
26		TOTAL MATERIAL WEIGHT	LB	1 267350	1 192 339	1 240994
27		TOTAL SEAM LENGTH	FT	190 189	165745	184827
28		STEEL RINGS (3)	—	30	28	32
29		TOTAL WEIGHT OF STEEL RINGS (IN AIR)	LB	944100	881160	1007040
30		BALLAST WEIGHT (STEEL) IN AIR	LB	1 495 000	2 070 000	1 840 000
31		TOTAL FREE LENGTH	FT	2250.	2072.	2310.
32		TOTAL PRESS. LENGTH	FT	2709.	2492. ?	2778.
33		NUMBER OF SECTIONS	—	15	14	16
34		SECTION LENGTH	FT	150	148	144

(1) AVERAGE BETWEEN WARP AND FILL DIRECTION
(2) UNPRESSURIZED
(3) TWO PER PIPE SECTION

BELL AEROSYSTEMS DATA

SHEET # 4

BROWN & ROOT, INC.
ENGINEERING DIVISION

CLIENT DEPARTMENT OF ENERGY JOB NO. ER-0425

SUBJECT BOTTOM-MOUNTED BUOYANT CWP CONCEPT

BASED ON PIPE AND SHELL DRAWING NO.

COMPUTER S. PORTER CHK'D. BY D. Fox APP'D. BY DATE 8 FEB 1979

THIS IS A CWP DESIGN TO UTILIZE PIPES, CAPPED AT EACH END, TO ACT AS BUOYANCY CONTAINERS. THE NUMBER OF THESE PIPES AND THE THICKNESS OF THE SHELL WILL BE DETERMINED BY THE MOMENTS ENCOUNTERED DURING SEVERE STORM CONDITIONS AT THE PUERTO RICO SITE.

CHOOSE 24-4'Ø PIPES. FIND THE NECESSARY SHELL DIAMETER TO BE EQUIVILENT TO A 30'Ø CWP.

$$\cancel{\frac{\pi}{4}}(30\ \text{FT})^2 = \cancel{\frac{\pi}{4}}(D)^2 + (24)\cancel{\frac{\pi}{4}}(4\ \text{FT})^2$$

$$D = 35.83\ \text{FT.}\quad (\text{USE } 36'\text{Ø})$$

BECAUSE OF CORROSION, MAINTAIN A MINIMUM OF 3/8 INCH WALL THICKNESS ON ALL STEEL PLATES AND PIPES.

ASSUME BUOYANCY IS NECESSARY IN THE TOP 1500 FT. OF THE CWP. PRESSURIZE ALL BUOYANCY CONTAINERS TO HYDROSTATIC PRESSURE. FROM THE "ASME BOILER AND PRESSURE VESSEL CODES," SECTION VIII, DIVISION 1, FOR INTERNAL PRESSURE:

$$t = \frac{PR}{SE - 0.6P} + C$$

WHERE t = WALL THICKNESS
P = HYDROSTATIC PRESSURE
R = RADIUS OF PRESSURE VESSEL = 24 IN
S = ALLOWABLE STRESS
E = WELD EFFICIENCY = 1.00
C = CORROSION ALLOWANCE = 0.06 IN

BROWN & ROOT, INC.
ENGINEERING DIVISION

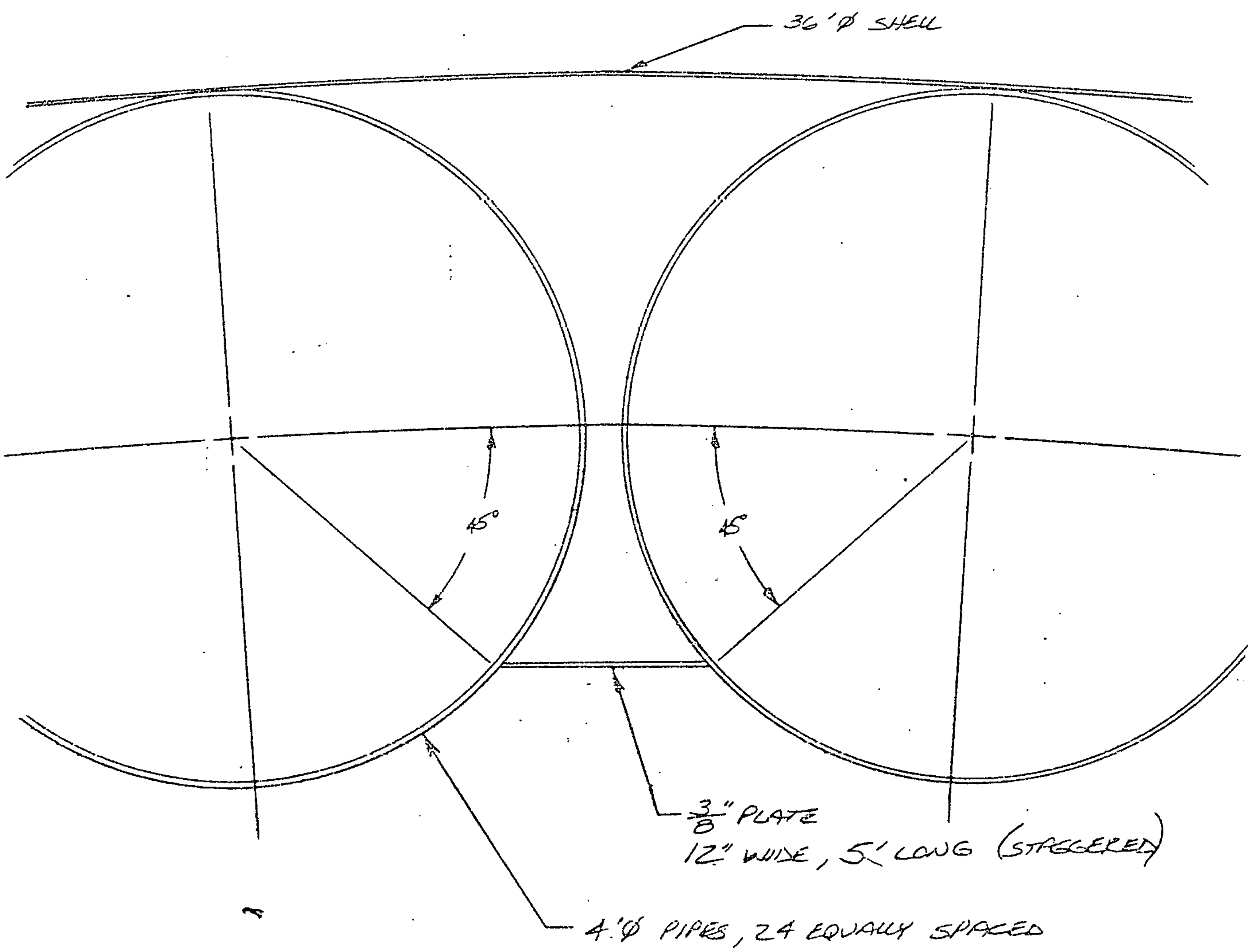
SHEET NO. 2 OF 10

CLIENT ______ JOB NO. ER-0925

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY GWD APP'D. BY ______ DATE 8 FEB 1979



TO REDUCE WEIGHT, USE A HIGH STRENGTH STEEL PIPE, API 5LX, GRADE X-60. ALLOWABLE STRESS = S = 18,750 PSI.

FOR 0-500 FT.: $t = \dfrac{(222\ LB/IN^2)(24\ IN)}{(18{,}750\ LB/IN^2) - 0.6(222\ LB/IN^2)} + 0.06\ IN$

$t = 0.346\ IN. \longrightarrow t = 3/8\ IN.$

FOR 500-1000 FT.: $t = \dfrac{(445\ LB/IN^2)(24\ IN)}{(18{,}750\ LB/IN^2) - 0.6(445\ LB/IN^2)} + 0.06\ IN.$

$t = 0.638\ IN \Longrightarrow t = 5/8\ IN.$

FOR 1000-1500 FT.: $t = \dfrac{(667\ LB/IN^2)(24\ IN)}{(18{,}750\ LB/IN^2) - 0.6(667\ LB/IN^2)} + 0.06\ IN.$

$t = 0.932\ IN \Longrightarrow t = 15/16\ IN.$

ASSUME ALL PIPES BELOW 1500 FT. ARE FLOODED, $t = 3/8$-IN.

TOTAL WEIGHT OF PIPES:

0-500 FT. $= (24)\frac{\pi}{4}\left((48\ IN)^2 - (47.25\ IN)^2\right)\left(\frac{1\ FT}{12\ IN}\right)^2(490\ LB/FT^3) = 4582\ LB/FT$

500-1000 FT. $= (24)\frac{\pi}{4}\left((48\ IN)^2 - (46.75\ IN)^2\right)\left(\frac{1\ FT}{12\ IN}\right)^2(490\ LB/FT^3) = 7597\ LB/FT$

1000-1500 FT. $= (24)\frac{\pi}{4}\left((48\ IN)^2 - (46.125\ IN)^2\right)\left(\frac{1\ FT}{12\ IN}\right)^2(490\ LB/FT^3) = 11{,}320\ LB/FT^3$

1500-2800 FT. $= 4582\ LB/FT$

$W = 17{,}706{,}100\ LBS$

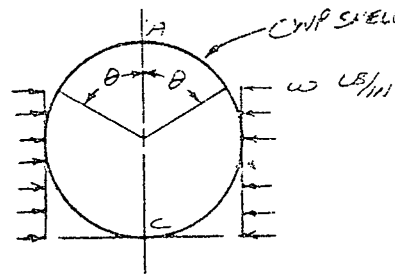
ASSUME A SHELL THICKNESS OF 3/8-INCH FOR THE ENTIRE LENGTH OF THE CWP:

$$W = (36\text{ FT})\pi(0.375\text{ IN})\left(\frac{1\text{ FT}}{12\text{ IN}}\right)(2800\text{ FT})(490\text{ LB/FT}^3) = 4,849,050\text{ LBS}$$

TO SIZE THE STAGGERED PLATES, ASSUME A THICKNESS OF 3/8-IN. WITH THE WIDTH BEING 12-IN. (SEE PAGE 2) AND THE LENGTH 60-IN. (120-IN CENTERS).

FROM ROARK, "FORMULAS FOR STRESS AND STRAIN," 5th ED., PP. 228,

CASE 10:



$$M_A = -wR^2\left[\cos\theta + \frac{\sin^2\theta}{2} - \frac{3}{4} + \frac{1}{\pi}\left(\sin\theta - \theta\cos\theta + \frac{3}{4}\left(\theta - \sin\theta\cos\theta\right) - \frac{\theta\sin^2\theta}{2} - \frac{\sin^3\theta}{3}k_4\right)\right]$$

WHERE: $\theta = 0$

w = UNIT LOAD

R = RADIUS OF RING = 18 FEET = 216 IN.

k_4 = CONSTANT

REWRITING, WITH $\theta = 0$: $M_A = -wR^2\left(1 - \frac{3}{4}\right) = \frac{-wR^2}{4}$

"w" IS DETERMINED FROM THE DRAG, LIFT, AND WAVE FORCES SUPPLIED BY SAI FOR PUERTO RICO, EXTREME STORM CONDITIONS, AT THE TOP OF THE PIPE (WORST CASE).

BROWN & ROOT, INC.
ENGINEERING DIVISION

CLIENT ______ JOB NO. ER-0925

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY D. FOX APP'D. BY ______ DATE 8 FEB 1977

$$\omega = 24.50 \text{ LB/IN-FT}$$

$$M_A = -\frac{1}{4}(24.50 \text{ LB/IN-FT})(216 \text{ IN})^2 = 285,722 \text{ IN-LBS/FT}$$

$$M = Fd$$

d = ONE-HALF THE DISTANCE FROM THE PLATES TO THE CWP SHELL

$$d = \frac{24 \text{ IN} + (24 \text{ IN}) \sin 45°}{2} = 20.49 \text{ IN}$$

F = FORCE ON STAGGERED PLATES

$$F = \frac{M}{d} = \frac{285,722 \text{ IN-LBS/FT}}{20.49 \text{ IN}} = 13,948 \text{ LBS/FT}$$

TOTAL FORCE ON THE FIVE FOOT LONG PLATE (SINCE THE PLATES ARE LOCATED ON TEN FOOT CENTERS, EACH PLATE MUST CARRY TWICE THE LOAD):

$$F = 2(13,948 \text{ LB/FT})(5 \text{ FT}) = 139,477 \text{ LBS}$$

NOW, SIZE THE PLATE TO WITHSTAND THIS FORCE IN BUCKLING. AGAIN, FROM ROARK, PP. 550:

CASE 1(a): $a = 12 \text{ IN}, \; b = 60 \text{ IN} \longrightarrow a/b = 0.20$

$$\sigma' = K \frac{E}{1-\mu^2}\left(\frac{t}{b}\right)^2 \Longrightarrow F' = KA \frac{E}{1-\mu^2}\left(\frac{t}{b}\right)^2$$

$$\text{IF } t = 3/8'' : \quad F' = 22.2(0.375 \text{ IN})(60 \text{ IN}) \frac{30(10)^6 \text{ LB/IN}^2}{1-(0.3)^2}\left(\frac{0.375 \text{ IN}}{60 \text{ IN}}\right)^2$$

BROWN & ROOT, INC.
ENGINEERING DIVISION

CLIENT ______ JOB NO. EE-0925

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY D. Fo APP'D. BY ______ DATE 8 FEB 1979

$$F' = 643,243 \text{ LBS}$$

$$\text{SAFETY FACTOR} = \frac{F'}{F} = \frac{643,243 \text{ LBS}}{139,477 \text{ LBS}} = 4.61$$

RISER DESIGN: USE A HEXAGONAL PATTERN OF 4'Ø PIPES WITH ONE LOCATED IN THE CENTER (A TOTAL OF SEVEN) TO PROVIDE STRENGTH IN BENDING.

INITIALLY, CHOOSE 3/8-INCH THICK WALLS ON THE RISER PIPES AND

$$\text{PLATE AREA} = 6(6 \text{ FT})^2 \sin 60° \cos 60° - (3)\frac{\pi}{4}(4 \text{ FT})^2 = 55.83 \text{ FT}^2$$

ASSUME PLATES ARE 1-IN. THICK AND SPACED EVERY 20-FT.

WEIGHT OF RISER:

$$W = \left[(7)\frac{\pi}{4}\left((48 \text{ IN})^2 - (47.25 \text{ IN})^2\right)\left(\frac{1 \text{ FT}}{12 \text{ IN}}\right)^2 (1000 \text{ FT}) + \left(\frac{1000}{20}\right)(55.83 \text{ FT}^2)\left(\frac{1.0}{12} \text{ FT}\right)\right](490 \text{ LB/FT}^3)$$

$$W = 1,450,420 \text{ LBS}$$

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 7 OF 10

JOB NO. ER-0925

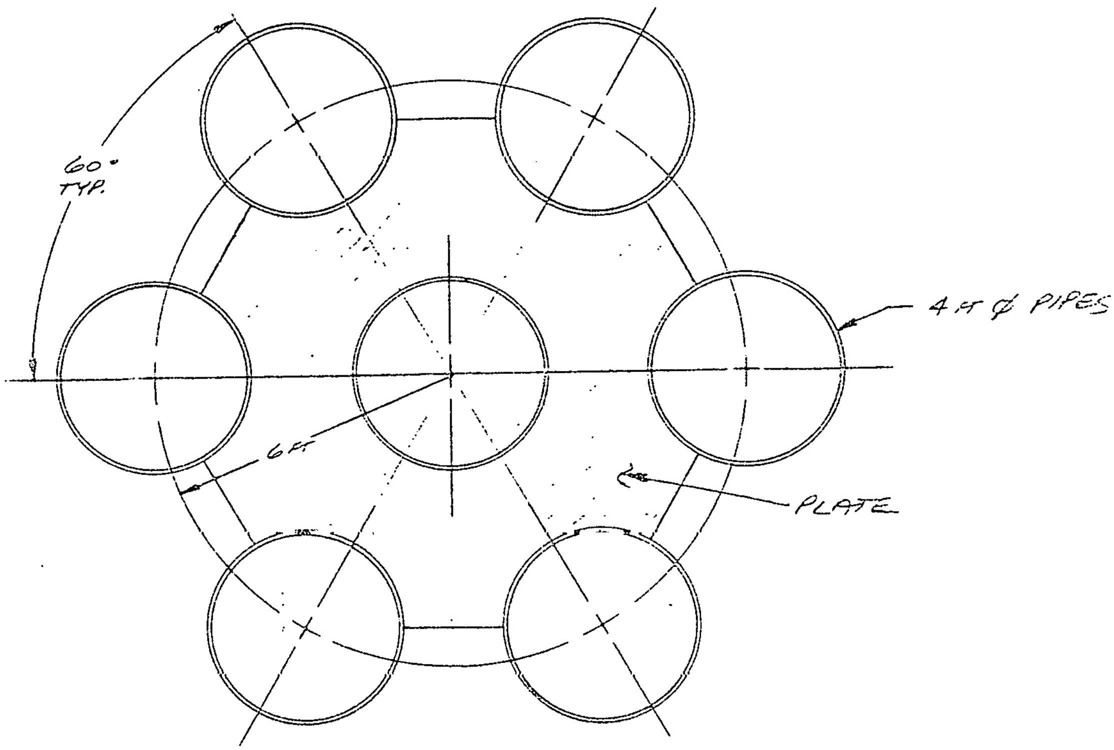
CLIENT

SUBJECT

BASED ON

DRAWING NO.

COMPUTER S. PORTER CHK'D. BY GWD APP'D. BY DATE 9 FEB 1979



TOTAL WEIGHTS AND FORCES:

SECTION	WEIGHT	BUOYANCY
0-500 FT	3,248,780 LBS	9,486,540 LBS
500-1000 FT	4,756,280 LBS	9,486,540 LBS
1000-1500 FT	6,642,780 LBS	9,486,540 LBS
1500-2800 FT	6,914,380 LBS	903,100 LBS
2800-3800 FT	1,450,420 LBS	189,440 LBS
TOTAL	23,012,640 LBS	29,552,160 LBS

REMOVE ALL BUOYANCY TANKS BELOW 1200 FT. AND REPLACE WITH 3/8-IN. WALL THICKNESS FLOODED TANKS.

REQUIRED WALL THICKNESS FOR A 48-INCH DIAMETER PIPE AT A DEPTH OF 1200-FT.: (FROM PAGE 1)

$$t = \frac{(533\ LB/IN^2)(24\ IN)}{18{,}750\ LB/IN^2 - 0.6(533\ LB/IN^2)} + 0.06\ IN = 0.75\ IN \Longrightarrow t = 3/4''$$

$$1000-1200\ FT:\ W = (24)\frac{\pi}{4}\left((48\ IN)^2(46.5\ IN)^2\right)\left(\frac{1\ FT}{12\ IN}\right)^2\left(440\ LB/FT^3\right) = 9092\ LB/FT$$

TOTAL WEIGHTS AND FORCES:

SECTION	WEIGHT	BUOYANCY
0 500 FT.	3,248,790 LBS	9,486,540 LBS
500 - 1000 FT.	4,756,280 LBS	9,486,540 LBS
1000 - 1200 FT.	2,201,510 LBS	3,794,620 LBS
1200 - 2800 FT.	8,510,010 LBS	1,111,510 LBS
2800 - 3800 FT.	1,450,420 LBS	189,440 LBS
TOTAL	20,166,990 LBS	24,068,650 LBS

TOTAL POSITIVE BUOYANCY = 3,901,660 LBS

REFER TO THE ATTACHED COMPUTER PRINTOUT TO CHECK STRESS LEVELS AT VARIOUS POINTS ALONG THE CWP. THE DISTANCE BETWEEN STATIONS IS TEN FEET. THE PROGRAM ANALIZES THE CWP DURING OPERATING CONDITIONS (ASSUMED PINNED AT THE TOP AND BOTTOM) AND EXTREME STORM CONDITIONS (PINNED AT BOTTOM ONLY).

CLIENT ______ JOB NO. ER-0925

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY D. FOX APP'D. BY ______ DATE 9 FEB 1979

CALCULATE MOMENTS OF INERTIA:

$$I_{SHELL} = \frac{\pi}{64}\left((432.75\ IN)^4 - (432.00\ IN)^4\right)\left(\frac{1\ FT}{12\ IN}\right)^4 = 574.05\ FT^4$$

FOR 0-500 FT: (1200-2800 FT)

$$I_{PIPES} = (24)\frac{\pi}{64}\left((48.0\ IN)^4 - (47.25\ IN)^4\right)\left(\frac{1\ FT}{12\ IN}\right)^4$$

SEE NOTE BELOW

$$+ \frac{\pi}{4}\left((48.0\ IN)^2 - (47.25\ IN)^2\right)\left(\frac{1\ FT}{12\ IN}\right)^2(2)(16\ FT)^2(6) = 1215.36\ FT^4$$

$$I = 1789.41\ FT^4$$

NOTE: THIS NUMER COMES FROM A SUMMATION OF SINE-SQUARED TERMS DEALING WITH THE DISTANCE OF THE PIPES FROM THE NEUTRAL AXIS;

$$\Sigma \sin^2 x = \sin^2 90° + (2)\sin^2 75° + (2)\sin^2 60° + (2)\sin^2 45° + (2)\sin^2 30° + (2)\sin^2 15° + (2)\sin^2 0° = 6$$

FOR 500-1000 FT: $I = 2588.70\ FT^4$

FOR 1000-1200 FT: $I = 2985.06\ FT^4$

FOR 2800-3800 FT: $I = 63.06\ FT^4$

USING THE EQUATION $\sigma = \frac{Mc}{I}$, CHECK THE BENDING STRESS AT VARIOUS STATIONS ALONG THE CWP.

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 10 OF 10

CLIENT ______ JOB NO. ER-0925

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY D. Fo. APP'D. BY ______ DATE 9 FEB 1979

TABLE OF BENDING STRESS VALUES:

CONDITION	STATION	MOMENT (IN-LBS)	STRESS (PSI)
OPERATING	32 (320 FT) MAX.	8.34×10^8 IN-LBS	4855 PSI
OPERATING	100 (1000 FT)	9.70×10^7 IN-LBS	390 PSI
OPERATING	120 (1200 FT)	5.38×10^7 IN-LBS	313 PSI
OPERATING	280 (2800 FT)	1.93×10^4 IN-LBS	1.4 PSI
OPERATING	340 (3400 FT) MAX.	3.24×10^5 IN-LBS	24 PSI.
STORM	52 (520 FT) MAX.	7.19×10^8 IN-LBS	4185 PSI
STORM	100 (1000 FT)	1.16×10^8 IN-LBS	467 PSI
STORM	120 (1200 FT)	7.95×10^7 IN LBS	463 PSI
STORM	280 (2800 FT) MAX.	9.54×10^7 IN-LBS	7004 PSI

NOTE:

ALTHOUGH THE STRESSES ABOVE ARE BENDING STRESSES ONLY, IT CAN BE SEEN THAT ALL ARE RELATIVELY LOW. A MORE COMPLETE ANALYSIS WOULD COMBINE THE BENDING, HOOP, AND AXIAL STRESSES.

