OTEC ELASTOMER COLD WATER PIPE PRELIMINARY DESIGN STUDY

Final Report, August—November 1979

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MASTER

November 13, 1979

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Goodyear Aerospace Corporation
Akron, Ohio

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OTEC ELASTOMER COLD WATER PIPE
PRELIMINARY DESIGN STUDY
FOR
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Goodyear Aerospace Corporation has analyzed the requirements for a 30 ft dia. 3280 ft long Cold Water Pipe for an Ocean Thermal Energy Conversion (OTEC) 10/40 MW Pilot Plant. A preliminary design using elastomer covered, flexible steel cable, conveyor belt material is presented. The design concept was predicated on employing state-of-the-art production techniques and having the capability for expansion to a commercial power plant size without further development. The report provides a data base for a compliant elastomer pipe and includes material properties, design details, cost, fabrication and schedule		

~~20.~~ ABSTRACT (cont'd)

information. Both cable and fabric reinforced constructions are addressed and a comparison of various concepts for assembly of the pipe sections has been made.

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I. INTRODUCTION

A. Background

The Goodyear Aerospace Corporation (GAC) became intrigued with the idea of making compliant elastomeric pipe for Ocean Thermal Energy Conversion (OTEC) plants. Using company funds GAC initiated an effort to review the OTEC requirements, and looked at various concepts for the cold water pipe. The concepts were screened for their relative advantages and disadvantages and this effort resulted in the selection of a conceptual cold water pipe configuration that could be developed using state-of-the-art design concepts, materials and manufacturing techniques. The major advantage of the elastomeric concept chosen is its adaptability to powerplants of any size without any additional effort in development or tooling.

Goodyear Aerospace used these company-funded elastomer or compliant pipe configuration data to prepare proposals and furnish technical information to NOAA/DOE contractors in their analysis for concept selection for the cold water pipe preliminary design project.

Under the contract for which this report is written, GAC had the opportunity of expanding the data base NOAA has on elastomeric cold water pipes and to supply such data in support of TRW's effort* on the baseline design phase of the cold water pipe preliminary design project.

*Reference No. 1

GAC's original effort included only a very cursory static analysis of the pipe. Due to limitation in funding, the effort on the cold water pipe has included no dynamic analysis since the major contractors were themselves performing such analysis.

It was then GAC's task under this program to provide material properties as required, design, cost, fabrication and schedule information to assist TRW in their analysis and evaluation of the elastomeric concept for the cold water pipe and to prepare a report to compile this information, previously dispensed in bits and pieces, in a logical and understandable manner.

B. Scope

The scope of the work was to provide NOAA with engineering services for further evaluation of the elastomeric pipe concept. The degree of analysis was consistent with the level required for the baseline design phase. The Cold Water Pipe (CWP) Concept studied had the following characteristics. (10/40 MW Pilot Plant)

Internal Diameter -- 30 ft

Length -- 3280 ft

TRW performed the structural analysis and baseline design analysis using the information provided in this report.

Specifically the following information was generated or provided.

- ° Material Properties
- ° Vertical and Horizontal Splice Joint Designs

- ° Stiffener Ring Design and Attachment
- ° Fabrication Costs
- ° Fabrication Plans
- ° Consulting Services

II. CONCEPT

The GAC concept for the CWP was predicated on the following requirements.

- ° Design expandable to larger size pipes with minimum development and tooling.
- ° Design to employ state-of-the-art production techniques.
- ° The major pipe loads are along the axis of the pipe.

As such GAC chose to employ standard conveyor belting material using a modular construction technique. See Figure 1.

The concept uses 6' wide conveyor belting running along the axis of the pipe. Conveyor belting normally has the strength members running along the axis as is required in this design. The 6' wide panels are assembled along their edges by vulcanization to form a cylinder 30' dia (or whatever is required) and a minimum of 50' long. The 50' long sections are mechanically spliced horizontally as shown on the sketch.

Horizontal stiffener rings are added at approximately 6' increments to prevent collapse of the pipe under the reduced internal pressures. The assembly and installation in the field would require only the metalcraft assembly of the pipe sections and attachment of the stiffener rings. There would be no seaming of the elastomeric materials in the field.

GAC's recommended concept for the basic conveyor belt material incorporates flexible steel cables as the load carrying members imbedded in a thickness of elastomer. The cables would run parallel to the length of the pipe with a mechanical termination at the horizontal splice. In the body of this report, GAC also presents information on the use of fabric as the substrate material in place of the steel cables. GAC's choice of the steel cable reinforced belting material was based on the following considerations.