HOME[redacted]ECT[redacted]ANA[redacted]
PUERTO RICO. DURING STORM CONDITIONS IT IS ASSUMED THE PLATF[redacted]IS [redacted]
AND THE CWP IS PINNED AT THE BOTTOM.

PROB (CONTD)
1 OPERATING CONDITIONS, PIPE AND TEE, RIGID RISER

STA I	X	W	DW/DX	M	DM/DX	NET REACT
-1	-0.120E 03	-0.330E 00	0.275E-02	0.0	0.0	0.0
0	0.0	0.0	0.275E-02	0.0	-0.167E 06	-0.334E 06
1	0.120E 03	0.330E 00	0.274E-02	-0.401E 08	-0.332E 06	0.407E 04
2	0.240E 03	0.659E 00	0.274E-02	-0.797E 08	-0.329E 06	0.273E 04
3	0.360E 03	0.987E 00	0.273E-02	-0.119E 09	-0.325E 06	0.338E 04
4	0.480E 03	0.131E 01	0.271E-02	-0.158E 09	-0.323E 06	0.246E 04
5	0.600E 03	0.164E 01	0.269E-02	-0.196E 09	-0.319E 06	0.368E 04
6	0.720E 03	0.196E 01	0.267E-02	-0.234E 09	-0.317E 06	0.614E 03
7	0.840E 03	0.228E 01	0.264E-02	-0.272E 09	-0.313E 06	0.737E 04
8	0.960E 03	0.259E 01	0.261E-02	-0.310E 09	-0.307E 06	0.614E 04
9	0.108E 04	0.291E 01	0.258E-02	-0.346E 09	-0.299E 06	0.922E 04
10	0.120E 04	0.321E 01	0.254E-02	-0.381E 09	-0.291E 06	0.676E 04
11	0.132E 04	0.351E 01	0.249E-02	-0.416E 09	-0.283E 06	0.860E 04
12	0.144E 04	0.381E 01	0.245E-02	-0.449E 09	-0.276E 06	0.553E 04
13	0.156E 04	0.410E 01	0.240E-02	-0.482E 09	-0.267E 06	0.135E 05
14	0.168E 04	0.439E 01	0.234E-02	-0.513E 09	-0.256E 06	0.799E 04
15	0.180E 04	0.466E 01	0.229E-02	-0.544E 09	-0.249E 06	0.614E 04
16	0.192E 04	0.494E 01	0.223E-02	-0.573E 09	-0.244E 06	0.369E 04
17	0.204E 04	0.520E 01	0.216E-02	-0.602E 09	-0.234E 06	0.160E 05
18	0.216E 04	0.545E 01	0.210E-02	-0.629E 09	-0.225E 06	0.246E 04
19	0.228E 04	0.570E 01	0.203E-02	-0.656E 09	-0.218E 06	0.104E 05
20	0.240E 04	0.594E 01	0.196E-02	-0.682E 09	-0.206E 06	0.141E 05
21	0.252E 04	0.617E 01	0.188E-02	-0.706E 09	-0.191E 06	0.166E 05
22	0.264E 04	0.639E 01	0.180E-02	-0.727E 09	-0.173E 06	0.190E 05
23	0.276E 04	0.660E 01	0.172E-02	-0.747E 09	-0.157E 06	0.129E 05
24	0.288E 04	0.681E 01	0.164E-02	-0.765E 09	-0.141E 06	0.190E 05
25	0.300E 04	0.700E 01	0.156E-02	-0.781E 09	-0.123E 06	0.160E 05
26	0.312E 04	0.718E 01	0.147E-02	-0.795E 09	-0.105E 06	0.209E 05
27	0.324E 04	0.735E 01	0.139E-02	-0.806E 09	-0.860E 05	0.172E 05
28	0.336E 04	0.751E 01	0.130E-02	-0.815E 09	-0.703E 05	0.141E 05
29	0.348E 04	0.766E 01	0.121E-02	-0.823E 09	-0.596E 05	0.737E 04
30	0.360E 04	0.780E 01	0.112E-02	-0.830E 09	-0.436E 05	0.246E 05
31	0.372E 04	0.793E 01	0.103E-02	-0.833E 09	-0.194E 05	0.240E 05
32	0.384E 04	0.805E 01	0.944E-03	-0.834E 09	0.614E 03	0.160E 05
33	0.396E 04	0.816E 01	0.854E-03	-0.833E 09	0.175E 05	0.178E 05
34	0.408E 04	0.826E 01	0.764E-03	-0.830E 09	0.255E 05	-0.185E 04
35	0.420E 04	0.834E 01	0.674E-03	-0.827E 09	0.359E 05	0.227E 05
36	0.432E 04	0.842E 01	0.586E-03	-0.822E 09	0.587E 05	0.227E 05
37	0.444E 04	0.848E 01	0.497E-03	-0.813E 09	0.857E 05	0.313E 05
38	0.456E 04	0.854E 01	0.410E-03	-0.801E 09	0.104E 06	0.553E 04
39	0.468E 04	0.858E 01	0.325E-03	-0.788E 09	0.117E 06	0.203E 05
40	0.480E 04	0.862E 01	0.240E-03	-0.773E 09	0.146E 06	0.369E 05
41	0.492E 04	0.864E 01	0.158E-03	-0.753E 09	0.165E 06	0.123E 04
42	0.504E 04	0.865E 01	0.779E-04	-0.733E 09	0.180E 06	0.301E 05
43	0.516E 04	0.866E 01	0.755E-07	-0.710E 09	0.194E 06	-0.307E 04
44	0.528E 04	0.865E 01	-0.753E-04	-0.687E 09	0.201E 06	0.166E 05
45	0.540E 04	0.864E 01	-0.148E-03	-0.662E 09	0.214E 06	0.104E 05
46	0.552E 04	0.862E 01	-0.218E-03	-0.635E 09	0.220E 06	0.123E 04
47	0.564E 04	0.859E 01	-0.285E-03	-0.609E 09	0.227E 06	0.129E 05
48	0.576E 04	0.855E 01	-0.349E-03	-0.581E 09	0.240E 06	0.215E 05

50	0.600E 04	0.845E 01	-0.463E-03	-0.519E 09	[illegible] 06	[illegible]
51	0.612E 04	0.839E 01	-0.502E-03	-0.486E 09	0.260E 06	-0.167E 05
52	0.624E 04	0.833E 01	-0.536E-03	-0.456E 09	0.254E 06	0.369E 04
53	0.636E 04	0.827E 01	-0.568E-03	-0.426E 09	0.259E 06	0.738E 04
54	0.648E 04	0.820E 01	-0.597E-03	-0.394E 09	0.251E 06	-0.249E 05
55	0.660E 04	0.812E 01	-0.625E-03	-0.365E 09	0.238E 06	0.213E 01
56	0.672E 04	0.805E 01	-0.650E-03	-0.337E 09	0.226E 06	-0.249E 05
57	0.684E 04	0.797E 01	-0.673E-03	-0.311E 09	0.206E 06	-0.148E 05
58	0.696E 04	0.788E 01	-0.695E-03	-0.287E 09	0.190E 06	-0.166E 05
59	0.708E 04	0.780E 01	-0.715E-03	-0.266E 09	0.180E 06	-0.369E 04
60	0.720E 04	0.771E 01	-0.733E-03	-0.244E 09	0.171E 06	-0.138E 05
61	0.732E 04	0.762E 01	-0.750E-03	-0.225E 09	0.165E 06	0.921E 03
62	0.744E 04	0.753E 01	-0.765E-03	-0.205E 09	0.154E 06	-0.231E 05
63	0.756E 04	0.744E 01	-0.779E-03	-0.188E 09	0.146E 06	0.738E 04
64	0.768E 04	0.735E 01	-0.792E-03	-0.170E 09	0.146E 06	-0.277E 04
65	0.780E 04	0.725E 01	-0.804E-03	-0.152E 09	0.151E 06	0.923E 04
66	0.792E 04	0.715E 01	-0.814E-03	-0.133E 09	0.157E 06	0.277E 04
67	0.804E 04	0.705E 01	-0.823E-03	-0.114E 09	0.157E 06	-0.277E 04
68	0.816E 04	0.695E 01	-0.830E-03	-0.957E 08	0.146E 06	-0.157E 05
69	0.828E 04	0.685E 01	-0.837E-03	-0.788E 08	0.135E 06	-0.102E 05
70	0.840E 04	0.675E 01	-0.842E-03	-0.632E 08	0.125E 06	-0.102E 05
71	0.852E 04	0.665E 01	-0.846E-03	-0.488E 08	0.125E 06	0.102E 05
72	0.864E 04	0.655E 01	-0.849E-03	-0.332E 08	0.119E 06	-0.221E 05
73	0.876E 04	0.645E 01	-0.851E-03	-0.203E 08	0.101E 06	-0.138E 05
74	0.888E 04	0.635E 01	-0.852E-03	-0.897E 07	0.969E 05	0.554E 04
75	0.900E 04	0.624E 01	-0.852E-03	0.299E 07	0.103E 06	0.738E 04
76	0.912E 04	0.614E 01	-0.851E-03	0.158E 08	0.106E 06	-0.277E 04
77	0.924E 04	0.604E 01	-0.850E-03	0.283E 08	0.951E 05	-0.185E 05
78	0.936E 04	0.594E 01	-0.847E-03	0.386E 08	0.790E 05	-0.120E 05
79	0.948E 04	0.584E 01	-0.844E-03	0.475E 08	0.670E 05	-0.129E 05
80	0.960E 04	0.574E 01	-0.840E-03	0.548E 08	0.554E 05	-0.111E 05
81	0.972E 04	0.564E 01	-0.836E-03	0.608E 08	0.484E 05	-0.277E 04
82	0.984E 04	0.554E 01	-0.832E-03	0.664E 08	0.503E 05	0.646E 04
83	0.996E 04	0.544E 01	-0.827E-03	0.729E 08	0.540E 05	0.923E 03
84	0.101E 05	0.534E 01	-0.821E-03	0.794E 08	0.517E 05	-0.554E 04
85	0.102E 05	0.524E 01	-0.815E-03	0.853E 08	0.484E 05	-0.923E 03
86	0.103E 05	0.514E 01	-0.809E-03	0.910E 08	0.406E 05	-0.148E 05
87	0.104E 05	0.504E 01	-0.802E-03	0.950E 08	0.254E 05	-0.157E 05
88	0.106E 05	0.495E 01	-0.795E-03	0.971E 08	0.175E 05	0.800E 00
89	0.107E 05	0.485E 01	-0.788E-03	0.992E 08	0.125E 05	-0.102E 05
90	0.108E 05	0.476E 01	-0.781E-03	0.100E 09	0.969E 04	0.461E 04
91	0.109E 05	0.467E 01	-0.774E-03	0.102E 09	0.102E 05	-0.369E 04
92	0.110E 05	0.457E 01	-0.767E-03	0.103E 09	0.646E 04	-0.369E 04
93	0.112E 05	0.448E 01	-0.759E-03	0.103E 09	0.554E 04	0.185E 04
94	0.113E 05	0.439E 01	-0.752E-03	0.104E 09	0.554E 04	-0.185E 04
95	0.114E 05	0.430E 01	-0.744E-03	0.104E 09	0.231E 04	-0.461E 04
96	0.115E 05	0.421E 01	-0.737E-03	0.104E 09	-0.508E 04	-0.102E 05
97	0.116E 05	0.412E 01	-0.729E-03	0.103E 09	-0.134E 05	-0.738E 04
98	0.118E 05	0.404E 01	-0.722E-03	0.101E 09	-0.160E 05	-0.924E 03
99	0.119E 05	0.395E 01	-0.715E-03	0.989E 08	-0.172E 05	0.246E 04
100	0.120E 05	0.387E 01	-0.706E-03	0.970E 08	-0.181E 05	-0.418E 04
101	0.121E 05	0.378E 01	-0.691E-03	0.945E 08	-0.204E 05	-0.525E 03
102	0.122E 05	0.370E 01	-0.672E-03	0.921E 08	-0.209E 05	-0.319E 03
103	0.124E 05	0.362E 01	-0.653E-03	0.895E 08	-0.212E 05	-0.319E 03
104	0.125E 05	0.354E 01	-0.635E-03	0.870E 08	-0.210E 05	0.637E 03
105	0.126E 05	0.347E 01	-0.617E-03	0.845E 08	-0.204E 05	0.637E 03
106	0.127E 05	0.340E 01	-0.599E-03	0.821E 08	-0.197E 05	0.637E 03
107	0.128E 05	0.332E 01	-0.583E-03	0.798E 08	-0.193E 05	0.319E 03
108	0.130E 05	0.326E 01	-0.566E-03	0.775E 08	-0.189E 05	0.319E 03
109	0.131E 05	0.319E 01	-0.550E-03	0.752E 08	-0.186E 05	0.318E 03

11	[redacted] 0[illegible]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
111	[redacted]33E 05	,30[redacted]1	20E	0,[redacted] 08	,17[redacted]5	19E [redacted]
112	0,134E 05	0,300E 01	-0,506E-03	0,688E 08	-0,172E 05	0,637E 03
113	0,136E 05	0,294E 01	-0,491E-03	0,667E 08	-0,172E 05	-0,637E 03
114	0,137E 05	0,288E 01	-0,478E-03	0,646E 08	-0,169E 05	0,127E 04
115	0,138E 05	0,282E 01	-0,465E-03	0,627E 08	-0,159E 05	0,637E 03
116	0,139E 05	0,277E 01	-0,452E-03	0,608E 08	-0,154E 05	0,318E 03
117	0,140E 05	0,272E 01	-0,439E-03	0,590E 08	-0,150E 05	0,637E 03
118	0,142E 05	0,266E 01	-0,427E-03	0,572E 08	-0,145E 05	0,318E 03
119	0,143E 05	0,261E 01	-0,415E-03	0,555E 08	-0,142E 05	0,319E 03
120	0,144E 05	0,256E 01	-0,404E-03	0,538E 08	-0,137E 05	0,637E 03
121	0,145E 05	0,252E 01	-0,393E-03	0,522E 08	-0,135E 05	-0,319E 03
122	0,146E 05	0,247E 01	-0,382E-03	0,506E 08	-0,135E 05	0,319E 03
123	0,148E 05	0,242E 01	-0,372E-03	0,490E 08	-0,129E 05	0,955E 03
124	0,149E 05	0,238E 01	-0,362E-03	0,475E 08	-0,124E 05	0,133E 00
125	0,150E 05	0,234E 01	-0,352E-03	0,460E 08	-0,119E 05	0,955E 03
126	0,151E 05	0,230E 01	-0,343E-03	0,446E 08	-0,113E 05	0,319E 03
127	0,152E 05	0,226E 01	-0,334E-03	0,433E 08	-0,108E 05	0,637E 03
128	0,154E 05	0,222E 01	-0,325E-03	0,420E 08	-0,107E 05	-0,318E 03
129	0,155E 05	0,218E 01	-0,316E-03	0,407E 08	-0,104E 05	0,955E 03
130	0,156E 05	0,214E 01	-0,308E-03	0,395E 08	-0,971E 04	0,319E 03
131	0,157E 05	0,210E 01	-0,300E-03	0,384E 08	-0,971E 04	-0,319E 03
132	0,158E 05	0,207E 01	-0,292E-03	0,372E 08	-0,971E 04	0,319E 03
133	0,160E 05	0,203E 01	-0,284E-03	0,360E 08	-0,955E 04	0,0
134	0,161E 05	0,200E 01	-0,277E-03	0,349E 08	-0,971E 04	-0,319E 03
135	0,162E 05	0,197E 01	-0,270E-03	0,337E 08	-0,924E 04	0,127E 04
136	0,163E 05	0,193E 01	-0,263E-03	0,327E 08	-0,876E 04	-0,319E 03
137	0,164E 05	0,190E 01	-0,256E-03	0,316E 08	-0,876E 04	0,318E 03
138	0,166E 05	0,187E 01	-0,250E-03	0,306E 08	-0,860E 04	0,133E 00
139	0,167E 05	0,184E 01	-0,244E-03	0,295E 08	-0,828E 04	0,637E 03
140	0,168E 05	0,182E 01	-0,237E-03	0,286E 08	-0,764E 04	0,637E 03
141	0,169E 05	0,179E 01	-0,232E-03	0,277E 08	-0,748E 04	-0,319E 03
142	0,170E 05	0,176E 01	-0,226E-03	0,268E 08	-0,717E 04	0,955E 03
143	0,172E 05	0,173E 01	-0,220E-03	0,260E 08	-0,669E 04	0,0
144	0,173E 05	0,171E 01	-0,215E-03	0,252E 08	-0,653E 04	0,319E 03
145	0,174E 05	0,168E 01	-0,210E-03	0,244E 08	-0,621E 04	0,318E 03
146	0,175E 05	0,166E 01	-0,205E-03	0,237E 08	-0,621E 04	-0,319E 03
147	0,176E 05	0,163E 01	-0,200E-03	0,229E 08	-0,637E 04	0,133E 00
148	0,178E 05	0,161E 01	-0,195E-03	0,222E 08	-0,621E 04	0,318E 03
149	0,179E 05	0,158E 01	-0,191E-03	0,214E 08	-0,557E 04	0,955E 03
150	0,180E 05	0,156E 01	-0,187E-03	0,208E 08	-0,510E 04	0,0
151	0,181E 05	0,154E 01	-0,182E-03	0,202E 08	-0,478E 04	0,637E 03
152	0,182E 05	0,152E 01	-0,178E-03	0,197E 08	-0,478E 04	-0,637E 03
153	0,184E 05	0,150E 01	-0,174E-03	0,191E 08	-0,494E 04	0,319E 03
154	0,185E 05	0,148E 01	-0,170E-03	0,185E 08	-0,478E 04	-0,133E 00
155	0,186E 05	0,146E 01	-0,166E-03	0,179E 08	-0,462E 04	0,319E 03
156	0,187E 05	0,144E 01	-0,163E-03	0,174E 08	-0,446E 04	0,0
157	0,188E 05	0,142E 01	-0,159E-03	0,169E 08	-0,414E 04	0,637E 03
158	0,190E 05	0,140E 01	-0,156E-03	0,164E 08	-0,382E 04	-0,250E-01
159	0,191E 05	0,138E 01	-0,152E-03	0,159E 08	-0,366E 04	0,319E 03
160	0,192E 05	0,136E 01	-0,149E-03	0,155E 08	-0,366E 04	-0,318E 03
161	0,193E 05	0,134E 01	-0,146E-03	0,151E 08	-0,366E 04	0,319E 03
162	0,194E 05	0,133E 01	-0,143E-03	0,146E 08	-0,334E 04	0,319E 03
163	0,196E 05	0,131E 01	-0,140E-03	0,143E 08	-0,303E 04	0,319E 03
164	0,197E 05	0,129E 01	-0,137E-03	0,139E 08	-0,287E 04	0,833E-02
165	0,198E 05	0,128E 01	-0,134E-03	0,136E 08	-0,271E 04	0,319E 03
166	0,199E 05	0,126E 01	-0,131E-03	0,133E 08	-0,271E 04	-0,318E 03
167	0,200E 05	0,125E 01	-0,129E-03	0,129E 08	-0,287E 04	0,0
168	0,202E 05	0,123E 01	-0,126E-03	0,126E 08	-0,239E 04	0,956E 03
169	0,203E 05	0,122E 01	-0,123E-03	0,123E 08	-0,175E 04	0,319E 03
170	0,204E 05	0,120E 01	-0,121E-03	0,122E 08	-0,191E 04	-0,637E 03

171	[redacted] 05	[illegible]	[illegible]	[redacted]	[redacted]	[redacted]
172	[redacted] 05E 05	0.117E 01	[illegible]	0. [redacted] 08	[illegible] [redacted]	[illegible] 8E [redacted]
173	0.208E 05	0.116E 01	-0.113E-03	0.114E 08	-0.207E 04	0.319E 03
174	0.209E 05	0.115E 01	-0.111E-03	0.112E 08	-0.191E 04	0.417E-01
175	0.210E 05	0.113E 01	-0.109E-03	0.109E 08	-0.207E 04	-0.318E 03
176	0.211E 05	0.112E 01	-0.106E-03	0.107E 08	-0.239E 04	-0.318E 03
177	0.212E 05	0.111E 01	-0.104E-03	0.104E 08	-0.223E 04	0.637E 03
178	0.214E 05	0.109E 01	-0.102E-03	0.101E 08	-0.191E 04	0.333E-01
179	0.215E 05	0.108E 01	-0.100E-03	0.990E 07	-0.191E 04	0.833E-01
180	0.216E 05	0.107E 01	-0.981E-04	0.967E 07	-0.175E 04	0.318E 03
181	0.217E 05	0.106E 01	-0.961E-04	0.948E 07	-0.143E 04	0.319E 03
182	0.218E 05	0.105E 01	-0.941E-04	0.932E 07	-0.175E 04	-0.955E 03
183	0.220E 05	0.104E 01	-0.922E-04	0.906E 07	-0.175E 04	0.956E 03
184	0.221E 05	0.102E 01	-0.903E-04	0.890E 07	-0.143E 04	-0.318E 03
185	0.222E 05	0.101E 01	-0.885E-04	0.871E 07	-0.143E 04	0.319E 03
186	0.223E 05	0.100E 01	-0.867E-04	0.856E 07	-0.126E 04	0.200E 02
187	0.224E 05	0.993E 00	-0.849E-04	0.841E 07	-0.121E 04	0.797E 02
188	0.226E 05	0.983E 00	-0.832E-04	0.827E 07	-0.106E 04	0.219E 03
189	0.227E 05	0.973E 00	-0.815E-04	0.815E 07	-0.111E 04	-0.318E 03
190	0.228E 05	0.964E 00	-0.798E-04	0.800E 07	-0.154E 04	-0.537E 03
191	0.229E 05	0.954E 00	-0.782E-04	0.778E 07	-0.144E 04	0.736E 03
192	0.230E 05	0.945E 00	-0.766E-04	0.766E 07	-0.134E 04	-0.537E 03
193	0.232E 05	0.936E 00	-0.750E-04	0.746E 07	-0.134E 04	0.537E 03
194	0.233E 05	0.927E 00	-0.735E-04	0.733E 07	-0.132E 04	-0.498E 03
195	0.234E 05	0.918E 00	-0.720E-04	0.714E 07	-0.125E 04	0.637E 03
196	0.235E 05	0.910E 00	-0.705E-04	0.703E 07	-0.985E 03	-0.995E 02
197	0.236E 05	0.901E 00	-0.691E-04	0.691E 07	-0.147E 04	-0.876E 03
198	0.238E 05	0.893E 00	-0.677E-04	0.668E 07	-0.159E 04	0.637E 03
199	0.239E 05	0.885E 00	-0.663E-04	0.653E 07	-0.131E 04	-0.705E 02
200	0.240E 05	0.877E 00	-0.649E-04	0.636E 07	-0.135E 04	-0.173E 02
201	0.241E 05	0.869E 00	-0.635E-04	0.620E 07	-0.127E 04	0.184E 03
202	0.242E 05	0.862E 00	-0.620E-04	0.606E 07	-0.127E 04	-0.176E 03
203	0.244E 05	0.855E 00	-0.606E-04	0.590E 07	-0.125E 04	0.211E 03
204	0.245E 05	0.847E 00	-0.593E-04	0.576E 07	-0.120E 04	-0.105E 03
205	0.246E 05	0.840E 00	-0.579E-04	0.561E 07	-0.125E 04	0.0
206	0.247E 05	0.833E 00	-0.566E-04	0.546E 07	-0.106E 04	0.369E 03
207	0.248E 05	0.827E 00	-0.554E-04	0.536E 07	-0.109E 04	-0.422E 03
208	0.250E 05	0.820E 00	-0.541E-04	0.520E 07	-0.984E 03	0.633E 03
209	0.251E 05	0.814E 00	-0.529E-04	0.512E 07	-0.835E 03	-0.334E 03
210	0.252E 05	0.808E 00	-0.517E-04	0.500E 07	-0.896E 03	0.211E 03
211	0.253E 05	0.801E 00	-0.506E-04	0.490E 07	-0.844E 03	-0.105E 03
212	0.254E 05	0.795E 00	-0.494E-04	0.480E 07	-0.703E 03	0.387E 03
213	0.256E 05	0.790E 00	-0.483E-04	0.474E 07	-0.703E 03	-0.387E 03
214	0.257E 05	0.784E 00	-0.472E-04	0.463E 07	-0.835E 03	0.123E 03
215	0.258E 05	0.778E 00	-0.461E-04	0.453E 07	-0.791E 03	-0.351E 02
216	0.259E 05	0.773E 00	-0.451E-04	0.444E 07	-0.984E 03	-0.352E 03
217	0.260E 05	0.767E 00	-0.440E-04	0.430E 07	-0.102E 04	0.281E 03
218	0.262E 05	0.762E 00	-0.431E-04	0.419E 07	-0.852E 03	0.527E 02
219	0.263E 05	0.757E 00	-0.421E-04	0.409E 07	-0.104E 04	-0.422E 03
220	0.264E 05	0.752E 00	-0.411E-04	0.394E 07	-0.949E 03	0.598E 03
221	0.265E 05	0.747E 00	-0.402E-04	0.387E 07	-0.826E 03	-0.352E 03
222	0.266E 05	0.742E 00	-0.393E-04	0.375E 07	-0.949E 03	0.105E 03
223	0.268E 05	0.738E 00	-0.385E-04	0.364E 07	-0.738E 03	0.316E 03
224	0.269E 05	0.733E 00	-0.376E-04	0.357E 07	-0.729E 03	-0.299E 03
225	0.270E 05	0.729E 00	-0.368E-04	0.346E 07	-0.729E 03	0.299E 03
226	0.271E 05	0.724E 00	-0.360E-04	0.339E 07	-0.703E 03	-0.246E 03
227	0.272E 05	0.720E 00	-0.352E-04	0.329E 07	-0.932E 03	-0.211E 03
228	0.274E 05	0.716E 00	-0.345E-04	0.317E 07	-0.116E 04	-0.246E 03
229	0.275E 05	0.712E 00	-0.337E-04	0.302E 07	-0.105E 04	0.475E 03
230	0.276E 05	0.708E 00	-0.330E-04	0.292E 07	-0.791E 03	0.352E 02
231	0.277E 05	0.704E 00	-0.324E-04	0.283E 07	-0.826E 03	-0.105E 03

[redacted]

2[illegible]	[redacted]E 0	0.7[redacted]00	[illegible]E	0[redacted]0	[redacted]	[redacted]
233	[illegible]0E 05	0.696E 00	-0.311E-04	0.262E 0[illegible]	0.95[redacted]03	[illegible]99E[redacted]
234	0.281E 05	0.693E 00	-0.305E-04	0.249E 07	-0.879E 03	0.457E 03
235	0.282E 05	0.689E 00	-0.299E-04	0.241E 07	-0.738E 03	-0.176E 03
236	0.283E 05	0.685E 00	-0.294E-04	0.231E 07	-0.562E 03	0.527E 03
237	0.284E 05	0.682E 00	-0.288E-04	0.228E 07	-0.554E 03	-0.510E 03
238	0.286E 05	0.678E 00	-0.283E-04	0.218E 07	-0.993E 03	-0.369E 03
239	0.287E 05	0.675E 00	-0.278E-04	0.204E 07	-0.712E 03	0.932E 03
240	0.288E 05	0.672E 00	-0.273E-04	0.201E 07	-0.800E 03	-0.111E 04
241	0.289E 05	0.669E 00	-0.269E-04	0.185E 07	-0.111E 04	0.492E 03
242	0.290E 05	0.665E 00	-0.265E-04	0.174E 07	-0.861E 03	-0.833E-02
243	0.292E 05	0.662E 00	-0.261E-04	0.164E 07	-0.756E 03	0.211E 03
244	0.293E 05	0.659E 00	-0.257E-04	0.156E 07	-0.809E 03	-0.316E 03
245	0.294E 05	0.656E 00	-0.253E-04	0.145E 07	-0.870E 03	0.193E 03
246	0.295E 05	0.653E 00	-0.250E-04	0.135E 07	-0.852E 03	-0.158E 03
247	0.296E 05	0.650E 00	-0.247E-04	0.124E 07	-0.940E 03	-0.176E 02
248	0.298E 05	0.647E 00	-0.244E-04	0.113E 07	-0.677E 03	0.545E 03
249	0.299E 05	0.644E 00	-0.242E-04	0.108E 07	-0.518E 03	-0.228E 03
250	0.300E 05	0.641E 00	-0.239E-04	0.100E 07	-0.580E 03	0.105E 03
251	0.301E 05	0.638E 00	-0.237E-04	0.941E 06	-0.606E 03	-0.158E 03
252	0.302E 05	0.636E 00	-0.235E-04	0.858E 06	-0.721E 03	-0.703E 02
253	0.304E 05	0.633E 00	-0.233E-04	0.768E 06	-0.413E 03	0.685E 03
254	0.305E 05	0.630E 00	-0.231E-04	0.759E 06	-0.334E 03	-0.527E 03
255	0.306E 05	0.627E 00	-0.230E-04	0.688E 06	-0.483E 03	0.228E 03
256	0.307E 05	0.624E 00	-0.228E-04	0.643E 06	-0.334E 03	0.703E 02
257	0.308E 05	0.622E 00	-0.227E-04	0.607E 06	-0.176E 03	0.246E 03
258	0.310E 05	0.619E 00	-0.225E-04	0.601E 06	-0.211E 03	-0.316E 03
259	0.311E 05	0.616E 00	-0.224E-04	0.557E 06	-0.334E 03	0.703E 02
260	0.312E 05	0.614E 00	-0.223E-04	0.521E 06	-0.272E 03	0.527E 02
261	0.313E 05	0.611E 00	-0.222E-04	0.491E 06	-0.114E 03	0.264E 03
262	0.314E 05	0.608E 00	-0.220E-04	0.494E 06	-0.176E 02	-0.703E 02
263	0.316E 05	0.606E 00	-0.219E-04	0.487E 06	-0.306E 03	-0.510E 03
264	0.317E 05	0.603E 00	-0.218E-04	0.420E 06	-0.431E 03	0.264E 03
265	0.318E 05	0.600E 00	-0.217E-04	0.384E 06	-0.527E 02	0.492E 03
266	0.319E 05	0.598E 00	-0.217E-04	0.407E 06	-0.167E 03	-0.721E 03
267	0.320E 05	0.595E 00	-0.216E-04	0.344E 06	-0.185E 03	0.685E 03
268	0.322E 05	0.593E 00	-0.215E-04	0.363E 06	-0.527E 02	-0.422E 03
269	0.323E 05	0.590E 00	-0.214E-04	0.331E 06	-0.156E 03	0.211E 03
270	0.324E 05	0.588E 00	-0.213E-04	0.325E 06	-0.141E 03	-0.176E 03
271	0.325E 05	0.585E 00	-0.213E-04	0.297E 06	-0.299E 03	-0.141E 03
272	0.326E 05	0.582E 00	-0.212E-04	0.253E 06	-0.554E 03	-0.369E 03
273	0.328E 05	0.580E 00	-0.212E-04	0.165E 06	-0.387E 03	0.703E 03
274	0.329E 05	0.577E 00	-0.211E-04	0.160E 06	-0.149E 03	-0.228E 03
275	0.330E 05	0.575E 00	-0.211E-04	0.129E 06	-0.228E 03	0.703E 02
276	0.331E 05	0.572E 00	-0.211E-04	0.105E 06	-0.132E 03	0.123E 03
277	0.332E 05	0.570E 00	-0.211E-04	0.970E 05	-0.422E 03	-0.703E 03
278	0.334E 05	0.567E 00	-0.211E-04	0.422E 04	-0.439E 03	0.668E 03
279	0.335E 05	0.565E 00	-0.211E-04	-0.844E 04	-0.980E 02	0.149E 02
280	0.336E 05	0.562E 00	-0.211E-04	-0.193E 05	-0.941E 02	-0.697E 01
281	0.337E 05	0.560E 00	-0.211E-04	-0.310E 05	-0.691E 02	0.570E 02
282	0.338E 05	0.557E 00	-0.212E-04	-0.359E 05	-0.271E 02	0.271E 02
283	0.340E 05	0.555E 00	-0.213E-04	-0.375E 05	-0.217E 02	-0.162E 02
284	0.341E 05	0.552E 00	-0.215E-04	-0.411E 05	-0.406E 02	-0.217E 02
285	0.342E 05	0.549E 00	-0.216E-04	-0.473E 05	-0.413E 02	0.203E 02
286	0.343E 05	0.547E 00	-0.218E-04	-0.510E 05	-0.196E 02	0.230E 02
287	0.344E 05	0.544E 00	-0.219E-04	-0.520E 05	-0.101E 02	-0.406E 01
288	0.346E 05	0.542E 00	-0.221E-04	-0.534E 05	-0.318E 02	-0.392E 02
289	0.347E 05	0.539E 00	-0.223E-04	-0.596E 05	-0.440E 02	0.149E 02
290	0.348E 05	0.536E 00	-0.225E-04	-0.640E 05	-0.277E 02	0.176E 02
291	0.349E 05	0.533E 00	-0.227E-04	-0.663E 05	-0.257E 02	-0.135E 02
292	0.350E 05	0.531E 00	-0.229E-04	-0.702E 05	-0.230E 02	0.189E 02

29[redacted]	[redacted] 05 [redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
294	E 05	0,52[illegible]E 00	-0,233[illegible]	-0,[illegible] 05	[redacted] -0,38 [redacted]	[redacted] 6E
295	E 05	0,522E 00	-0,236E-04	-0,810E 05	-0,325E 02	-0,514E 02
296	0,355E 05	0,520E 00	-0,238E-04	-0,880E 05	-0,325E 02	0,514E 02
297	0,356E 05	0,517E 00	-0,241E-04	-0,888E 05	-0,277E 02	-0,419E 02
298	0,358E 05	0,514E 00	-0,244E-04	-0,947E 05	-0,359E 02	0,257E 02
299	0,359E 05	0,511E 00	-0,247E-04	-0,974E 05	-0,365E 02	-0,271E 02
300	0,360E 05	0,508E 00	-0,250E-04	-0,103E 06	-0,467E 02	0,677E 01
301	0,361E 05	0,505E 00	-0,253E-04	-0,109E 06	-0,406E 02	0,541E 01
302	0,362E 05	0,502E 00	-0,257E-04	-0,113E 06	-0,460E 02	-0,162E 02
303	0,364E 05	0,499E 00	-0,260E-04	-0,120E 06	-0,494E 02	0,947E 01
304	0,365E 05	0,495E 00	-0,264E-04	-0,125E 06	-0,460E 02	-0,271E 01
305	0,366E 05	0,492E 00	-0,268E-04	-0,131E 06	-0,474E 02	0,521E-03
306	0,367E 05	0,489E 00	-0,272E-04	-0,136E 06	-0,528E 02	-0,108E 02
307	0,368E 05	0,486E 00	-0,276E-04	-0,143E 06	-0,568E 02	0,271E 01
308	0,370E 05	0,482E 00	-0,281E-04	-0,150E 06	-0,541E 02	0,271E 01
309	0,371E 05	0,479E 00	-0,285E-04	-0,156E 06	-0,528E 02	0,521E-03
310	0,372E 05	0,476E 00	-0,290E-04	-0,163E 06	-0,514E 02	0,271E 01
311	0,373E 05	0,472E 00	-0,295E-04	-0,169E 06	-0,521E 02	-0,406E 01
312	0,374E 05	0,468E 00	-0,301E-04	-0,175E 06	-0,548E 02	-0,135E 01
313	0,376E 05	0,465E 00	-0,306E-04	-0,182E 06	-0,555E 02	0,0
314	0,377E 05	0,461E 00	-0,312E-04	-0,189E 06	-0,541E 02	0,271E 01
315	0,378E 05	0,457E 00	-0,318E-04	-0,195E 06	-0,528E 02	0,0
316	0,379E 05	0,454E 00	-0,324E-04	-0,201E 06	-0,528E 02	-0,521E-03
317	0,380E 05	0,450E 00	-0,330E-04	-0,208E 06	-0,521E 02	0,135E 01
318	0,382E 05	0,446E 00	-0,336E-04	-0,214E 06	-0,535E 02	-0,406E 01
319	0,383E 05	0,442E 00	-0,343E-04	-0,220E 06	-0,562E 02	-0,135E 01
320	0,384E 05	0,437E 00	-0,350E-04	-0,227E 06	-0,595E 02	-0,541E 01
321	0,385E 05	0,433E 00	-0,357E-04	-0,235E 06	-0,609E 02	0,271E 01
322	0,386E 05	0,429E 00	-0,364E-04	-0,242E 06	-0,582E 02	0,271E 01
323	0,388E 05	0,424E 00	-0,372E-04	-0,249E 06	-0,555E 02	0,271E 01
324	0,389E 05	0,420E 00	-0,379E-04	-0,255E 06	-0,562E 02	-0,406E 01
325	0,390E 05	0,415E 00	-0,387E-04	-0,262E 06	-0,568E 02	0,271E 01
326	0,391E 05	0,411E 00	-0,396E-04	-0,269E 06	-0,562E 02	-0,135E 01
327	0,392E 05	0,406E 00	-0,404E-04	-0,276E 06	-0,521E 02	0,947E 01
328	0,394E 05	0,401E 00	-0,412E-04	-0,281E 06	-0,480E 02	-0,135E 01
329	0,395E 05	0,396E 00	-0,421E-04	-0,287E 06	-0,494E 02	-0,135E 01
330	0,396E 05	0,391E 00	-0,430E-04	-0,293E 06	-0,494E 02	0,135E 01
331	0,397E 05	0,386E 00	-0,439E-04	-0,299E 06	-0,453E 02	0,677E 01
332	0,398E 05	0,380E 00	-0,448E-04	-0,304E 06	-0,399E 02	0,406E 01
333	0,400E 05	0,375E 00	-0,458E-04	-0,309E 06	-0,332E 02	0,947E 01
334	0,401E 05	0,369E 00	-0,467E-04	-0,312E 06	-0,244E 02	0,812E 01
335	0,402E 05	0,364E 00	-0,477E-04	-0,314E 06	-0,189E 02	0,271E 01
336	0,403E 05	0,358E 00	-0,486E-04	-0,316E 06	-0,189E 02	-0,271E 01
337	0,404E 05	0,352E 00	-0,496E-04	-0,319E 06	-0,189E 02	0,271E 01
338	0,406E 05	0,346E 00	-0,506E-04	-0,321E 06	-0,142E 02	0,677E 01
339	0,407E 05	0,340E 00	-0,516E-04	-0,322E 06	-0,101E 02	0,135E 01
340	0,408E 05	0,334E 00	-0,525E-04	-0,323E 06	-0,744E 01	0,406E 01
341	0,409E 05	0,327E 00	-0,535E-04	-0,324E 06	-0,135E 01	0,812E 01
342	0,410E 05	0,321E 00	-0,545E-04	-0,324E 06	0,271E 01	0,521E-03
343	0,412E 05	0,314E 00	-0,555E-04	-0,323E 06	0,406E 01	0,270E 01
344	0,413E 05	0,307E 00	-0,565E-04	-0,323E 06	0,812E 01	0,541E 01
345	0,414E 05	0,301E 00	-0,575E-04	-0,322E 06	0,108E 02	0,0
346	0,415E 05	0,294E 00	-0,585E-04	-0,320E 06	0,115E 02	0,135E 01
347	0,416E 05	0,286E 00	-0,595E-04	-0,319E 06	0,156E 02	0,677E 01
348	0,418E 05	0,279E 00	-0,604E-04	-0,316E 06	0,176E 02	-0,271E 01
349	0,419E 05	0,272E 00	-0,614E-04	-0,315E 06	0,156E 02	-0,135E 01
350	0,420E 05	0,265E 00	-0,623E-04	-0,313E 06	0,162E 02	0,271E 01
351	0,421E 05	0,257E 00	-0,633E-04	-0,311E 06	0,210E 02	0,677E 01
352	0,422E 05	0,249E 00	-0,642E-04	-0,308E 06	0,257E 02	0,270E 01
353	0,424E 05	0,242E 00	-0,652E-04	-0,304E 06	0,304E 02	0,677E 01

35[illegible]	[redacted] 05	.23[redacted]	[illegible]	-0.[redacted] 06	[illegible].325[redacted] 02	-0.271E
355	[redacted]426E 05	0.226E 00	-0.670E-04	-0.297E 06	[illegible].33[redacted]	6E
356	0.427E 05	0.218E 00	-0.679E-04	-0.292E 06	0.352E 02	0.521E-03
357	0.428E 05	0.209E 00	-0.688E-04	-0.288E 06	0.372E 02	0.406E 01
358	0.430E 05	0.201E 00	-0.697E-04	-0.284E 06	0.399E 02	0.135E 01
359	0.431E 05	0.193E 00	-0.705E-04	-0.279E 06	0.798E 02	0.785E 02
360	0.432E 05	0.184E 00	-0.714E-04	-0.264E 06	0.115E 03	-0.812E 01
361	0.433E 05	0.176E 00	-0.722E-04	-0.251E 06	0.112E 03	0.135E 01
362	0.434E 05	0.167E 00	-0.729E-04	-0.238E 06	0.113E 03	0.135E 01
363	0.436E 05	0.158E 00	-0.736E-04	-0.224E 06	0.114E 03	0.135E 01
364	0.437E 05	0.149E 00	-0.743E-04	-0.210E 06	0.112E 03	-0.541E 01
365	0.438E 05	0.140E 00	-0.749E-04	-0.197E 06	0.111E 03	0.271E 01
366	0.439E 05	0.131E 00	-0.755E-04	-0.183E 06	0.112E 03	-0.135E 01
367	0.440E 05	0.122E 00	-0.760E-04	-0.170E 06	0.110E 03	-0.135E 01
368	0.442E 05	0.113E 00	-0.765E-04	-0.157E 06	0.110E 03	-0.521E-03
369	0.443E 05	0.104E 00	-0.770E-04	-0.144E 06	0.110E 03	0.0
370	0.444E 05	0.945E-01	-0.774E-04	-0.131E 06	0.109E 03	-0.135E 01
371	0.445E 05	0.852E-01	-0.778E-04	-0.118E 06	0.108E 03	-0.135E 01
372	0.446E 05	0.758E-01	-0.781E-04	-0.105E 06	0.108E 03	0.237E 01
373	0.448E 05	0.664E-01	-0.784E-04	-0.918E 05	0.108E 03	-0.161E 01
374	0.449E 05	0.570E-01	-0.787E-04	-0.789E 05	0.108E 03	0.127E 01
375	0.450E 05	0.476E-01	-0.789E-04	-0.658E 05	0.109E 03	-0.424E 00
376	0.451E 05	0.381E-01	-0.791E-04	-0.528E 05	0.110E 03	0.271E 01
377	0.452E 05	0.286E-01	-0.792E-04	-0.394E 05	0.110E 03	-0.186E 01
378	0.454E 05	0.191E-01	-0.793E-04	-0.263E 05	0.109E 03	0.844E-01
379	0.455E 05	0.953E-02	-0.794E-04	-0.132E 05	0.110E 03	0.592E 00
380	0.456E 05	0.0	-0.794E-04	0.304E 02	0.549E 02	-0.110E 03
381	0.457E 05	-0.953E-02	-0.794E-04	0.0	-0.127E 00	0.254E 00

[redacted]OME N ECT [redacted]
PUERT[redacted] URING STORM CONDITI[redacted] IT [redacted] ASS[redacted] THE[redacted]ATE [redacted]S D[redacted]NNE[redacted]
AND THE C PINNED AT THE BOTTOM.