Steel Cable Reinforced Advantages

- A. There is more data and history available on the use of steel cable construction for long life and fatigue resistance. Typical of these applications is the use of flexible cable in elevators, winches, cranes, aerial cable cars and bridge construction.
- B. The termination of the cables at the horizontal splice is much simpler, since it is a mechanical attachment as opposed to the hand wrapping of the fabric plies. See figures 22 & 23 of this report.
- C. The cost of fabrication of the pipe section is considerably less due to the simpler termination of the load carrying members.

Fabric Reinforced Disadvantages

- A. Fabric structures are more susceptible to long term creep rupture and as such require higher design factors.
- B. The cost of the fabric reinforced conveyor belt material is slightly higher than the cable reinforced material.

- C. The cost of the metalcraft parts for the horizontal splice is much higher because of the requirement to shape the part to conform to the contour of the termination bead. See figures 22 & 23 of this report.
- D. The clamp type horizontal splice is not as structurally sound as the mechanical splice for the cables.

FIGURE 1 -- COMPLIANT ELASTOMERIC CWP

III. MATERIALS PROPERTIES

A. General

The effort here involved compiling data on existing-off-the-shelf belting constructions to see if they were in the regime of the requirements as specified by the dynamic analysis supplied by others. Basically the belt construction consisted of a single layer of flexible steel cables or multi-layers of fabric covered by an elastomer. Neoprene was chosen as the elastomer basically because more historical data was available on this material in exposure to sea water and its successful use on many applications under this condition. Neoprene has been used on conveyor belting and is no problem in manufacture although SBR (Styrene Butadiene Rubber) is a cheaper and more commonly used material. Again somewhat arbitrarily, the thickness of the belting material was chosen such that at least 1/4" of rubber would be covering the basic substrate material to protect it from handling and abrasion deterioration. In the detail design phase the particular neoprene compound and thickness of elastomer would be further explored. The original static analysis conducted by GAC indicated that 1/4" cables at 6" spacing would provide a M.S. of 3. The final design criteria presented to GAC was as follows.

For Cable Reinforced Belting:

1/2" steel cables at 2 1/4" spacing

For Fabric Reinforced Belting:

Ultimate material strength of 20,000 #/inch

Information was then compiled in such areas as:

Fatigue Life
Ocean Aging Characteristics
Modulus of Elasticity
Flexural Fatigue
Creep Rupture
Tensile Strength

B. Cable Data

1. Cable Strength

The strength of standard flexible steel cable is text-book type information available from any manufacturer of steel cables and will vary depending on material and construction. The ultimate strength of typical cables used in standard conveyor belting is as follows:

TABLE I
STEEL CABLE FOR USE IN CONVEYOR BELTS

<u>DIAMETER</u>	<u>MINIMUM BREAKING STRENGTH</u>
5/32	3,240
7/32	6,380
1/4	8,030
5/16	13,620
3/8	18,000
1/2	24,500

A study was made of the minimum cable spacing that could be achieved with the present production equipment and maintaining sufficient elastomer between the cables. Figure 2 shows the minimum cable spacing for 3/8" up to 1" dia. cables.

FIGURE 2 -- MINIMUM CABLE SPACING

The minimum spacing, as can be seen, is approximately $1 \frac{1}{4} \times$ diameter of the cable.

2. Modulus

The elastic modulus for cables is defined by the cable manufacturer and again depends on the cable construction and materials. Typical load deformation data for steel cables (ref ANC-5 - Strength of metal aircraft elements) indicates that a modulus of between 12,850,000 psi and 16,440,000 psi for cables up to 1/2" dia with a 7 x 19 construction.

3. Fatigue Resistance & Life Expectancy

Since flexible steel cable is widely used in the industry for cranes, elevators, etc., considerable data exists on the flexure capability and no attempt has been made to obtain this data at this point.

Standard conveyor belts using steel cables as the load carrying members have been in service over twenty years and cable failure has never been a mode of failure. Keeping in mind that conveyor belting flexing over pulleys where the material flexes 180° is a much more severe condition than that in the CWP. This mode of failure is not to be of concern. Data has been collected by conveyor belt engineers and they have used data furnished by Bekaert Steel Company concerning flexural fatigue of cables. Typical of this is Figure 3. This is for a 7 x 19 x 1/4" steel cable with a breaking strength of 8030#. The figure indicates repeated cyclic stresses will approach infinity when the cable load is below 2500# or 31% of its breaking load. Flexural fatigue tests have been run also using 7/32 - 7 x 19 cables with standard neoprene compounds which are being considered for this construction. The actual test consisted of flexing a sample of belt over a 3 inch dia. pulley with a 90° wrap. No loss in cable pullout force was experienced after 500,000 flexures.