PROB (CONTD)
2 STORM CONDITIONS, PIPE AND TEE, RIGID RISER

STA I	X	W	DW/DX	M	DM/DX	NET REACT
-1	-0.120E 03	-0.343E 02	0.539E-02	0.0	0.0	0.0
0	0.0	-0.336E 02	0.539E-02	0.0	0.147E 05	0.295E 05
1	0.120E 03	-0.330E 02	0.539E-02	0.354E 07	0.983E 04	-0.393E 05
2	0.240E 03	-0.324E 02	0.539E-02	0.236E 07	-0.246E 05	-0.295E 05
3	0.360E 03	-0.317E 02	0.539E-02	-0.236E 07	-0.442E 05	-0.983E 04
4	0.480E 03	-0.311E 02	0.539E-02	-0.826E 07	-0.442E 05	0.983E 04
5	0.600E 03	-0.304E 02	0.539E-02	-0.130E 08	-0.590E 05	-0.393E 05
6	0.720E 03	-0.298E 02	0.539E-02	-0.224E 08	-0.786E 05	0.0
7	0.840E 03	-0.291E 02	0.538E-02	-0.318E 08	-0.885E 05	-0.197E 05
8	0.960E 03	-0.285E 02	0.538E-02	-0.436E 08	-0.786E 05	0.393E 05
9	0.108E 04	-0.278E 02	0.537E-02	-0.507E 08	-0.639E 05	-0.983E 04
10	0.120E 04	-0.272E 02	0.537E-02	-0.590E 08	-0.639E 05	0.983E 04
11	0.132E 04	-0.265E 02	0.536E-02	-0.661E 08	-0.836E 05	-0.491E 05
12	0.144E 04	-0.259E 02	0.535E-02	-0.790E 08	-0.113E 06	-0.983E 04
13	0.156E 04	-0.253E 02	0.534E-02	-0.932E 08	-0.118E 06	0.533E 00
14	0.168E 04	-0.246E 02	0.533E-02	-0.107E 09	-0.108E 06	0.197E 05
15	0.180E 04	-0.240E 02	0.532E-02	-0.119E 09	-0.885E 05	0.197E 05
16	0.192E 04	-0.233E 02	0.531E-02	-0.129E 09	-0.103E 06	-0.492E 05
17	0.204E 04	-0.227E 02	0.529E-02	-0.144E 09	-0.128E 06	-0.667E 00
18	0.216E 04	-0.221E 02	0.528E-02	-0.159E 09	-0.128E 06	-0.133E 01
19	0.228E 04	-0.214E 02	0.526E-02	-0.175E 09	-0.128E 06	-0.147E 01
20	0.240E 04	-0.208E 02	0.524E-02	-0.190E 09	-0.128E 06	0.667E 00
21	0.252E 04	-0.202E 02	0.522E-02	-0.205E 09	-0.133E 06	-0.983E 04
22	0.264E 04	-0.196E 02	0.519E-02	-0.222E 09	-0.133E 06	0.983E 04
23	0.276E 04	-0.189E 02	0.517E-02	-0.237E 09	-0.143E 06	-0.295E 05
24	0.288E 04	-0.183E 02	0.514E-02	-0.256E 09	-0.162E 06	-0.983E 04
25	0.300E 04	-0.177E 02	0.511E-02	-0.276E 09	-0.152E 06	0.295E 05
26	0.312E 04	-0.171E 02	0.508E-02	-0.293E 09	-0.156E 06	-0.369E 05
27	0.324E 04	-0.165E 02	0.505E-02	-0.313E 09	-0.176E 06	-0.369E 04
28	0.336E 04	-0.159E 02	0.502E-02	-0.335E 09	-0.175E 06	0.614E 04
29	0.348E 04	-0.153E 02	0.498E-02	-0.355E 09	-0.159E 06	0.258E 05
30	0.360E 04	-0.147E 02	0.494E-02	-0.373E 09	-0.167E 06	-0.412E 05
31	0.372E 04	-0.141E 02	0.490E-02	-0.396E 09	-0.180E 06	0.154E 05
32	0.384E 04	-0.135E 02	0.485E-02	-0.416E 09	-0.173E 06	-0.184E 04
33	0.396E 04	-0.129E 02	0.481E-02	-0.437E 09	-0.177E 06	-0.614E 04
34	0.408E 04	-0.124E 02	0.476E-02	-0.459E 09	-0.182E 06	-0.307E 04
35	0.420E 04	-0.118E 02	0.471E-02	-0.481E 09	-0.178E 06	0.104E 05
36	0.432E 04	-0.112E 02	0.466E-02	-0.501E 09	-0.170E 06	0.430E 04
37	0.444E 04	-0.107E 02	0.460E-02	-0.522E 09	-0.171E 06	-0.614E 04
38	0.456E 04	-0.101E 02	0.454E-02	-0.542E 09	-0.178E 06	-0.676E 04
39	0.468E 04	-0.957E 01	0.449E-02	-0.564E 09	-0.178E 06	0.614E 04
40	0.480E 04	-0.904E 01	0.442E-02	-0.585E 09	-0.169E 06	0.129E 05
41	0.492E 04	-0.851E 01	0.436E-02	-0.605E 09	-0.153E 06	0.184E 05
42	0.504E 04	-0.799E 01	0.429E-02	-0.622E 09	-0.146E 06	-0.369E 04
43	0.516E 04	-0.746E 01	0.423E-02	-0.640E 09	-0.144E 06	0.737E 04
44	0.528E 04	-0.698E 01	0.416E-02	-0.656E 09	-0.135E 06	0.104E 05
45	0.540E 04	-0.648E 01	0.408E-02	-0.672E 09	-0.121E 06	0.172E 05
46	0.552E 04	-0.600E 01	0.401E-02	-0.685E 09	-0.101E 06	0.233E 05
47	0.564E 04	-0.552E 01	0.394E-02	-0.696E 09	-0.799E 05	0.184E 05
48	0.576E 04	-0.505E 01	0.386E-02	-0.705E 09	-0.614E 05	0.184E 05

4[illegible]	[redacted] 04	.4[redacted]1	[illegible]	-0.[redacted] 09	[illegible].45[redacted]05	[illegible]30E[redacted]
50	[redacted]600E 04	-0.415E 01	0.372E-02	-0.716E 09	-0.2[redacted]05	[illegible]01E [redacted]
51	0.612E 04	-0.370E 01	0.366E-02	-0.718E 09	-0.133F C5	0.117E 05
52	0.624E 04	-0.327E 01	0.361E-02	-0.719E 09	0.0	0.148E 05
53	0.636E 04	-0.284E 01	0.356E-02	-0.718E 09	0.171E 05	0.194E 05
54	0.648E 04	-0.241E 01	0.350E-02	-0.715E 09	0.351E 05	0.166E 05
55	0.660E 04	-0.200E 01	0.345E-02	-0.710E 09	0.512E 05	0.157E 05
56	0.672E 04	-0.158E 01	0.340E-02	-0.702E 09	0.653E 05	0.125E 05
57	0.684E 04	-0.118E 01	0.335E-02	-0.694E 09	0.763E 05	0.952E 04
58	0.696E 04	-0.780E 00	0.330E-02	-0.684E 09	0.874E 05	0.127E 05
59	0.708E 04	-0.387E 00	0.325E-02	-0.673E 09	0.100E 06	0.126E 05
60	0.720E 04	0.583E-03	0.321E-02	-0.660E 09	0.111E 06	0.981E 04
61	0.732E 04	0.383E 00	0.316E-02	-0.646E 09	0.120E 06	0.744E 04
62	0.744E 04	0.759E 00	0.311E-02	-0.631E 09	0.126E 06	0.559E 04
63	0.756E 04	0.113E 01	0.307E-02	-0.616E 09	0.133E 06	0.738E 04
64	0.768E 04	0.150E 01	0.303E-02	-0.599E 09	0.141E 06	0.923E 04
65	0.780E 04	0.186E 01	0.298E-02	-0.582E 09	0.149E 06	0.554E 04
66	0.792E 04	0.221E 01	0.294E-02	-0.564E 09	0.154E 06	0.554E 04
67	0.804E 04	0.256E 01	0.290E-02	-0.545E 09	0.160E 06	0.554E 04
68	0.816E 04	0.291E 01	0.286E-02	-0.525E 09	0.161E 06	-0.277E 04
69	0.828E 04	0.325E 01	0.283E-02	-0.506E 09	0.161E 06	0.369E 04
70	0.840E 04	0.359E 01	0.279E-02	-0.487E 09	0.166E 06	0.554E 04
71	0.852E 04	0.392E 01	0.276E-02	-0.466E 09	0.167E 06	-0.277E 04
72	0.864E 04	0.425E 01	0.272E-02	-0.446E 09	0.171E 06	0.102E 05
73	0.876E 04	0.457E 01	0.269E-02	-0.425E 09	0.176E 06	-0.922E 03
74	0.888E 04	0.489E 01	0.266E-02	-0.404E 09	0.175E 06	-0.922E 03
75	0.900E 04	0.521E 01	0.263E-02	-0.383E 09	0.171E 06	-0.739E 04
76	0.912E 04	0.553E 01	0.261E-02	-0.363E 09	0.170E 06	0.646E 04
77	0.924E 04	0.584E 01	0.258E-02	-0.343E 09	0.168E 06	-0.111E 05
78	0.936E 04	0.615E 01	0.256E-02	-0.323E 09	0.160E 06	-0.461E 04
79	0.948E 04	0.645E 01	0.254E-02	-0.304E 09	0.161E 06	0.554E 04
80	0.960E 04	0.675E 01	0.252E-02	-0.284E 09	0.155E 06	-0.157E 05
81	0.972E 04	0.706E 01	0.250E-02	-0.267E 09	0.149E 06	0.185E 04
82	0.984E 04	0.735E 01	0.248E-02	-0.249E 09	0.144E 06	-0.111E 05
83	0.996E 04	0.765E 01	0.246E-02	-0.232E 09	0.132E 06	-0.129E 05
84	0.101E 05	0.794E 01	0.244E-02	-0.217E 09	0.115E 06	-0.203E 05
85	0.102E 05	0.824E 01	0.243E-02	-0.205E 09	0.107E 06	0.277E 04
86	0.103E 05	0.853E 01	0.241E-02	-0.192E 09	0.918E 05	-0.323E 05
87	0.104E 05	0.882E 01	0.240E-02	-0.182E 09	0.729E 05	-0.554E 04
88	0.106E 05	0.910E 01	0.239E-02	-0.174E 09	0.844E 05	0.286E 05
89	0.107E 05	0.939E 01	0.238E-02	-0.162E 09	0.891E 05	-0.194E 05
90	0.108E 05	0.967E 01	0.236E-02	-0.153E 09	0.664E 05	-0.258E 05
91	0.109E 05	0.996E 01	0.235E-02	-0.146E 09	0.512E 05	-0.462E 04
92	0.110E 05	0.102E 02	0.234E-02	-0.140E 09	0.554E 05	0.129E 05
93	0.112E 05	0.105E 02	0.233E-02	-0.133E 09	0.503E 05	-0.231E 05
94	0.113E 05	0.108E 02	0.232E-02	-0.128E 09	0.360E 05	-0.554E 04
95	0.114E 05	0.111E 02	0.231E-02	-0.124E 09	0.226E 05	-0.212E 05
96	0.115E 05	0.114E 02	0.231E-02	-0.123E 09	0.111E 05	-0.185E 04
97	0.116E 05	0.116E 02	0.230E-02	-0.122E 09	0.272E 05	0.341E 05
98	0.118E 05	0.119E 02	0.229E-02	-0.116E 09	0.157E 05	-0.572E 05
99	0.119E 05	0.122E 02	0.228E-02	-0.118E 09	-0.405E 03	0.250E 05
100	0.120E 05	0.125E 02	0.227E-02	-0.116E 09	0.525E 04	-0.137E 05
101	0.121E 05	0.127E 02	0.225E-02	-0.117E 09	-0.208E 04	-0.935E 03
102	0.122E 05	0.130E 02	0.223E-02	-0.117E 09	-0.175E 04	0.159E 04
103	0.124E 05	0.133E 02	0.220E-02	-0.117E 09	-0.127E 04	-0.637E 03
104	0.125E 05	0.135E 02	0.218E-02	-0.117E 09	0.414E 04	0.115E 05
105	0.126E 05	0.138E 02	0.215E-02	-0.116E 09	0.744E 04	-0.478E 04
106	0.127E 05	0.140E 02	0.213E-02	-0.115E 09	0.987E 04	0.955E 04
107	0.128E 05	0.143E 02	0.211E-02	-0.114E 09	0.108E 05	-0.764E 04
108	0.130E 05	0.145E 02	0.208E-02	-0.113E 09	0.137E 05	0.134E 05
109	0.131E 05	0.148E 02	0.206E-02	-0.110E 09	0.150E 05	-0.108E 05

[redacted]

111	05	0.153E 02	0.201E-02	-0.107E 09	0.20[illegible] 05	-0.255E [redacted]
112	0.134E 05	0.155E 02	0.199E-02	-0.104E 09	0.196E 05	0.159E 04
113	0.136E 05	0.158E 02	0.197E-02	-0.102E 09	0.252E 05	0.955E 04
114	0.137E 05	0.160E 02	0.195E-02	-0.984E 08	0.226E 05	-0.147E 05
115	0.138E 05	0.162E 02	0.193E-02	-0.966E 08	0.204E 05	0.102E 05
116	0.139E 05	0.165E 02	0.191E-02	-0.936E 08	0.255E 05	0.533E 00
117	0.140E 05	0.167E 02	0.189E-02	-0.905E 08	0.280E 05	0.510E 04
118	0.142E 05	0.169E 02	0.187E-02	-0.868E 08	0.306E 05	-0.133E 00
119	0.143E 05	0.171E 02	0.185E-02	-0.832E 08	0.306E 05	0.0
120	0.144E 05	0.174E 02	0.184E-02	-0.795E 08	0.280E 05	-0.510E 04
121	0.145E 05	0.176E 02	0.182E-02	-0.764E 08	0.357E 05	0.204E 05
122	0.146E 05	0.178E 02	0.180E-02	-0.709E 08	0.382E 05	-0.153E 05
123	0.148E 05	0.180E 02	0.179E-02	-0.673E 08	0.331E 05	0.510E 04
124	0.149E 05	0.182E 02	0.178E-02	-0.630E 08	0.357E 05	0.0
125	0.150E 05	0.184E 02	0.176E-02	-0.587E 08	0.382E 05	0.510E 04
126	0.151E 05	0.186E 02	0.175E-02	-0.538E 08	0.382E 05	-0.510E 04
127	0.152E 05	0.189E 02	0.174E-02	-0.495E 08	0.382E 05	0.510E 04
128	0.154E 05	0.191E 02	0.173E-02	-0.446E 08	0.382E 05	-0.510E 04
129	0.155E 05	0.193E 02	0.172E-02	-0.404E 08	0.331E 05	-0.510E 04
130	0.156E 05	0.195E 02	0.171E-02	-0.367E 08	0.357E 05	0.102E 05
131	0.157E 05	0.197E 02	0.171E-02	-0.318E 08	0.408E 05	0.133E 00
132	0.158E 05	0.199E 02	0.170E-02	-0.269E 08	0.382E 05	-0.510E 04
133	0.160E 05	0.201E 02	0.170E-02	-0.226E 08	0.382E 05	0.510E 04
134	0.161E 05	0.203E 02	0.169E-02	-0.177E 08	0.408E 05	-0.208E 00
135	0.162E 05	0.205E 02	0.169E-02	-0.128E 08	0.408E 05	0.117E 00
136	0.163E 05	0.207E 02	0.169E-02	-0.795E 07	0.382E 05	-0.510E 04
137	0.164E 05	0.209E 02	0.169E-02	-0.367E 07	0.331E 05	-0.510E 04
138	0.166E 05	0.211E 02	0.169E-02	0.0	0.331E 05	0.510E 04
139	0.167E 05	0.213E 02	0.169E-02	0.428E 07	0.306E 05	-0.102E 05
140	0.168E 05	0.215E 02	0.169E-02	0.734E 07	0.280E 05	0.510E 04
141	0.169E 05	0.217E 02	0.169E-02	0.110E 08	0.280E 05	-0.510E 04
142	0.170E 05	0.219E 02	0.169E-02	0.141E 08	0.255E 05	0.0
143	0.172E 05	0.221E 02	0.169E-02	0.171E 08	0.255E 05	0.133E 00
144	0.173E 05	0.223E 02	0.170E-02	0.202E 08	0.229E 05	-0.510E 04
145	0.174E 05	0.225E 02	0.170E-02	0.226E 08	0.204E 05	0.0
146	0.175E 05	0.227E 02	0.171E-02	0.251E 08	0.204E 05	-0.133E 00
147	0.176E 05	0.229E 02	0.171E-02	0.275E 08	0.229E 05	0.510E 04
148	0.178E 05	0.231E 02	0.172E-02	0.306E 08	0.255E 05	0.0
149	0.179E 05	0.233E 02	0.173E-02	0.336E 08	0.280E 05	0.510E 04
150	0.180E 05	0.236E 02	0.173E-02	0.373E 08	0.280E 05	-0.510E 04
151	0.181E 05	0.238E 02	0.174E-02	0.404E 08	0.306E 05	0.102E 05
152	0.182E 05	0.240E 02	0.175E-02	0.446E 08	0.331E 05	-0.510E 04
153	0.184E 05	0.242E 02	0.176E-02	0.483E 08	0.255E 05	-0.102E 05
154	0.185E 05	0.244E 02	0.177E-02	0.508E 08	0.255E 05	0.102E 05
155	0.186E 05	0.246E 02	0.178E-02	0.544E 08	0.331E 05	0.510E 04
156	0.187E 05	0.248E 02	0.179E-02	0.587E 08	0.306E 05	-0.102E 05
157	0.188E 05	0.250E 02	0.181E-02	0.618E 08	0.255E 05	0.0
158	0.190E 05	0.253E 02	0.182E-02	0.648E 08	0.229E 05	-0.510E 04
159	0.191E 05	0.255E 02	0.183E-02	0.673E 08	0.229E 05	0.510E 04
160	0.192E 05	0.257E 02	0.185E-02	0.703E 08	0.255E 05	0.0
161	0.193E 05	0.259E 02	0.186E-02	0.734E 08	0.229E 05	-0.510E 04
162	0.194E 05	0.261E 02	0.188E-02	0.758E 08	0.255E 05	0.102E 05
163	0.196E 05	0.264E 02	0.189E-02	0.795E 08	0.306E 05	0.400E 00
164	0.197E 05	0.266E 02	0.191E-02	0.832E 08	0.306E 05	0.0
165	0.198E 05	0.268E 02	0.193E-02	0.868E 08	0.306E 05	0.133E 00
166	0.199E 05	0.271E 02	0.195E-02	0.905E 08	0.280E 05	-0.510E 04
167	0.200E 05	0.273E 02	0.197E-02	0.936E 08	0.229E 05	-0.510E 04
168	0.202E 05	0.275E 02	0.199E-02	0.960E 08	0.255E 05	0.102E 05
169	0.203E 05	0.278E 02	0.201E-02	0.997E 08	0.280E 05	-0.510E 04
170	0.204E 05	0.280E 02	0.203E-02	0.103E 09	0.204E 05	-0.102E 05

[redacted]						
172	[illegible] 05	0,265E 02	0,207E-02	0,107E 09	0,15[redacted]5	[redacted]02E [redacted]
173	0,208E 05	0,288E 02	0,209E-02	0,108E 09	0,102E 05	-0,667E 00
174	0,209E 05	0,290E 02	0,212E-02	0,109E 09	0,764E 04	-0,509E 04
175	0,210E 05	0,293E 02	0,214E-02	0,110E 09	0,764E 04	0,509E 04
176	0,211E 05	0,295E 02	0,216E-02	0,111E 09	0,153E 05	0,102E 05
177	0,212E 05	0,298E 02	0,218E-02	0,114E 09	0,204E 05	-0,667E 00
178	0,214E 05	0,300E 02	0,221E-02	0,116E 09	0,153E 05	-0,102E 05
179	0,215E 05	0,303E 02	0,223E-02	0,117E 09	0,102E 05	-0,667E 00
180	0,216E 05	0,306E 02	0,226E-02	0,119E 09	0,127E 05	0,510E 04
181	0,217E 05	0,309E 02	0,228E-02	0,120E 09	0,127E 05	-0,510E 04
182	0,218E 05	0,311E 02	0,231E-02	0,122E 09	0,127E 05	0,510E 04
183	0,220E 05	0,314E 02	0,233E-02	0,124E 09	0,102E 05	-0,102E 05
184	0,221E 05	0,317E 02	0,236E-02	0,124E 09	0,510E 04	0,0
185	0,222E 05	0,320E 02	0,238E-02	0,125E 09	0,510E 04	0,533E 00
186	0,223E 05	0,323E 02	0,241E-02	0,125E 09	0,510E 04	-0,533E 00
187	0,224E 05	0,325E 02	0,244E-02	0,126E 09	0,510E 04	-0,133E 00
188	0,226E 05	0,328E 02	0,246E-02	0,127E 09	-0,255E 04	-0,153E 05
189	0,227E 05	0,331E 02	0,249E-02	0,125E 09	-0,102E 05	-0,667E 00
190	0,228E 05	0,334E 02	0,252E-02	0,124E 09	-0,102E 05	0,0
191	0,229E 05	0,337E 02	0,254E-02	0,123E 09	-0,102E 05	0,667E 00
192	0,230E 05	0,341E 02	0,257E-02	0,122E 09	-0,178E 05	-0,153E 05
193	0,232E 05	0,344E 02	0,259E-02	0,119E 09	-0,204E 05	0,102E 05
194	0,233E 05	0,347E 02	0,262E-02	0,117E 09	-0,178E 05	-0,510E 04
195	0,234E 05	0,350E 02	0,264E-02	0,114E 09	-0,229E 05	-0,510E 04
196	0,235E 05	0,353E 02	0,266E-02	0,111E 09	-0,204E 05	0,102E 05
197	0,236E 05	0,356E 02	0,269E-02	0,109E 09	-0,204E 05	-0,102E 05
198	0,238E 05	0,360E 02	0,271E-02	0,106E 09	-0,229E 05	0,509E 04
199	0,239E 05	0,363E 02	0,273E-02	0,104E 09	-0,235E 05	-0,630E-04
200	0,240E 05	0,366E 02	0,275E-02	0,101E 09	-0,259E 05	0,152E 04
201	0,241E 05	0,369E 02	0,278E-02	0,977E 08	-0,193E 05	0,117E 05
202	0,242E 05	0,373E 02	0,280E-02	0,961E 08	-0,157E 05	-0,450E 04
203	0,244E 05	0,376E 02	0,282E-02	0,939E 08	-0,180E 05	-0,533E 00
204	0,245E 05	0,379E 02	0,284E-02	0,918E 08	-0,225E 05	-0,900E 04
205	0,246E 05	0,383E 02	0,286E-02	0,885E 08	-0,247E 05	0,450E 04
206	0,247E 05	0,386E 02	0,288E-02	0,859E 08	-0,157E 05	0,135E 05
207	0,248E 05	0,390E 02	0,290E-02	0,848E 08	-0,180E 05	-0,180E 05
208	0,250E 05	0,393E 02	0,292E-02	0,815E 08	-0,225E 05	0,900E 04
209	0,251E 05	0,397E 02	0,294E-02	0,794E 08	-0,202E 05	-0,450E 04
210	0,252E 05	0,400E 02	0,296E-02	0,767E 08	-0,270E 05	-0,900E 04
211	0,253E 05	0,404E 02	0,298E-02	0,729E 08	-0,270E 05	0,900E 04
212	0,254E 05	0,408E 02	0,300E-02	0,702E 08	-0,315E 05	-0,180E 05
213	0,256E 05	0,411E 02	0,301E-02	0,653E 08	-0,337E 05	0,135E 05
214	0,257E 05	0,415E 02	0,303E-02	0,621E 08	-0,247E 05	0,450E 04
215	0,258E 05	0,418E 02	0,304E-02	0,594E 08	-0,247E 05	-0,450E 04
216	0,259E 05	0,422E 02	0,305E-02	0,562E 08	-0,247E 05	0,450E 04
217	0,260E 05	0,426E 02	0,307E-02	0,535E 08	-0,225E 05	0,133E 00
218	0,262E 05	0,429E 02	0,308E-02	0,508E 08	-0,247E 05	-0,450E 04
219	0,263E 05	0,433E 02	0,309E-02	0,475E 08	-0,292E 05	-0,450E 04
220	0,264E 05	0,437E 02	0,310E-02	0,437E 08	-0,270E 05	0,900E 04
221	0,265E 05	0,441E 02	0,311E-02	0,410E 08	-0,247E 05	-0,450E 04
222	0,266E 05	0,444E 02	0,312E-02	0,378E 08	-0,270E 05	0,0
223	0,268E 05	0,448E 02	0,313E-02	0,346E 08	-0,292E 05	-0,450E 04
224	0,269E 05	0,452E 02	0,314E-02	0,308E 08	-0,292E 05	0,450E 04
225	0,270E 05	0,456E 02	0,314E-02	0,275E 08	-0,270E 05	0,0
226	0,271E 05	0,459E 02	0,315E-02	0,243E 08	-0,292E 05	-0,450E 04
227	0,272E 05	0,463E 02	0,316E-02	0,205E 08	-0,315E 05	0,833E-01
228	0,274E 05	0,467E 02	0,316E-02	0,167E 08	-0,292E 05	0,450E 04
229	0,275E 05	0,471E 02	0,316E-02	0,135E 08	-0,315E 05	-0,900E 04
230	0,276E 05	0,475E 02	0,317E-02	0,918E 07	-0,405E 05	-0,900E 04
231	0,277E 05	0,478E 02	0,317E-02	0,378E 07	-0,405E 05	0,900E 04