FIGURE 3 -- STRESS FATIGUE - 7 x 19 x 1/4" CABLE

4. Long Term Ocean Immersion

GAC has accumulated seven years of ocean immersion test data on samples of Code MA 874 neoprene coated steel wire cord. This material is Code A801 and is the fabric used in the AN/SQQ-23 sonar domes. Samples are coated on both sides with anti-fouling rubber to eliminate fouling that would interfere with ocean water permeating the samples. Samples were made with 9" lap seams so that failure would be forced to the wire in one case and 3" lap seams so that the failure would be forced to the adhesion between the steel cord and the rubber in the other case. Test data is shown in Figure 4.

After 7 years immersion the tensile specimens are failing at 94% of original values, and considering the 6% reduction is within experimental error, this would indicate that the steel cord is not being affected. Even though we suspect that the rubber is saturated with water, GAC feels that it is acting as a semi-permeable membrane and preventing salt from reaching the wire. Without electrolyte and oxygen, the wire won't rust.

The 3" lap seam samples are failing in adhesion between the rubber and the steel cord at 62% of original values, but were at equilibrium after two years immersion indicating that performance should remain the same for several years. In addition, this type of degradation is not significant in the design of the Cold Water Pipe where the significant loads are carried by the steel cables.

FIGURE 4 -- OCEAN AGING OF SONAR DOME MATERIAL AT MIAMI MARINE RESEARCH

C. Fabric Data

1. Strength

The strength of the fabric belting can be tailored to the particular design requirements. Either nylon or polyester can be used. Nylon is somewhat more standard and slightly cheaper, but polyester is more stable if exposed to salt water and has a higher creep rupture design factor. Standard strength per ply per in. of belt width of nylon material presently in use in belting is 1000#/in, 1500 #/in, 2000 #/in, and 3000 #/in. Standard belting is made of up to 6 plies of the 3000 #/in material for a total of 18,000 #/in of belt width. Additional plies could be used as required.

2. Stress-Strain Relationship

The stress-strain relationship for fabrics is considerably different than that for metals. The stress-strain curve is non-linear all the way to failure and does not exhibit a definite yield point. In addition, fabric strength and modulus can only be expressed in terms of pounds/inch of width of material with the thickness not a parameter which characterizes the strength or stiffness of the material since the material is not homogenous. The stress-strain relationship will vary with the strength of the material, make-up of the fabric and the type of weave. The variation is not of a significant difference from one fabric to another when compared to the difference in relative stiffness of fabric compared to metals. In any case the actual stress-strain relationship

for a particular fabric must be determined by test upon receipt of the material. A typical stress-strain curve for standard conveyor belting with an ultimate tensile strength of approximately 2000 #/in of width is shown in figure 5.

3. Creep Rupture Factors

One of the principal design factors for fabrics is the ability to sustain long term pressure (tensile) stresses. This has been of particular significance in the design of the Goodyear Airships. Creep rupture data has been generated to confirm service life in excess of five years. A preliminary design relationship taken from this data base is given by the formula

$$C = 0.73 - .0652 \log_{10} t$$

C = design factor

t = time in days

Assuming a design life of 30 years or 10,950 days the design factor becomes

$$C = 0.73 - .0652 \log 10,950$$

$$C = .47$$

For Dacron, the relationship is

$$C = 0.786 - .0596 \log_{10} t$$

$$C = 0.786 - .0596 \log 10,950$$

$$C = .54$$

GAC suggests that these factors be used in any analysis to determine ultimate fabric strength required.

FIGURE 5 -- TYPICAL STRESS-STRAIN RELATIONSHIP NYLON RE-INFORCED CONVEYOR BELT.

D. Elastomer Data

1. Physical Properties

Although the physical properties of the elastomer are not of significance in the design of the CWP (except for wt.) information on a typical neoprene compound used in conveyor belting is as follows.

Specific Gravity -- 1.38

Hardness (Shore A) -- 50-60

Tensile Strength -- 1900 psi

Elongation (ultimate) -- 300%

Neoprenes as a whole exhibit excellent flex cracking resistance and abrasion resistance. Overall typical properties* for a wide range of neoprenes show the following characteristics and are compounded as required.