[redacted]

233	[redacted]280E 05	0.480E 02	[redacted]0.317[illegible]	0[redacted] 07	[redacted].38[redacted]5	35E [redacted]
234	0.281E 05	0.490E 02	0.317E-02	-0.972E 07	-0.337E 05	-0.450E 04
235	0.282E 05	0.494E 02	0.316E-02	-0.140E 08	-0.315E 05	0.900E 04
236	0.283E 05	0.497E 02	0.316E-02	-0.173E 08	-0.337E 05	-0.135E 05
237	0.284E 05	0.501E 02	0.315E-02	-0.221E 08	-0.382E 05	0.450E 04
238	0.286E 05	0.505E 02	0.315E-02	-0.265E 08	-0.337E 05	0.450E 04
239	0.287E 05	0.509E 02	0.314E-02	-0.302E 08	-0.292E 05	0.450E 04
240	0.288E 05	0.512E 02	0.313E-02	-0.335E 08	-0.247E 05	0.450E 04
241	0.289E 05	0.516E 02	0.313E-02	-0.362E 08	-0.225E 05	0.267E 00
242	0.290E 05	0.520E 02	0.312E-02	-0.389E 08	-0.270E 05	-0.900E 04
243	0.292E 05	0.524E 02	0.311E-02	-0.427E 08	-0.270E 05	0.900E 04
244	0.293E 05	0.527E 02	0.310E-02	-0.454E 08	-0.135E 05	0.180E 05
245	0.294E 05	0.531E 02	0.309E-02	-0.459E 08	-0.225E 04	0.450E 04
246	0.295E 05	0.535E 02	0.308E-02	-0.459E 08	-0.900E 04	-0.180E 05
247	0.296E 05	0.538E 02	0.306E-02	-0.481E 08	-0.202E 05	-0.450E 04
248	0.298E 05	0.542E 02	0.305E-02	-0.508E 08	-0.157E 05	0.135E 05
249	0.299E 05	0.546E 02	0.304E-02	-0.518E 08	-0.180E 05	-0.180E 05
250	0.300E 05	0.549E 02	0.303E-02	-0.551E 08	-0.202E 05	0.135E 05
251	0.301E 05	0.553E 02	0.302E-02	-0.567E 08	-0.135E 05	0.133E 00
252	0.302E 05	0.557E 02	0.300E-02	-0.583E 08	-0.157E 05	-0.450E 04
253	0.304E 05	0.560E 02	0.299E-02	-0.605E 08	-0.225E 05	-0.900E 04
254	0.305E 05	0.564E 02	0.297E-02	-0.637E 08	-0.292E 05	-0.450E 04
255	0.306E 05	0.567E 02	0.296E-02	-0.675E 08	-0.292E 05	0.450E 04
256	0.307E 05	0.571E 02	0.294E-02	-0.707E 08	-0.337E 05	-0.135E 05
257	0.308E 05	0.574E 02	0.292E-02	-0.756E 08	-0.472E 05	-0.135E 05
258	0.310E 05	0.578E 02	0.291E-02	-0.821E 08	-0.472E 05	0.135E 05
259	0.311E 05	0.581E 02	0.289E-02	-0.869E 08	-0.382E 05	0.450E 04
260	0.312E 05	0.585E 02	0.286E-02	-0.912E 08	-0.292E 05	0.135E 05
261	0.313E 05	0.588E 02	0.284E-02	-0.939E 08	-0.202E 05	0.450E 04
262	0.314E 05	0.592E 02	0.282E-02	-0.961E 08	-0.157E 05	0.450E 04
263	0.316E 05	0.595E 02	0.280E-02	-0.977E 08	-0.157E 05	-0.450E 04
264	0.317E 05	0.598E 02	0.277E-02	-0.999E 08	-0.135E 05	0.900E 04
265	0.318E 05	0.602E 02	0.275E-02	-0.101E 09	-0.450E 04	0.900E 04
266	0.319E 05	0.605E 02	0.273E-02	-0.101E 09	-0.450E 04	-0.900E 04
267	0.320E 05	0.608E 02	0.270E-02	-0.102E 09	-0.450E 04	0.900E 04
268	0.322E 05	0.612E 02	0.268E-02	-0.102E 09	0.225E 04	0.450E 04
269	0.323E 05	0.615E 02	0.266E-02	-0.102E 09	0.450E 04	0.120E 01
270	0.324E 05	0.618E 02	0.263E-02	-0.101E 09	0.900E 04	0.900E 04
271	0.325E 05	0.621E 02	0.261E-02	-0.993E 08	0.900E 04	-0.900E 04
272	0.326E 05	0.624E 02	0.258E-02	-0.988E 08	0.112E 05	0.135E 05
273	0.328E 05	0.627E 02	0.256E-02	-0.966E 08	0.900E 04	-0.180E 05
274	0.329E 05	0.630E 02	0.254E-02	-0.966E 08	-0.225E 04	-0.450E 04
275	0.330E 05	0.633E 02	0.252E-02	-0.972E 08	-0.225E 04	0.450E 04
276	0.331E 05	0.636E 02	0.249E-02	-0.972E 08	0.225E 04	0.450E 04
277	0.332E 05	0.639E 02	0.247E-02	-0.966E 08	0.0	-0.900E 04
278	0.334E 05	0.642E 02	0.245E-02	-0.972E 08	0.225E 04	0.135E 05
279	0.335E 05	0.645E 02	0.242E-02	-0.961E 08	0.759E 04	-0.282E 04
280	0.336E 05	0.648E 02	0.239E-02	-0.954E 08	0.588E 04	-0.601E 03
281	0.337E 05	0.651E 02	0.223E-02	-0.947E 08	0.123E 05	0.135E 05
282	0.338E 05	0.653E 02	0.194E-02	-0.924E 08	0.189E 05	-0.346E 03
283	0.340E 05	0.656E 02	0.166E-02	-0.902E 08	0.185E 05	-0.347E 03
284	0.341E 05	0.657E 02	0.139E-02	-0.880E 08	0.173E 05	-0.208E 04
285	0.342E 05	0.659E 02	0.112E-02	-0.860E 08	0.161E 05	-0.346E 03
286	0.343E 05	0.660E 02	0.862E-03	-0.841E 08	0.156E 05	-0.693E 03
287	0.344E 05	0.661E 02	0.608E-03	-0.823E 08	0.152E 05	-0.133E 00
288	0.346E 05	0.662E 02	0.359E-03	-0.804E 08	0.149E 05	-0.693E 03
289	0.347E 05	0.662E 02	0.116E-03	-0.787E 08	0.147E 05	0.347E 03
290	0.348E 05	0.662E 02	-0.122E-03	-0.769E 08	0.151E 05	0.346E 03
291	0.349E 05	0.662E 02	-0.355E-03	-0.751E 08	0.147E 05	-0.104E 04
292	0.350E 05	0.661E 02	-0.582E-03	-0.734E 08	0.140E 05	-0.346E 03

294	[redacted] 0.353E 05	0.657E 02 [redacted]	-0.10[illegible]	[redacted] 0E	0.[redacted] 05	104[redacted]
295	0.354E 05	0.658E 02	-0.123E-02	-0.684E 08	0.130E 05	-0.346E 03
296	0.355E 05	0.656E 02	-0.144E-02	-0.669E 08	0.126E 05	-0.346E 03
297	0.356E 05	0.654E 02	-0.164E-02	-0.654E 08	0.128E 05	0.693E 03
298	0.358E 05	0.652E 02	-0.184E-02	-0.638E 08	0.125E 05	-0.139E 04
299	0.359E 05	0.650E 02	-0.203E-02	-0.624E 08	0.118E 05	0.133E 00
300	0.360E 05	0.647E 02	-0.222E-02	-0.610E 08	0.116E 05	-0.347E 03
301	0.361E 05	0.645E 02	-0.241E-02	-0.596E 08	0.111E 05	-0.693E 03
302	0.362E 05	0.642E 02	-0.259E-02	-0.583E 08	0.104E 05	-0.693E 03
303	0.364E 05	0.638E 02	-0.276E-02	-0.571E 08	0.100E 05	0.0
304	0.365E 05	0.635E 02	-0.293E-02	-0.559E 08	0.100E 05	0.0
305	0.366E 05	0.631E 02	-0.310E-02	-0.547E 08	0.953E 04	-0.104E 04
306	0.367E 05	0.627E 02	-0.327E-02	-0.536E 08	0.883E 04	-0.346E 03
307	0.368E 05	0.623E 02	-0.343E-02	-0.526E 08	0.849E 04	-0.346E 03
308	0.370E 05	0.619E 02	-0.359E-02	-0.516E 08	0.849E 04	0.346E 03
309	0.371E 05	0.615E 02	-0.375E-02	-0.505E 08	0.849E 04	-0.346E 03
310	0.372E 05	0.610E 02	-0.390E-02	-0.496E 08	0.762E 04	-0.139E 04
311	0.373E 05	0.605E 02	-0.405E-02	-0.487E 08	0.710E 04	0.347E 03
312	0.374E 05	0.601E 02	-0.420E-02	-0.478E 08	0.727E 04	0.0
313	0.376E 05	0.595E 02	-0.434E-02	-0.470E 08	0.779E 04	0.104E 04
314	0.377E 05	0.590E 02	-0.449E-02	-0.460E 08	0.797E 04	-0.693E 03
315	0.378E 05	0.585E 02	-0.463E-02	-0.451E 08	0.727E 04	-0.693E 03
316	0.379E 05	0.579E 02	-0.476E-02	-0.442E 08	0.710E 04	0.347E 03
317	0.380E 05	0.573E 02	-0.490E-02	-0.434E 08	0.745E 04	0.346E 03
318	0.382E 05	0.567E 02	-0.503E-02	-0.424E 08	0.762E 04	-0.133E 00
319	0.383E 05	0.561E 02	-0.516E-02	-0.415E 08	0.797E 04	0.693E 03
320	0.384E 05	0.555E 02	-0.528E-02	-0.405E 08	0.814E 04	-0.346E 03
321	0.385E 05	0.548E 02	-0.540E-02	-0.396E 08	0.745E 04	-0.104E 04
322	0.386E 05	0.542E 02	-0.552E-02	-0.387E 08	0.710E 04	0.347E 03
323	0.388E 05	0.535E 02	-0.564E-02	-0.379E 08	0.745E 04	0.346E 03
324	0.389E 05	0.528E 02	-0.575E-02	-0.370E 08	0.762E 04	0.133E 00
325	0.390E 05	0.521E 02	-0.587E-02	-0.360E 08	0.745E 04	-0.346E 03
326	0.391E 05	0.514E 02	-0.598E-02	-0.352E 08	0.693E 04	-0.693E 03
327	0.392E 05	0.507E 02	-0.608E-02	-0.344E 08	0.658E 04	0.0
328	0.394E 05	0.500E 02	-0.619E-02	-0.336E 08	0.589E 04	-0.139E 04
329	0.395E 05	0.492E 02	-0.629E-02	-0.330E 08	0.520E 04	0.133E 00
330	0.396E 05	0.485E 02	-0.639E-02	-0.323E 08	0.520E 04	-0.133E 00
331	0.397E 05	0.477E 02	-0.649E-02	-0.317E 08	0.485E 04	-0.693E 03
332	0.398E 05	0.469E 02	-0.658E-02	-0.312E 08	0.468E 04	0.346E 03
333	0.400E 05	0.461E 02	-0.668E-02	-0.306E 08	0.485E 04	0.0
334	0.401E 05	0.453E 02	-0.677E-02	-0.300E 08	0.485E 04	0.0
335	0.402E 05	0.445E 02	-0.686E-02	-0.294E 08	0.502E 04	0.347E 03
336	0.403E 05	0.437E 02	-0.695E-02	-0.288E 08	0.485E 04	-0.693E 03
337	0.404E 05	0.428E 02	-0.704E-02	-0.283E 08	0.433E 04	-0.346E 03
338	0.406E 05	0.420E 02	-0.712E-02	-0.278E 08	0.450E 04	0.693E 03
339	0.407E 05	0.411E 02	-0.721E-02	-0.272E 08	0.485E 04	0.133E 00
340	0.408E 05	0.402E 02	-0.729E-02	-0.266E 08	0.485E 04	-0.133E 00
341	0.409E 05	0.394E 02	-0.737E-02	-0.260E 08	0.468E 04	-0.346E 03
342	0.410E 05	0.385E 02	-0.745E-02	-0.255E 08	0.485E 04	0.693E 03
343	0.412E 05	0.376E 02	-0.752E-02	-0.249E 08	0.502E 04	-0.347E 03
344	0.413E 05	0.367E 02	-0.760E-02	-0.243E 08	0.502E 04	0.346E 03
345	0.414E 05	0.357E 02	-0.767E-02	-0.237E 08	0.537E 04	0.347E 03
346	0.415E 05	0.348E 02	-0.774E-02	-0.230E 08	0.520E 04	-0.693E 03
347	0.416E 05	0.339E 02	-0.781E-02	-0.224E 08	0.520E 04	0.693E 03
348	0.418E 05	0.329E 02	-0.788E-02	-0.217E 08	0.537E 04	-0.347E 03
349	0.419E 05	0.320E 02	-0.795E-02	-0.211E 08	0.537E 04	0.347E 03
350	0.420E 05	0.310E 02	-0.801E-02	-0.205E 08	0.572E 04	0.346E 03
351	0.421E 05	0.301E 02	-0.807E-02	-0.197E 08	0.589E 04	0.0
352	0.422E 05	0.291E 02	-0.813E-02	-0.190E 08	0.606E 04	0.346E 03
353	0.424E 05	0.281E 02	-0.819E-02	-0.183E 08	0.606E 04	-0.346E 03

[redacted]						
356	0.427E 05	0.251E 02	-0.835E-02	-0.160E 08	0.6[illegible]E 04	-0.346E 03
357	0.428E 05	0.241E 02	-0.839E-02	-0.153E 08	0.606E 04	-0.346E 03
358	0.430E 05	0.231E 02	-0.844E-02	-0.145E 08	0.589E 04	-0.667E-01
359	0.431E 05	0.221E 02	-0.848E-02	-0.138E 08	0.589E 04	-0.117E 00
360	0.432E 05	0.211E 02	-0.852E-02	-0.131E 08	0.572E 04	-0.346E 03
361	0.433E 05	0.201E 02	-0.856E-02	-0.125E 08	0.554E 04	-0.117E 00
362	0.434E 05	0.190E 02	-0.860E-02	-0.118E 08	0.554E 04	-0.100E 00
363	0.436E 05	0.180E 02	-0.864E-02	-0.111E 08	0.553E 04	-0.217E 02
364	0.437E 05	0.170E 02	-0.867E-02	-0.105E 08	0.568E 04	0.325E 03
365	0.438E 05	0.159E 02	-0.870E-02	-0.978E 07	0.602E 04	0.346E 03
366	0.439E 05	0.149E 02	-0.873E-02	-0.903E 07	0.584E 04	-0.715E 03
367	0.440E 05	0.138E 02	-0.875E-02	-0.838E 07	0.553E 04	0.108E 03
368	0.442E 05	0.128E 02	-0.878E-02	-0.771E 07	0.575E 04	0.325E 03
369	0.443E 05	0.117E 02	-0.880E-02	-0.700E 07	0.561E 04	-0.606E 03
370	0.444E 05	0.107E 02	-0.882E-02	-0.636E 07	0.543E 04	0.260E 03
371	0.445E 05	0.960E 01	-0.884E-02	-0.569E 07	0.536E 04	-0.411E 03
372	0.446E 05	0.854E 01	-0.886E-02	-0.507E 07	0.546E 04	0.606E 03
373	0.448E 05	0.748E 01	-0.887E-02	-0.438E 07	0.551E 04	-0.498E 03
374	0.449E 05	0.641E 01	-0.888E-02	-0.375E 07	0.523E 04	-0.650E 02
375	0.450E 05	0.535E 01	-0.889E-02	-0.313E 07	0.516E 04	-0.649E 02
376	0.451E 05	0.428E 01	-0.890E-02	-0.251E 07	0.515E 04	0.433E 02
377	0.452E 05	0.321E 01	-0.891E-02	-0.189E 07	0.517E 04	0.833E-02
378	0.454E 05	0.214E 01	-0.891E-02	-0.127E 07	0.521E 04	0.649E 02
379	0.455E 05	0.107E 01	-0.892E-02	-0.642E 06	0.529E 04	0.108E 03
380	0.456E 05	0.0	-0.446E-02	0.0	0.267E 04	-0.535E 04
381	0.457E 05	0.0	0.0	0.0	0.0	0.0

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 1 OF 5

CLIENT ______ JOB NO. FR-0925

SUBJECT BOTTOM-MOUNTED BUOYANT CWP - SIZING THE INTERFACE

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY D. FOX APP'D. BY ______ DATE 17 FEB 1979

ASSUMING THE ROLLERS ARE MOST NEARLY FRICTIONLESS, i.e. NO VERTICAL RESISTANCE, THE ONLY FORCES THE SUPPORT MEMBERS MUST NEGOTIATE ARE PRODUCED BY THE HORIZONTAL COMPONANT OF THE FORCES. THIS OCCURS WHENEVER THE CWP/PLATFORM INTERFACE REACHES ITS MAXIMUM DESIGN ANGLE OF TEN DEGREES OR LESS.

A VERTICAL FORCE COULD OCCUR IF THE HEAVE COMPENSATION DEVICE WERE TO "BOTTOM OUT" FOR SOME REASON.

FROM BEAMCOL PROGRAM J7836 A, OPERATING CONDITIONS, PIPE AND TEE, RIGID RISER, THE NET REACTION AT STATION 0 IS 334,000 LBS. REFER TO DRAWING ON NEXT PAGE.

LET THE SAFETY FACTOR = 4.0

TO SIZE THE ROLLERS: (USE HILLMAN ROLLERS)

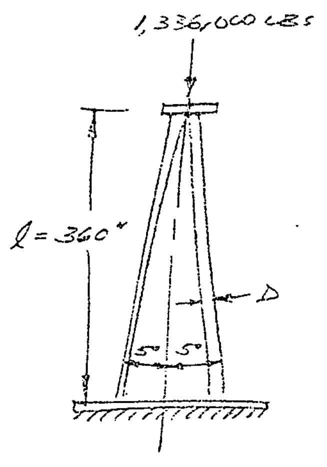
$$\text{HORIZONTAL FORCE} = F_H = \frac{(334{,}000 \text{ LBS})(4.0)}{2000 \text{ LBS/TON}} = 668 \text{ TONS}$$

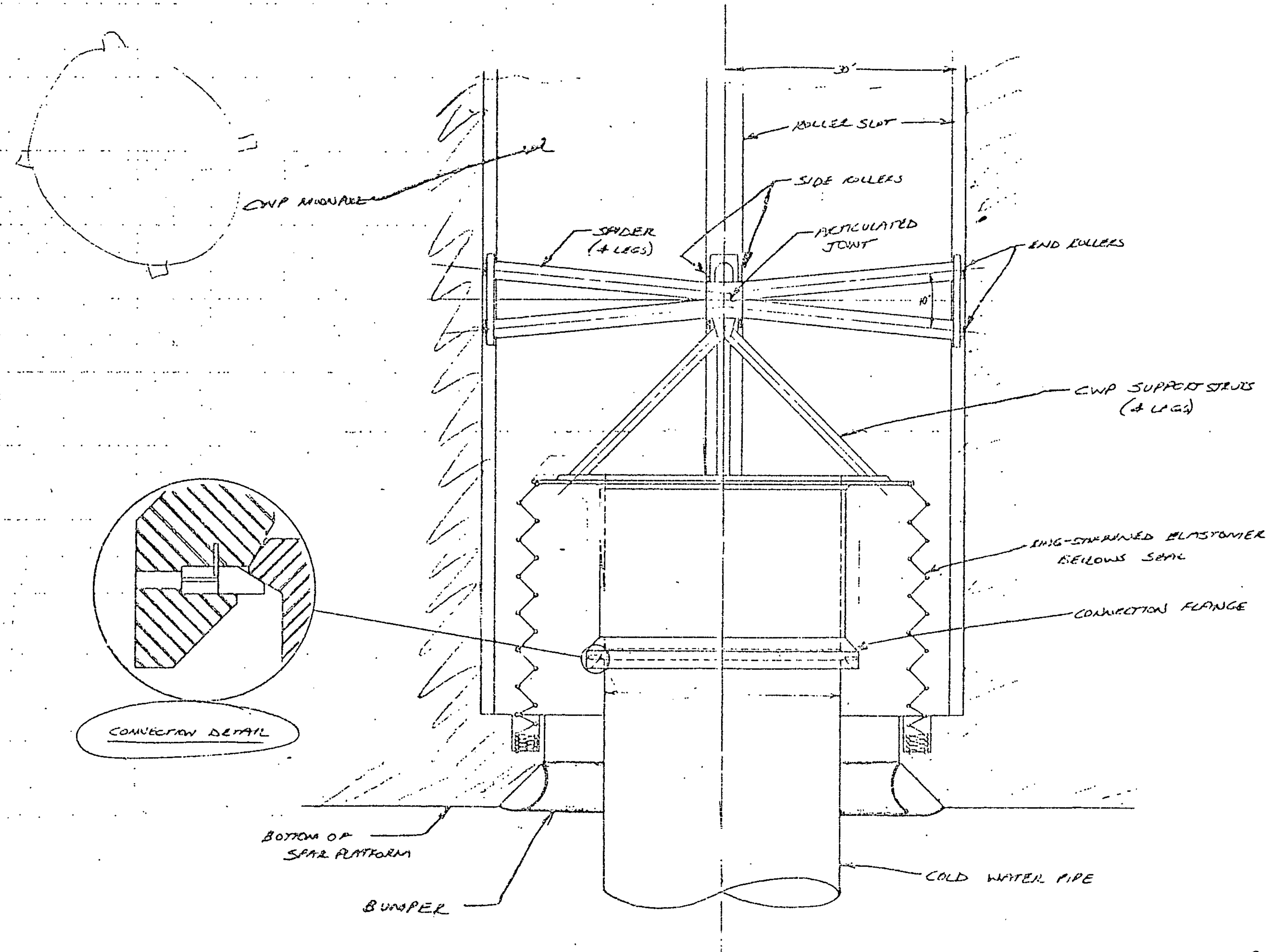
USE 4 - HILLMAN SXT-DW ROLLERS, EQUIPPED WITH "CAM ROLLER GUIDES," PER SPIDER LEG ASSEMBLY. THE GUIDES ELIMINATE THE NEED FOR SIDE ROLLERS.

TO SIZE THE SPIDER LEGS:

FOR COLUMN ANALYSIS, TREAT AS IF ENDS ARE ROUNDED.

USE PIPE WITH A DIAMETER D AND A WALL THICKNESS t.





BOTTOM-MOUNTED BUOYANT CWP INTERFACE

3/12/79

INITIALLY, LET $D = 12$ IN AND $t = 1$ IN

RADIUS OF GYRATION, $k = \frac{\sqrt{D^2 + d^2}}{4}$ WHERE $d = D - 2t$

$$k = \frac{\sqrt{(12 \text{ IN})^2 + (10 \text{ IN})^2}}{4} = 3.91 \text{ IN}$$

USE ASTM A106, GRADE B STEEL PIPE, $\sigma_y = 35{,}000$ PSI

FROM THE J.B. JOHNSON FORMULA FOR COLUMNS,

$$P_{CR} = A\sigma_y\left(1 - \frac{Q}{4k^2}\right) \text{ WHERE } Q = \frac{\sigma_y l^2}{n\pi^2 E}$$

WITH BOTH ENDS CONSIDERED ROUNDED, $n = 1.0$

$$Q = \frac{(35{,}000 \text{ LB/IN}^2)(360 \text{ IN})^2}{(\pi^2)30(10)^6 \text{ LB/IN}^2} = 15.32 \text{ IN}^2$$

$$P_{CR} = \frac{\pi}{4}\left((12 \text{ IN})^2 - (10 \text{ IN})^2\right)(35{,}000 \text{ LB/IN}^2)\left(1 - \frac{15.32 \text{ IN}^2}{4(3.91 \text{ IN})^2}\right) = 905{,}750 \text{ LBS}$$

TAKING INTO ACCOUNT THE 5° ANGLE,

$$P_{CR} = \frac{905{,}750 \text{ LBS}}{\cos 5°} = 909{,}210 \text{ LBS/LEG}$$

REDUCE WALL THICKNESS TO 3/8-IN AND INCREASE DIAMETER TO 18-IN.

$$k = \frac{\sqrt{(18\ \text{IN})^2 + (17.25\ \text{IN})^2}}{4} = 6.23\ \text{IN}$$

$$P_{CR} = \frac{\pi}{4}\left((18\ \text{IN})^2 - (17.25\ \text{IN})^2\right)(35{,}000\ \text{LB/IN}^2)\left(1 - \frac{15.32\ \text{IN}^2}{4(6.23\ \text{IN})^2}\right)\left(\frac{1}{\cos 5^\circ}\right)$$

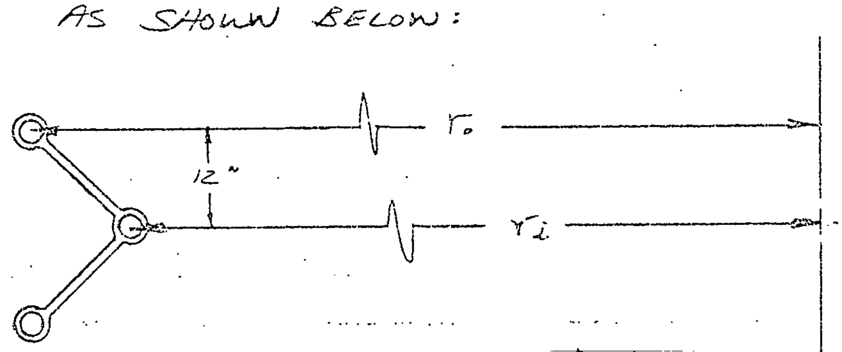
$$P_{CR} = 657{,}115\ \text{LBS/LEG}$$

$$P = \frac{1{,}336{,}000\ \text{LBS}}{2\ \text{LEGS}} = 668{,}000\ \text{LBS/LEG}$$

USE 18 IN. DIA., (7/16-IN.) SCH. 30, ASTM A106 GRADE B STEEL PIPE.

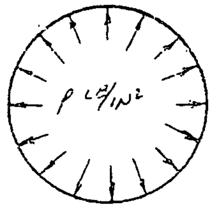
CWP SUPPORT STRUTS: THE ONLY LOAD THESE STRUTS SEE IS A HORIZONTAL FORCE COMPONENT. TREATING ALL FOUR AS COLUMNS WITH ONE IN TENSION AND ONE IN COMPRESSION, BUCKLING OF THE COMPRESSION MEMBER WILL NOT OCCUR BECAUSE OF A BICYCLE WHEEL SPOKE EFFECT. IN THIS CASE, USE THE SAME SIZE PIPE AS ABOVE.

RING STIFFENED ELASTOMER BELLOWS SEAL: THE RINGS WOULD COME IN TWO DIAMETERS AS SHOWN BELOW:



ACCORDING TO ESTIMATES, $r_o = 31$ FT. , $r_i = 30$ FT. THE FORCES ACT AS IN A THIN-SHELLED PRESSURE VESSEL.

$$\sigma_y = \frac{pr}{2t} \Rightarrow t = \frac{pr}{2\sigma_y}$$



THE PRESSURE OF 10 PSI ACTS OVER 12 IN WITH A SAFETY FACTOR OF 4.0.

$$p = (10\ \text{LB/IN}^2)\,4.0 = 40\ \text{PSI}$$

EQUATE THE MOMENTS OF INERTIA TO FIND d BELOW:

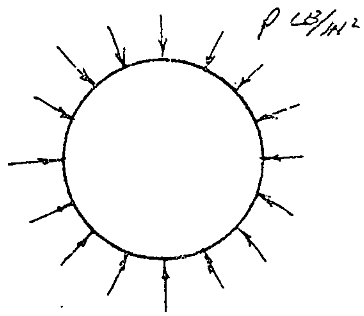
$$I = \frac{1}{12}(12\ \text{IN})t^3 = \frac{\pi}{64}(d)^4 \Rightarrow d = \left(\frac{64}{\pi}t^3\right)^{1/4}$$

IF σ_y = 36,000 PSI (ASTM A36 STEEL)

$$t = \frac{(40\ \text{LB/IN}^2)(372\ \text{IN})}{2(36{,}000\ \text{LB/IN}^2)} = 0.21\ \text{IN}$$

$$d = \left(\frac{64}{\pi}(0.21\ \text{IN})^3\right)^{1/4} = 0.65\ \text{IN}$$

IN THE CASE OF REVERSED FLOW:



$$p = \frac{E}{4(1-\mu^2)}\left(\frac{t}{r_o}\right)^3$$

$$t = \left(\frac{4(1-\mu^2)r_o^3 p}{E}\right)^{1/3}$$

BROWN & ROOT, INC.
ENGINEERING DIVISION

SHEET NO. 5 OF 5

CLIENT ______ JOB NO. ER-095

SUBJECT ______

BASED ON ______ DRAWING NO. ______

COMPUTER S. PORTER CHK'D. BY D. FOX APP'D. BY ______ DATE 19 FEB 1979

$$t = \left(\frac{4(1-(0.3)^2)(372\ IN)^3(10\ LB/IN^2)}{30(10)^6\ LB/IN^2} \right)^{1/3} = 3.97\ IN$$

$$d = \left(\frac{64}{\pi}(3.97\ IN)^3 \right)^{1/4} = 5.97\ IN$$

COMPROMISE AND USE 2-IN. DIAMETER PIPE WITH A ½-IN. WALL THICKNESS. FOR A 30-FT. HEAVE:

30 FT. RAD. ⇒ 15 REQ'D.
31 FT. RAD. ⟶ 15 REQ'D.

ASSUME A WEIGHT FOR THE CONNECTION AND IT'S COMPONENTS FOR A COST ESTIMATE.

WEIGHTS:

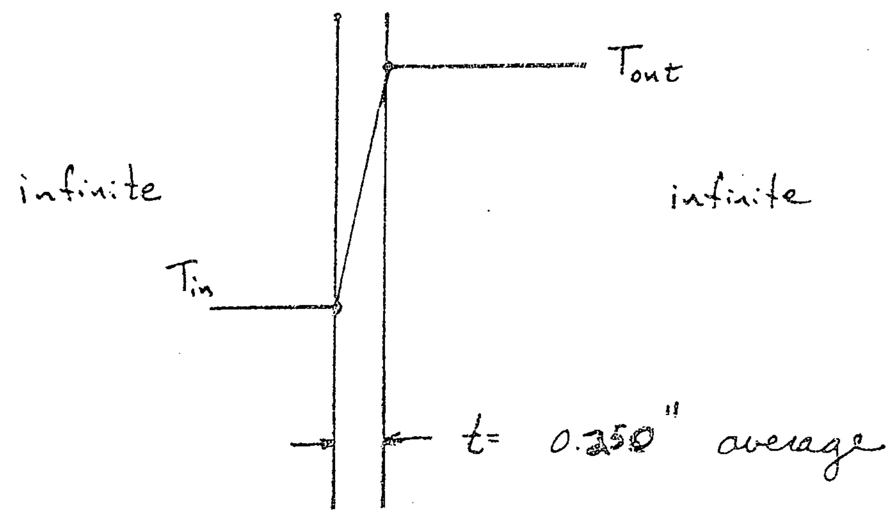
CONNECTION	FLANGE =	400,000 LBS
	RINGS =	45,720 LBS (SEAL)
	SPIDER =	19,715 LBS
	STRUTS =	8830 LBS
	TOTAL =	474,265 LBS

COST OF ROLLERS =

APPENDIX D - CWP THERMAL PERFORMANCE

APPENDIX D CWP THERMAL PERFORMANCE

First investigate temperature rise in cold water due to conduction across wall. A worst case approach is



$T_{out} = 42 + 0.0165\ Z$ at Puerto Rico   Z in ft measured up, T in °F

$$\dot{q} = \int_0^{2300} k \frac{dT}{dX} \pi D \, dZ$$

assume constant at T_{BOTTOM}

$$\frac{dT}{dX} = \frac{T_{out} - T_{in}}{t_w} = \frac{0.0165 Z}{(.25/12)} = 0.7924\, Z \ {}^{\circ}F/Ft$$

$k \doteq 30 \frac{BTU}{HR\ FT\ {}^{\circ}F}$ for steel

D = 30 FT

$$\frac{k}{t} \approx h = \left(\frac{.25/12}{30}\right)^{-1} = 1440$$

$$\dot{q} = \pi(30) \quad 0.7924 \frac{z^2}{2} \cancel{\ } 30 \Big|_0^{2300}$$

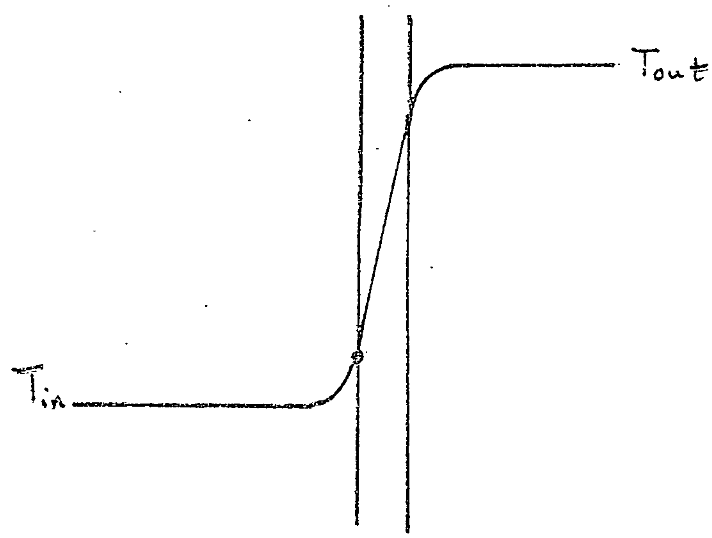
$$= 5.9 \times 10^9 \quad \frac{BTU}{HR}$$

Temperature rise is

$$\Delta T = \frac{5.9 \times 10^9}{(64)(6.5)\left(\frac{\pi \cdot 900}{4}\right)(1)(3600)} = 5.57 \ ^{o}F$$

this is a conservative number and is too high

Now look at this situation:



convection controls heat transfer

problem is modeled as a series of resistances

$$T_{in} \;\text{—}\; r = 1/h_i \;\text{—}\; T_{w_{in}} \;\text{—}\; r_w = t/k \;\text{—}\; T_{w_{out}} \;\text{—}\; r = 1/h_o \;\text{—}\; T_{out}$$

$$\mathcal{R} = r_i + r_w + r_o$$

$$= \frac{1}{h_i} + t/k + \frac{1}{h_o}$$

$h_i \Rightarrow Nu_D$ for flow in tube

$$Re_D = 10^5 (6.5)(30) = 1.9 \times 10^7 \quad \text{turbulent}$$

$$h_i = \frac{k}{D} \; \frac{0.04 \; Re^{+3/4} \cdot Pr}{1 + 1.7 \; Re^{-1/8} \; (Pr - 1) \; (Pr)^{-1/4}}$$

$$Pr = 13.6 \qquad k = 0.3 \; \frac{BTU}{HR \; FT^2 \; {}^\circ F}$$

$$h_i = 600 \; \frac{BTU}{HR \; FT^2 \; {}^\circ F}$$

$h_o \Rightarrow Nu_D$ for cylinder crossflow

$$Re_D \doteq 10^5 \, 2\,(30) = 6\times10^6$$

$$P_r = 13.6$$

$$h = \frac{k}{D}\left[\,0.43 + 0.03\, Re_D^{0.8}\, P_r^{0.3}\,\right]$$

$$= 220 \quad \frac{BTU}{HR\ FT^2\ {}^\circ F}$$

$$R = \frac{1}{600} + \frac{(0.25/12)}{30} + \frac{1}{220}$$

$$= 0.69\times10^{-2}$$

$$H = 1/R = 145 \quad \frac{BTU}{HR\ FT^2\ {}^\circ F}$$

ratio previous result

$$\dot{q} = 5.9\times10^9 \left(\frac{145}{1440}\right) = 5.9\times10^8$$

$\boxed{\Delta T = 0.56\ {}^\circ F}$ for thin walled steel

this is acceptable and others will be much less.

Temperature rise in the CWP might occur due to leakage at joints either due to faulty seal design or seal failure. Two simple flow models are

Couette

$$\bar{u} = \frac{4b^2}{3\mu}\frac{dp}{dx}$$

$\frac{dp}{dx}$ = pressure gradient
b = gap
μ = viscosity
ρ = density

Bernoulli

$$\bar{u} = \sqrt{2\frac{\Delta p}{\rho}}$$

$b \sim 10^{-3}$ ft
$\mu \sim 10^{-5}$ slug/ftsec
$dp \sim 100$ lbs/ft^2
$\rho \sim 2$ slugs/ft^2

$$\frac{\bar{u}_{couette}}{\bar{u}_{Bernoulli}} \approx \frac{4(10^{-6})}{3(10^{-5})}100 \Big/ \sqrt{2\frac{100}{2}} \simeq 1$$

therefore, use Bernoulli unless $\frac{dp}{dx} < 100$ lb/ft^2
or $b < 10^{-3}$ ft

heat balance

$$\dot{Q}_{OUT} = \left(\rho u_{out} A - \sum_i \rho u_i A_i\right) C_p T_{BOT} + C_p \sum_i \rho u_i A_i T_i$$

desired differential energy flow rate

$$\dot{Q}_d = \rho u_{out} A C_p (T_{TOP} - T_{BOT})$$

achieved differential energy flow rate

$$\dot{Q}_a = \rho u_{out} A C_p T_{TOP} - \dot{Q}_{out}$$

normalizing

$$\frac{\dot{Q}_a}{\dot{Q}_d} = \frac{\cancel{\rho u_{out} A C_p} T_{TOP} - \left[\left(\cancel{\rho u_{out} A} - \sum_i \cancel{\rho} \frac{u_i}{u_{out}} \frac{A_i}{A}\right) \cancel{C_p} T_{BOT} + \cancel{C_p} \sum_i \cancel{\rho} \frac{u_i}{u_{out}} \frac{A_i}{A} T_i\right]}{\cancel{\rho u_{out} A}\, \cancel{C_p} (T_{TOP} - T_{BOT})}$$

$$\frac{\dot{Q}_a}{\dot{Q}_d} = \frac{T_{TOP} - \left[\left(1 - \sum_i \frac{u_i}{u_{out}} \frac{A_i}{A_{out}}\right) T_{BOT} + \sum_i \frac{u_i}{u_{out}} \frac{A_i}{A_{out}} T_i\right]}{T_{TOP} - T_{BOT}}$$

The worst case here must be the APC design with 60 joints where seals can fail. For an estimate assume each seal has a gap of 0.25 inches. For the Puerto Rico T profile, only the first 2300 feet are important

DEPTH (FT)	# SEALS	ΔP	$\bar{U}/U_o$	$\bar{T}_{OUT}$	$\frac{UA}{U_oA_o}$	$\frac{UA\,T_{out}}{U_oA_oT_o}$
0-300	6	2.3	2.8	76	0.008	0.65
300-600	6	1.6	2.3	72	0.007	0.5
600-900	6	1.1	2.0	67	0.006	0.375
900-1200	6	0.8	1.7	64	0.005	0.315
1200-1500	6	0.6	1.4	57	0.004	0.24
1500-1800	6	0.6	1.4	54	0.004	0.20
1800-2300	10	0.6	1.4	47	0.004	0.19
					$\Sigma n \frac{UA}{U_oA_o} = 0.244$	$\Sigma n \frac{UAT}{UAT_o} = 15.6$

$$\boxed{\frac{\dot{Q}_{achieved}}{\dot{Q}_{desired}} = \frac{80 - [(1-.244)(42) + 15.6]}{38} = 0.86}$$

this could be a substantial impact if seals fail

APPENDIX E - INVESTIGATION OF THE APL/ABAM CWP DESIGN

APPENDIX E

INVESTIGATION OF THE APL/ABAM CWP DESIGN

1 INTRODUCTION

The purpose of this study was:

1. To check the feasibility of the APL/ABAM CWP
2. To make realistic criticism on this design if necessary
3. To give an estimated cost of the CWP precasting on shore and consequently to build the general scheme of the construction site organization as well as a schedule
4. To suggest some changes in the design in order to improve its feasibility
5. To present new ideas which could be developed in a further step.

It should be noted that:

At the time this effort was undertaken -

- some elements of the design, e.g. the intermediate results of the bending moment calculation the angle of rotation or on the shear forces of the cold water pipe with the different positions of hinges were lacking so the problem could not be analysed completely. This could be a source of deficiencies or inaccuracies in the conclusions and recommendations.
- all the problems involved in the conception and/or erection of the CWP were not investigated in depth as the leading idea to be as "constructive" as possible to ensure the feasibility of the concept as well as to obtain a reasonable cost estimate.

- some alternatives to the APL/ABAM concept are: It should be understood that these suggestions would need a complete analysis which has not been herein performed. Some of the problems are found interesting: time delivery, construction or erection problems and cost to name a few.

2.1 Hydraulic Considerations

2.1.1 General Platform Layout

Two types of platforms are considered:

- Spar platform
- Barge platform

Taking in account the fact that the evaporator uses surface waters that contain quite a lot of living organisms implying that periodic cleaning operations will be needed the barge type platform seems preferable as it provides easier access to this element.

2.1.2 Suction Mesh

A protective conical mesh is placed at the extreme lowest part of the pipe in order to prevent any foreign body from entering the pipe. It is to be feared that these bodies will remain fixed on the mesh by the pressure difference existing between both sides. For cleaning purpose it seems appropriate to place this mesh at the top of the pipe.

2.1.3 Top Part

In the present design the pipe is obturated by the pump housing element equipped with four cold water pumps. Such an arrangement may be criticized with respect to pressure variations due to changes in the cold water flow speed or to barge heave.

Letting the upper part of the cold water pipe be totally free would create (in the middle of the barge) a cold water well freely communicating with deep waters. It may be estimated that water level in the well will be a bit lower (about 6') than sea level mainly because of - the greater density of cold water, - pressure losses due to pipe flow.

Pumps may be located on the barge with protective grids on the sides of the well. Foreign bodies will be easily removed at this level. To decrease the lowering of cold water level when starting the pumps, a system of by-passes is provided. Progressively shut they should allow an easy start of cold water motion. On the other hand non-return valves situated to the outside when pumps are stopped. It will limit efficiently the increase of water level in the pipe at that time.

The alternative hydraulic design resulting from these considerations is shown in Figure 1.

2.2 Technical Considerations

2.2.1 Materials

The concept is based on the use of a special lightweight concrete on which a detailed study has been performed.

Experience does not exist on this particular type of lightweight concrete. Experience does exist on structures such as bridges using a 116 PCF gravity lightweight concrete. From this experience, it should be noted that: the use of lightweight concrete needs a permanent control of the mixing proportions to ensure the desired final breaking strength. The concrete workability is very dependant upon the quantity of water and sand in the mixture and thus need a very accurate batch plant which must be specially modified for this type of concrete. The standard deviation (or the percentage of variation) of material properties is somewhat greater than for regular concrete. The use of steam curing to accelerate the hardening of the concrete does not substantially affect the final breaking strength.

In the case of the CWP, the proposed lightweight concrete has a very small Young modulus. This fact, in combination with the use of elastomeric bearing pads in hinges is favorable for a good distribution of the axial load between the 12 teeth of each junction. On the other hand it should be necessary to use a special grout mixture for prestressing cables in order to avoid cracks in this grout due to elongation. This is due to the variation of stresses between storage and working conditions as sea. Further investigations into this matter seem warrented as it is of prime interest for the life expectancy of the cold water pipe.

2.2.2 Forms

Apart from structural considerations, the forms given to the actual design seem to be right. Nevertheless, it should be noted that with a thickness of 4 1/2 inches, the placing of concrete will have to be very accurately surveyed. Performing a full scale test before a final decision to use this concept is strongly urged. This takes in consideration the fact that there is no basis of experience to determine the behavior of the proposed lightweight concrete in similar casting conditions. We have ample experience with regular concrete.

After a review of general industry practice, for the body of the CWP the concrete cover of prestressing sheaths is sufficient providing that ducts are made with continuous steel pipes 1 to 2" thick and that special devices, such as heat shrink plastic tubes, are placed at the construction joint to ensure watertightness.

2.2.3 Construction Joint

In the APL/ABAM design a construction joint is a necessary requirement for the completion of each segment. This point presents several drawbacks:

- It is always a weak structural part where cracks may be expected and where there is no reinforcing steel continuity which is a serious flaw in the design.
- In such a corrosive environment as sea water, peculiar attention should be given to the watertightness of the prestressing sheaths. This is a hard problem to solve in a satisfactory manner for such a joint. Usually in marine works, sheaths should be made watertight at each connection for instance by the use of heat shrink plastic hoses. For the actual design a suggestion is the use of rubber seals compressed by the weight of the upper segment before grouting the remaining necessary gap.

. Another very important problem is the roundness of the two facing sections. With such a small wall thickness, no big misalignment of generatrices may be tolerated. This implies that very stiff steel forms must be used. The addition of a concrete circular stiffener at the joint level would help alleviate must of the problems already mentioned.

2.2.4 Structural Analysis

First consider the design of the "teeth" between the CWP segments. Assuming that normal stresses due to prestressing forces are distributed with a 45° angle on each side of the bearing plate (and this is already an optimistic assumption) it is seen from Figures 2 and 3 that on both sides of the pad, a non-negligible part of the load is not properly transfered to the rest of the structure. Cracks and even rupture may be encountered in these areas.

In the region where the thickness of the shell is tapered, preliminary analysis of the shell shows the existence of weak points where shell thickness is insufficient. In particular at level of section A-A (Fig. 2) and B-B (Fig. 3). The first two approaches were as follows:

- A simple shell analysis by a finite element program was used to find out stresses in the structure considered as a system of shells and rings subjected to the maximum vertical static load (2.4 tons) and to its own prestressing system. It is assumed that there is a symmetry of revolution around a vertical axis for the structure as well as for the loads (see Fig. 4).

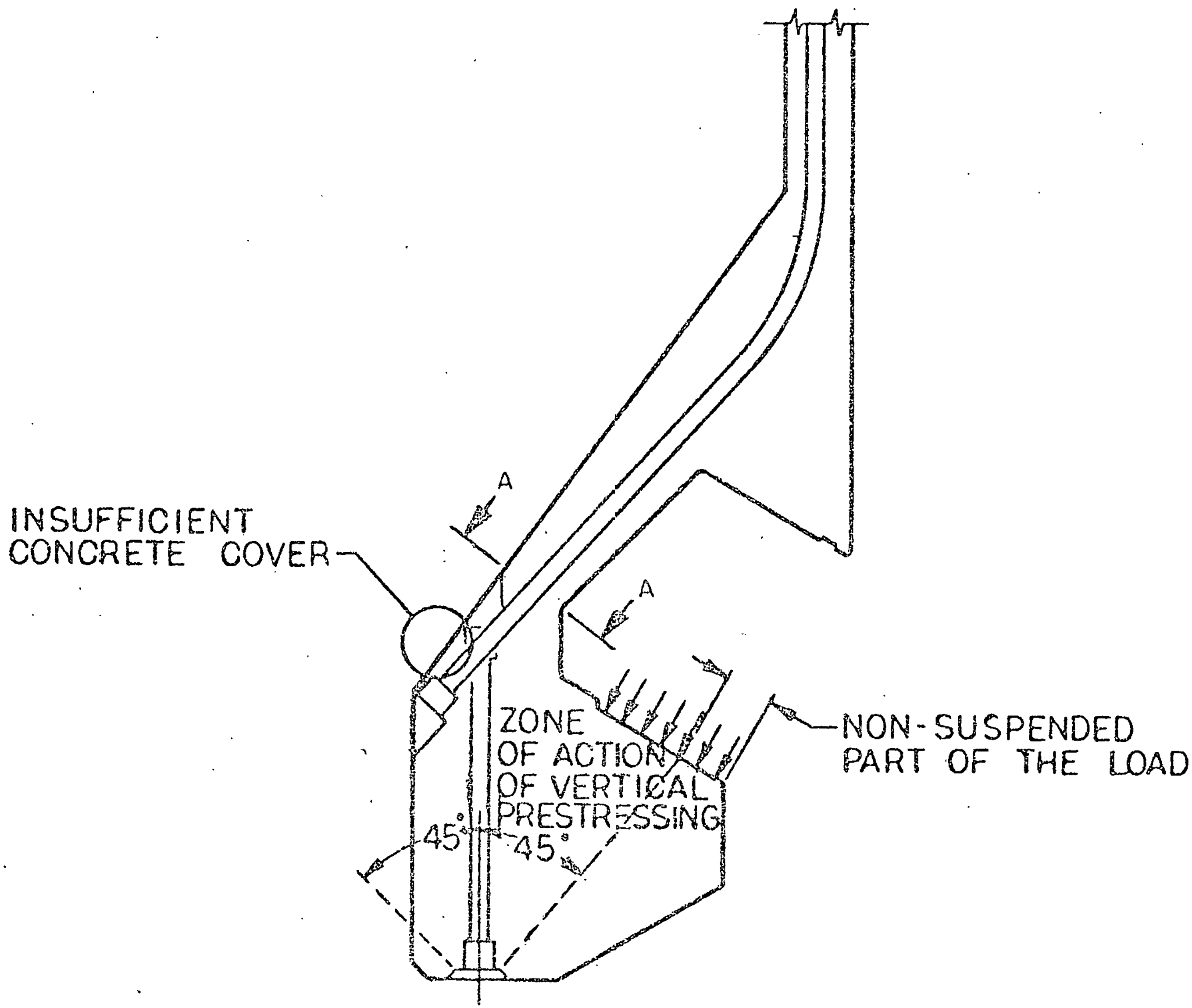

A
A
INSUFFICIENT
CONCRETE COVER
ZONE
OF ACTION
OF VERTICAL
PRESTRESSING
45°
45°
NON-SUSPENDED
PART OF THE LOAD

FIGURE 2

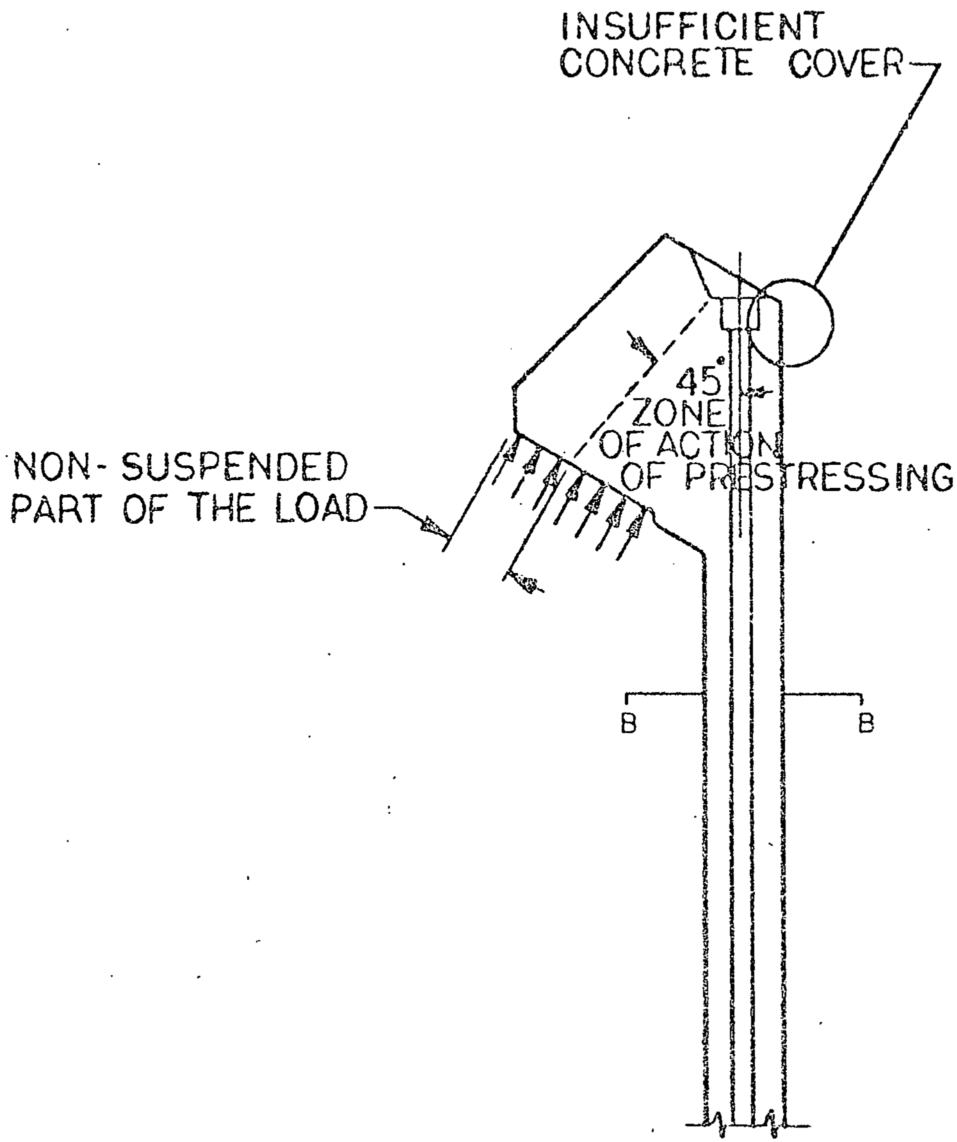

INSUFFICIENT
CONCRETE COVER
45°
ZONE
OF ACTION
OF PRESTRESSING
NON- SUSPENDED
PART OF THE LOAD
B
B

FIGURE 3

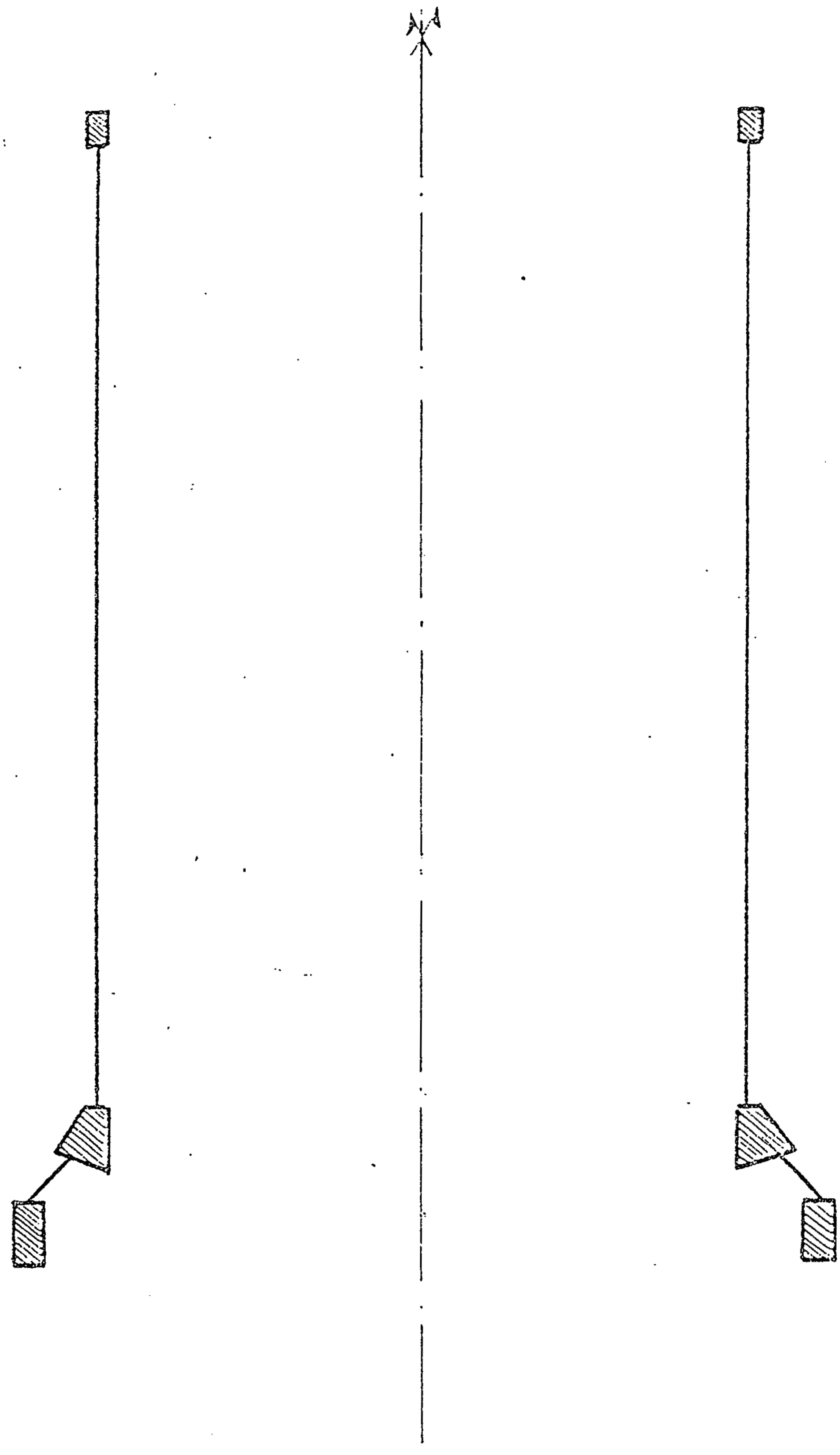


FIGURE F.4

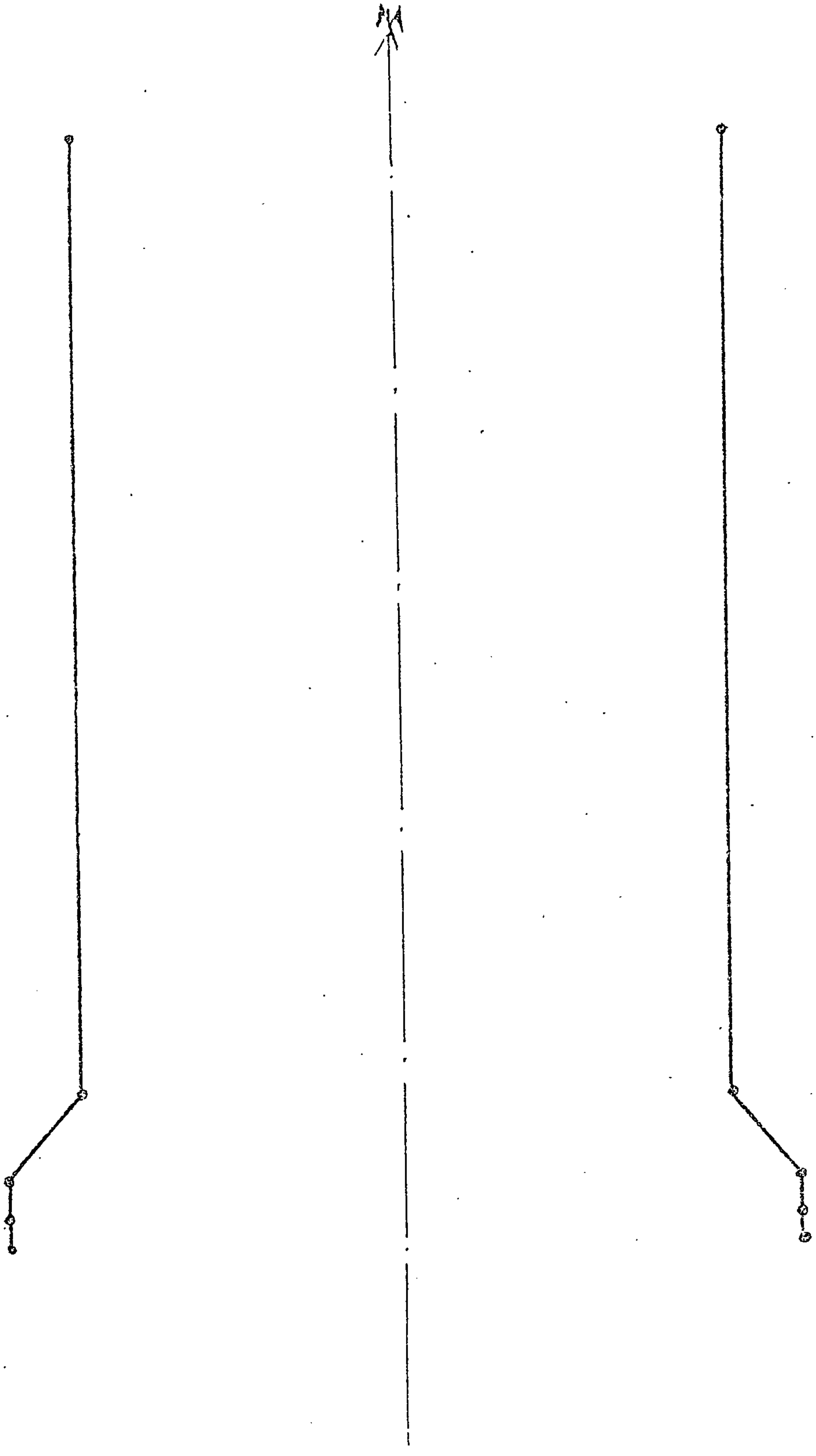


FIGURE .. 5

- A second analysis with the same program on a very similar structure was made because of the difficulty in modeling the rings, their dimensions being in most cases quite of the same order as those of the shells. Therefore all rings were eliminated the structure was modeled as a combination of shells only (see Fig. 5). Table 1 shows that in both analyses concrete stresses reach unacceptable levels in both sections:

Table 1

	Section A-A		Section B-B	
	Normal stress on inner fiber	Normal stress on outer fiber	Normal stress on inner fiber	Normal stress on outer fiber
First computer run (Fig. 4)	- 4540 psi (- 3180 t/m2)	5170 psi (3620 t/m2)	6370 psi (4460 t/m2)	- 5340 psi (- 3740 t/m2)
Second computer run (Fig. 5)	- 4060 psi (- 2840 t/m2)	4720 psi (3300 t/m2)	8260 psi (5780 t/m2)	- 7170 psi (- 5020 t/m2)

(tensile stresses are negative and compressive stresses are positive)..

These results have led to a finite element analysis of the joint area in order to find out with more accuracy the stress distribution existing in this part of the structure. The chosen mesh is joined with the drawings of stress distributions for:

- prestressing alone
- prestressing and static load (2400 metric tons)
- prestressing and assumed dynamic load (3800 metric tons)

All stresses are principal stresses and for the sake of clarity their representation is limited to the areas where serious problems may be expected. Numerical results in sections A-A and B-B are found as:

	Section A-A		Section B-B	
	Principal compressive stress	Principal tensile stress	Principal compressive stress	Principal tensile stress
Prestressing + static load	2730 psi (1920 t/m2)	- 3290 psi (- 2310 t/m2)	3310 psi (2330 t/m2)	- 2570 psi (- 1810 t/m2)
Prestressing + dynamic load	4460 psi (3135 t/m2)	- 6120 psi (- 4300 t/m2)	4550 psi (3200 t/m2)	5050 psi (- 3550 t/m2)

From these results it is concluded that the APL/ABAM design should be altered in several points to give a sufficient strength to the structure in particular in the joint area.

Very high stresses always exist in the areas situated just below the prestressing anchorages, in particular under the bearing plate and around the "trumpet".

To avoid splitting and cracking two measures are normally taken:

- a well defined hoop reinforcement is placed
- a sufficient concrete cover is required.

If Freyssinet "K" range* anchorages were used to ensure the vertical prestressing of each element, it would require:

- 19 K 5 type with 16 strands in segments 20 to 60.

Taking for example the 19 K 5 type, a typical spiral reinforcement would be 9 turns of ½" bar to form a 13½" outer diameter spiral, 19" long and that the recommended distance between cable axis and concrete surface is 7 3/4". Spiral reinforcement as well below these values (see Fig. F.6).

In the prestressing layout

several important details are missing:

-Vertical prestressing is needed at the lower part of the joint to carry the load up to the level of the inclined cables. Ducts and recesses are shown but without indication of the type of prestressing - likely rods because of the small length - which is of prime importance to the resistance of this part.

-Circumferential prestressing is shown but only in the cross-section drawings. A detailed layout showing the shape of each cable in a horizontal plane together with anchoring points - that must be situated on the outer side of the shell - is needed.

The mechanical behavior of the hinges is of prime concern. Rotation between two consecutive segments is essentially obtained by distorsion of neoprene pads. It may be assumed that the maximum distorsion is:

- equal to the thickness of the pad, corresponding to a transvers displacement equal to the pad thickness, or to an angle of 45° which is the

common maximum value.

- equal to 0.58 times the thickness of the pad corresponding to an angle of 30° that may be a maximum value for geometrical reasons (i.e. the shape of concrete recess)

For pads inclined of 30° with respect to the horizontal plane, the center of rotation is situated at the summit of an equilateral triangle and its distance to the pad is equal to the horizontal distance between two opposite pads:

$$d = 10.30 \text{ m}$$

If o_m is the rotation and d_n the neoprene movement, then

$$o_m = \frac{d_n}{d}$$

Thus yielding :

for a <u>45° angle</u> $d_n = h = 102$ mm (4")

$$o_m = \frac{102}{10\ 300} = 0.0099 \text{ rad}$$

$$\underline{\underline{o_m = 0.57^\circ}}$$

Similarly for a <u>30° angle</u>

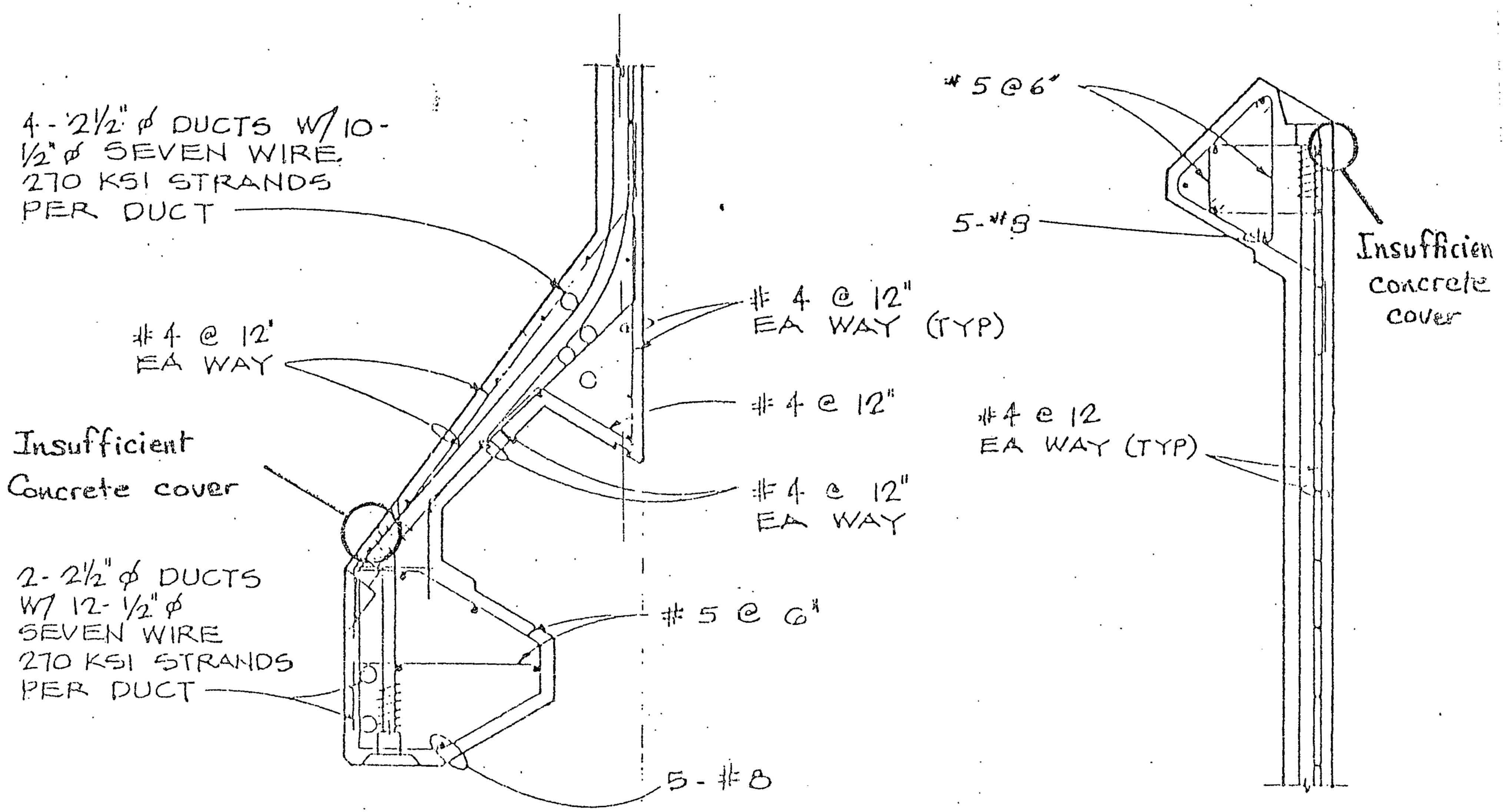
$$d_n = 0.58\ h = 59 \text{ mm}$$

$$o_m = \frac{59}{10\ 300} = 0.0057$$

$$\underline{\underline{o_m = 0.33^\circ}}$$

Both values are below the required 1.0° angle of rotation of each joint for the Brazil site requirement and below the 2.6 to 2.8° rotation requirement for the Puerto Rico site. It seems that with such an angle it will not be possible to keep the same mechanical principle for joint design, but at the same time no alternative could be developed to cope with such a rotation.

FIGURE I.6 POST TENSIONING DETAILS AT JOINTS



2.2.5. Elastomeric Pads

The vertical load is carried from one CWP segment to the next by means of twelve elastomeric pads. Each pad has a total thickness of 4" (102 mm). This kind of pad is usually made of a succession of neoprene layers separated by steel plates. Typical layer thicknesses range from 1/3" to 1/2" and may reach the maximum value of 1". Bigger values would induce excessive deformations of this soft material, especially for this case where the pad carries compression and shear at the same time.

The normal, (through the pad thickness) stiffness of the pad should be as small as possible. As the stiffness increases with the number of layers, the use of pads made with four 1" thick neoprene layers separated by 1/8" to 1/16" thick steel plates is recommended. Under the static load such a pad will flatten of about 1/7" (3.6 mm). Assuming that a very accurate precasting is made, followed by an accurate level control of all concrete pads, which results in a final correction that could be actually made by means of steel shims for example, a final accuracy in the pad level (for load distribution) of 1/25" (1 mm) may be acheived. It is then obvious that a problem of load distribution may arise and that further investigations are definitely needed on this topic to make sure that the structure is able to withstand uneven values of loads on the pads. Furthermore this shows that the normal stiffness of the elastomeric pad should be minimized which is what lead to the choice of the minimum acceptable number of layers.

2.2.6. Circumferential Seal

In the APL/ABAM CWP design leakage of water flow is avoided by the use of a hollow circumferential seal filled with fluid or silastic compound. During the movements of one CWP segment with respect to the other the top part of the seal will follow the upper element movement while the bottom part will follow the lower element movement. If in a certain cross-section the seal distorsion is purely radial, a deformation for which it is well suited, in the section situated at a 90° angle of rotation with respect to a vertical axis, the deformation will be purely tangential and the seal will not function properly under this condition for thirty years.

2.3.1 General

The CWP segments will be precast on an area near the seashore. Figure 7 shows a possible general lay out of the construction site, without knowledge of general lay out of the exact location, the study of the harbour for pipe segment shipment was not performed one 50' long pipe segment could be cast every three days, with each 50' pipe segment being made in = as shown in APL design.

The manufacture of the CWP segments will take about 8 months. To this time 3 months must be added for tapered segment and Pump Housing precasting. It means a total fabrication time of 11 to 12 months when accounting is made for the beginning of the work which is always a little more difficult.

2.3.2. Typical Segment Casting

Concrete will be made by means of a batch plant located near the concrete work area. This plant must be able to produce 20 to 25 cubic yards of concrete per hour.

A tower crane with a 100/120 foot boom can take the concrete directly from the batch plant and pour it into the forms. This tower crane is also employed for other operations. Its load capacity must be about 3 metric tons within 100 feet reach.

The two half-pipes will be precast with two steel forms located within the track rails of a gantry-crane. The concrete is placed in forms by small openings located at different places and levels to avoid segregation and to ensure proper filling of the forms. The concrete will be vibrated by needles going through the openings which will be closed when concrete reaches that level.

The gantry-crane moves on a 100 feet track and can carry various equipment. It will be used to transfer the prefabricated reinforcing cages into the forms, to carry these forms, for transportation of the pipes to the storage area, and for loading the CWP segments onto the barges.

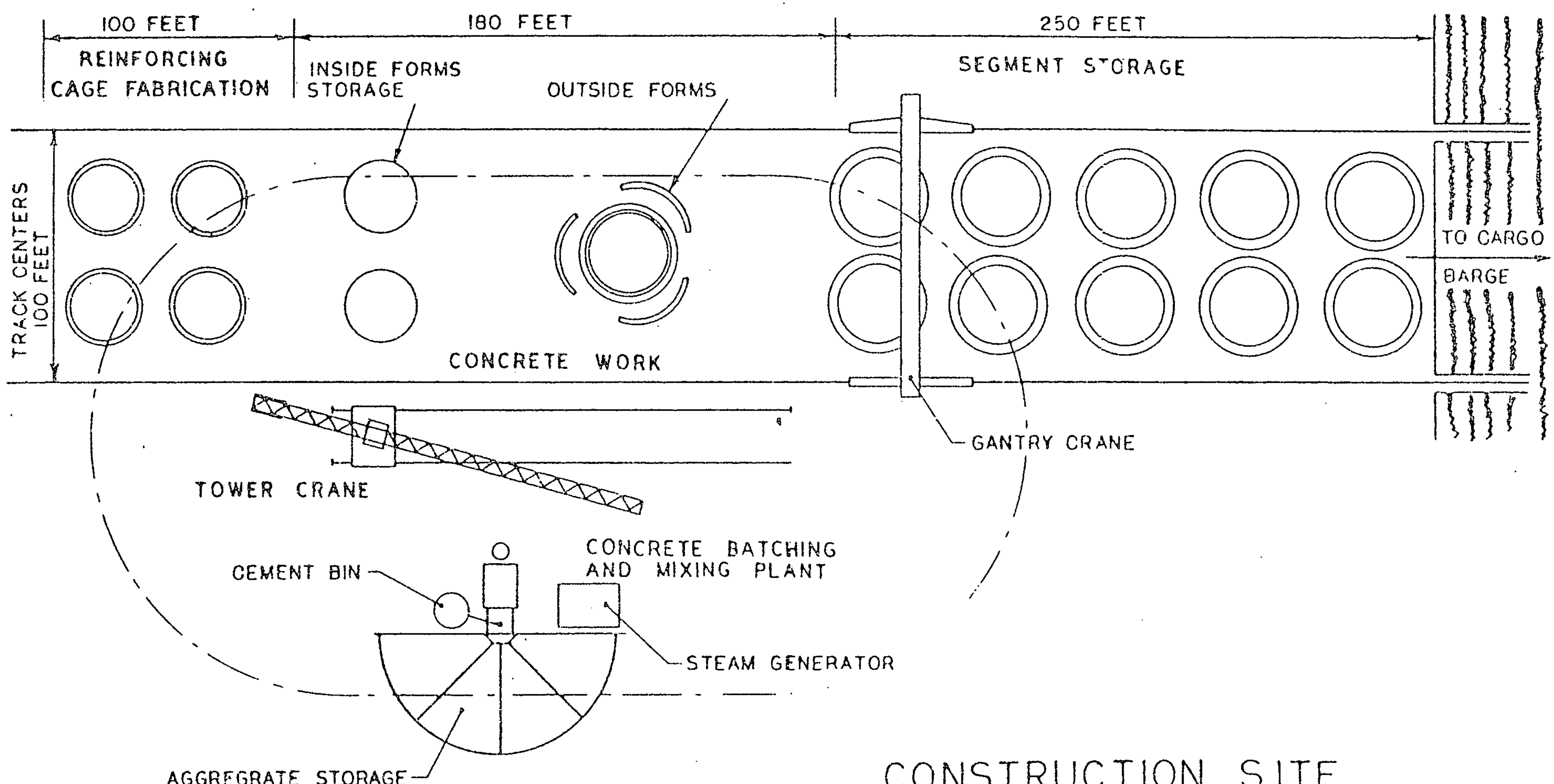
A complete CWP typical segment weights about 130 metric tons. Tapered segment and pump housing must also be lifted but in separated pieces. The maximum weight to be lifted is about 170 metric tons which is why the gantry crane is designed for 200 metric tons capacity.

The upper segment will be cast inverted in order to carry out the joint in good condition. This segment is then tilted by means of a rocking device and put on the lower segment with which it is assembled by prestressing cables.

The complete pipes are located on the storage area to be transported to the installation site barge.

2.3.3. Tapered and Pump Housing Segments

Once all CWP typical segments are precast, the top segment can be precast at the same place. This section will be made in separated pieces. First the tapered segment is manufactured. On the top of this piece the lower housing can then be cast. Then the top ring on the lower housing and the upper housing on the top ring are made. The four support inserts are prefabricated and their external diameter will be smaller than the internal diameter of the pump housing to leave room between both for this



CONSTRUCTION SITE

FIGURE 7

joint to be grouted. The pump housing segments can be successively loined on the support inserts by means of prestressing cables.

2.4 Bill of Quantities

1- Typical Segments

- Lightweight concrete for precast segments	m3	6.000
- Forms for precast segments	m2	65.000
- Reinforcing steel for precast segments	kg	360.000
- Prestressing steel for precast segments	kg	327.000
- Anchorages for prestressing cables		
Type 19 K 5	U	864
Type 12 K 5	U	2.676
- Ducts for prestressing cables		
2 1/2" (64 mm) I.D.	m	6.700
3" (76 mm) I.D.	m	27.000
- Elastomeric bearings	dm3	24.000
- Circumferential seal	m	1.750
- Laminated steel for embedded pieces	kg	46.000
- Prestressing rods Ø 36 mm	kg	27.500
- Anchorages for prestressing rods	U	6.528
- Ducts for prestressing rods 1 5/16" (41 mm)	m	3.000
- Rubber seals for construction joints	U	1.416
- Cement grout for construction joints	dm3	2.250

2- Pump Housing Element

- Lightweight concrete	m3	490
- Forms	m2	2.850
- Reinforcing steel	kg	39.000
- Prestressing steel	kg	13.000
- Anchorages for prestressing cables		
Type 27 K 5	U	12
Type 19 K 5	U	48
Type 12 K 5	U	88
- Ducts for prestressing cables		
2 1/2" (64 mm) I.D	m	700
3" (76 mm) I.D	m	170
4" (102 mm) I.D	m	250

Assumptions for Quantities Calculation

- It was assumed that:
  - . the percentage or rebars is 60 kg/m3 in typical segments and 80 kg/m3 in pump housing elements.
  - . the vertical prestressing in the bottom part of each joint is made with 36 mm diameter rods with a nominal force of 60 metric tons each.
  - . laminated steel for embedded pieces is estimated on the basis of cxisting drawings.
  - . prestressing cables and anchorages are FREYSSINET K type.

It should be noticed that all quantities are computed from the drawings on which some details are missing thus yielding a certain inaccuracy.

2.5 Cost Estimate

(Precast elements ashore at plant site)

2.5.1 Cost Estimate Breakdown

- Bare Costs -		$
. General facilities		370,000
. Site Fringe Benefits and Miscellaneous		280,000
. Main Contractor Works		
- Concrete	725,000	
- Forms	1,050,000	
- Prestressing rods and laminated steel	335,000	
- Elastomeric bearings and seal	680,000	
- Tilting and storage of precast segments and standard	1,145,000	
- Equipment rental		
Sub total (1)		3,935,000
Sub-Contracted Works		
. Reinforcing steel	275,000	
. Prestressing steel	1,260,000	
Sub total (2)		1,535,000
- Sale Price -		
. General facilities and main contractor works		
(370,000 + 280,000 + 3,935,000) 1,333 =	6,111,805	
- Subcontracted works 1,535,000 x 1,282 =	1,967,870	
		8,079,675
Rounded to $		8,100,000

2.5.2 Cost Estimate Per Item

	Sale Prices in $
Casting Plant	620,000
Typical Pipe Segments	6,960,000
Tapered and Pump Housing Segments	520,000
	$ 8,100,000

Note: This cost should be considered as a lower bound estimate of the APL design as described in the preliminary file without any changes of the APL design.

Estimated cost for designing of site facilities and special equipment: $ 50,000.

2.5.3 Cost Estimate Assumptions

- Average labor rate, including fringe benefits due to site staff $ 11.20 per hour.
- Standard equipment: normal amortization rate.
- Special equipment: 100% amortization (for example: the gantry crane is 100% included in the item "Tilting and storage of precast segments")
- Livlite aggregates $ 30./cubic yard
- Cement $ 56./metric ton
- Elastomeric material to be at the same price as elastomeric material used for bridges $ 19.5/ dm3
- Circumferential seal $ 45./metre

. The gantry crane with its appliances is estimated to:

roughly $ 500,000.

. No engineering cost included for C.W.P

. No engineering cost included for designing of site facilities and special equipment.

. Coefficient breakdown on bare costs are:

	Main contractor works (%)	Subcontracted works (%)
Corporate overhead	5	2
Contingencies	10	10
Profit	10	10
	25	22

That is to say coefficients on bare cost of

	1.333	1.282

. No charge included for site rental.

. No charge included for escalation

. Time delivery of present segments: 12 months

. Bonding, insurances, and finance charges are not included.

3 - CBC ALTERNATIVE

3.1 Alternate Design Possibilities

3.1.1 General

Having considered the various problems raised by the basic design as explained in chapter 2, an effort was made to improve the joint with the assumptions that the same distance between joints and the same mechanical principles would be employed. The overall behavior of the structure is not altered and even the joint distorsion capabilities were kept identical. The first goal was to ensure a safer transfer of the load through all structural elements. This led to an alternative design for which concrete and steel quantities are somewhat increased but in reasonable proportions that allow retention of the barge platform principle.

In the bottom part of the element prestressing has been drastically increased and shapes are deeply altered. In the top part the alternation is less visible but a great improvement made is due to the fact that the upper free surface is horizontal thus allowing casting in the vertical position. With convenient alternations to the equipment and to the casting process this will permit elimination of the casting join.

3.1.2 Structural Analysis

It was tried to improve the structural behavior at joint level with a more straightforward load transfer. The vertical load is carried through continuous ring beams at the top as well as at the bottom of the segment. Moreover the torsional stiffness of these beams reduces the flexural moment in the connection shells. Post-tensioning is always carried far enough to be evenly distributed in the necessary areas. Hoop prestressing is increased and distributed all along the bottom shell thus bringing extra strength to this part of the structure.

Computer analyses have shown that a much smaller prestressing force was sufficient to ensure the strength of the vertical cylindrical shell while high stresses could be expected in the tapered part. For that reason vertical prestressing of the element is made:

- 24 long cables, going from the bottom to the top of the element, that carry the load from the lower ring beam to the upper one
- 36 short cables anchored by means of closed loop anchors in the ring connecting the tapered shell to the vertical shell. Their purpose is to add the necessary prestressing force to the previous ones in the tapered shell.

Concrete volume is increased by 20% thus increasing the values of maximum loads in the same proportion from 2,400 metric tons to 2,900 metric tons. It is desirable to keep the structure fully compressed (no normal tensile stress) under the applied dynamic load but also the allowable compressive stresses must not be exceeded at the storage area when prestressing is applied. For an assumed dynamic load of 4600 metric tons, the normal stress values are found as shown below in the most critical parts of the structures at the point where shell thickness is equal to 0.35 m (tapered shell zone).

Prestressing + full dynamic load

maxi =	1,570 psi	(1,100 t/m2)
mini =	60 psi	(42 t/m2)

Prestressing alone:

maxi =	2,570 psi	(1,800 t/m2)
mini =	30 psi	(21 t/m2)

3.1.3 Circumferential Seal

A different type of seal is proposed. Commonly used in hydraulic applications its particular shape is well suited to the watertightness problem. Made of plain rubber, its own flexibility added to the slight pressure difference between the exterior and interior of the pipe ensures a good contact with concrete at the top rounded part. As sliding between the joint and the concrete surface is free it accomodates radial motion as well as tangential movement, the joint being thus watertight in any configuration without excessive stresses in the rubber seal.

3.1.4 Construction Methods

It was already mentioned that casting could be performed continuously without the necessity of a construction joint (see 3.1.1). This is the main and only difference with construction methods defined previously in 2.3.

Some equipment will no longer be necessary as the system used to tilt half segments but on the other hand the portal crane will have to be higher and some other items may be more expensive because of a greater height. Though a detailed analysis was not made, this was taken in account in the cost estimate given hereafter.

2- PUMP HOUSING ELEMENT

- Lightweight concrete	m3	490
- Forms	m2	2,850
- Reinforcing steel	kg	39,000
- Prestressing steel	kg	13,000
- Anchorages for prestressing cables		
Type 18 K 6	U	12
" 12 K 6	U	136
- Ducts for prestressing cables		
4" (102 mm) I.D	m	250
3" (76 mm) I.D	m	870

3.2 Alternative Design Bill of Quantities

1- TYPICAL SEGMENTS

- Lightweight concrete for precast segments	m3	7,300
- Forms for precast segments	m2	68,000
- Reinforcing steel for precast segments	kg	440,000
- Prestressing steel for precast segments	kg	560,000
- Anchorages for prestressing cables		
Type 4 K 6	U	780
7 K 6	U	4,428
12 K 6	U	2,334
- Ducts for prestressing cables		
2" (51 mm) I.D	m	13,500
2" ½ (64 mm) I.D	m	30,000
3" (76 mm) I.D	m	20,000
- Elastomeric bearings	dm3	24,000
- Circular seal	m	1,750
- Laminated steel for embedded pieces	kg	46,000

ASSUMPTIONS FOR QUANTITIES CALCULATION

It was assumed that :

- the percentage or rebars is 60 kg/m3 in typical segments and 80 kg/m3 in pump housing elements.
- Laminated steel for embedded pieces is estimated on the basis of existing drawings.
- Prestressing cables and anchorages are FREYSSINET K type.

It should be noticed that all quantities are computed from the drawings on which some details are missing thus yielding a certain inaccuracy.

3.3 Alternative Design Cost Estimate (Tentative)

(Precast elements ashore at plant site)

COST ESTIMATE BREAKDOWN

- BARE COSTS -

			$
. GENERAL FACILITIES, SITE FRINGE BENEFITS AND MISCELLANEOUS			635 000
. MAIN CONTRACTOR WORKS			
- Concrete		805 000	
- Forms		1 100 000	
- Laminated steel		75 000	
- Elastomeric bearings and seal		675 000	
- Standard and special equipment rental		1 145 000	
	Sub total (1)		3 800 000

SUB CONTRACTED WORKS

. Reinforcing steel		325 000	
. Prestressing steel		2 120 000	
	Sub total (2)		2 445 000

- SALE PRICE -

. General facilities and main contractor works (635 000 + 3 800 000) 1,33	5 911 855	
. Subcontracted works 2 445 000 x 1,282	3 134 490	
		9 046 345
	rounded to $	9 100 000

Cost estimate assumptions are the same as for the ABAM CWP Design. This estimated cost is closer to the actual price because of changes in the design which make it more feasible. Nevertheless there were so many problems to be checked that this result must be only considered as a first approach.

Assumping that technological points for which uncertainties were stated can be resolved in a timely manner, roughly 15% should be added to the estimated cost to reach upper bounded estimated cost which could be:

$ 10,500,000

INFORMATIONS ON LIGHTWEIGHT CONCRETE USED FOR

TRICASTIN BRIDGE (Results of laboratory tests)

LIGHTWEIGHT CONCRETE SPECIFICATION

Cement	400 kg	equivalent to ASTM type 1 cement
Water	190 l	
Absorbed water	19.2 l	(3.7 % at 2 hours)
Sand	600 kg	
Lightweight aggregate	517 kg	
Admixture	0,5 %	water reductor and fluidizer

SLUMP TEST	7,5 cm	(3")
GRAVITY at batching plant	1800 kg/m^3	(112 PCF)
COMPRESSION STRENGTH at 7 days	365 kg/cm^2	(5 200 PSI)
at 28 days	440 kg/cm^2	(6 300 PSI)
TENSION STRENGTH (Brasilian test)		
at 7 days	33 kg/cm^2	(200 PSI)
at 28 days	40 kg/cm^2	(250 PSI)
GRAVITY OF GRAIN AGGREGATE	1260 kg/m^3	(79 PCF)
GRAVITY OF BULK AGGREGATES	716 kg/m^3	(45 PCF)

ABSORPTION OF WATER AT 20° C

at 30 minutes	3.2 %	(without external pressure)
at 2 hours	3.7 %	
at 2 days	4.9 %	
at 7 days	8.7 %	