Specific Gravity -- 1.23 - 1.40

Hardness (Shore A) -- 30-95

Tensile Strength -- 500-3500 psi

Elongation (ultimate) -- 100-800%

2. Long Term Ocean Immersion

Neoprene compounds, as a class, are resistant to the affects of ocean immersion. Neoprenes used in anti-submarine warfare applications will swell approximately 10% by volume during long term water immersion and this should be typical of all properly compounded neoprenes. HN 180, an industrial products neoprene compound, retained 87% of its tensile strength and 84% of its original elongation after 12 months exposure.

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MA852, GAC anti-fouling neoprene retains 88% of its tensile and 93% of its elongation after 7 months ocean exposure in Biscayne Bay, Miami Beach, Florida. Samples were removed monthly and equilibrium was established after 2 months immersion, so performance should apply for several years.

3. Fatigue Resistance

As previously indicated in the discussion of conveyor belt life expectancy, cable fatigue or rubber fatigue is not a mode of failure in belting material. Many years of service have been experienced and the failure mode is always of the abrasion of the carrying surface.

IV. DESIGN

A. General

In looking at the design concept for a CWP, GAC first looked at the method of construction of existing suction hose.

Conventional compliant suction hose (or pipe) is fabricated by wrapping the raw material on a mandrel in plies to form an abrasion-resistant rubber liner, a coated fabric body to carry longitudinal tension, spiral wire reinforcement to prevent buckling and an outer cover of abrasion and weather-resistant rubber. In this process the rubber and rubber-coated fabric are applied "green" (uncured) and the complete assembly

is vulcanized.

In order to build reinforced elastomer pipe in the sizes required for commercial OTEC systems, where mandrel wrapping and autoclave curing are impractical, a built-up construction using cured material appeared to be a better approach. In this structure the spiral-wrapped wire will be replaced by metal rings and steel cables or fabric would be moulded in to carry the vertical load using conveyor belt fabrication techniques.

Typical suction hose and steel cable belt construction are shown in Figure 6. As pointed out, the method of construction that was decided upon lends itself readily to pipe sizes of up to 100' or more in dia. with no changes in tooling or development of the design. Since it was determined that approximately 6' spacing of the stiffener rings would be required, the choice of which direction to run the belt strips had to be made. The main load carrying members are required in the longitudinal direction of the pipe. Since standard belting construction has the cables running parallel to the belt axis and any change from this would require extensive tooling and development, it was decided to run the belt sections along the pipe axis as shown in Figure 7. This then became the baseline configuration for the compliant pipe construction.

B. Vertical Seam

The vertical splice, 16 required in each minimum 50' long section,

CONSTRUCTION: TUBE: SBR, resists sand, grit and alkaline or slightly acid water. REINFORCEMENT: Plies of wrapped fabric plus helix of round steel wire. COVER: SBR, sun and weather-resisting. Black color.

STEEL CABLE CONVEYOR BELT

FIGURE 6 -- TYPICAL SUCTION HOSE AND STEEL CABLE CONVEYOR BELT

FIGURE 7 -- COMPLIANT COLD WATER PIPE (CWP)

can be made in a similar manner to that used for standard belt splicing. In conveyor belt splicing the cables are not physically attached to each other. The seam is made by carrying the tensile load from the cable by shear in the elastomer. Since the CWP load carrying members are vertical, the vertical splice would be a vulcanized scarfed or offset splice as shown in Figure 8.

FIGURE 8 -- VERTICAL SPLICE

The splice would be made at the contractor's facility so that no vulcanization would be required in the field. A special curing press similar to the existing press at GAC's Rockmart facility would be required. The splice would be made 50-75' long and would be cured in one pass for each vertical seam. As completed, the assembly would then be a cylinder 30' in diameter and a minimum of 50' long. The assembly, without steel stiffener rings could then be folded since it would be relatively flexible and shipped as an assembly by railroad flat car.

C. Stiffener Rings and Attachment

The purpose of the stiffener rings is to prevent the collapse of the pipe under the suction pressure and to minimize the necking down of the pipe to the point where it would seriously affect the flow. Some initial static calculations showed that with a 5% reduction in area and an assumed spacing of 6' the ring required moment of inertia at the top would be in the neighborhood of 26 in^4 , or an approximate 6" pipe with .25" wall thickness. In the detail design phase of the cold water pipe, trade-off studies can be made of the most efficient, weight and cost cross-section for the rings.

In addition, the spacing of the stiffener rings could be varied due to the change in delta pressure down the pipe or the cross-section itself can be varied. This trade-off of course is dependent on the dynamic analysis and the ballast weight required for dynamic stability.

GAC attempted to look at the attachment and any requirements thereof, rather than the specific cross-section of the stiffener ring.

Two cross-sections were considered for the rings, tubular and I-beam. The tubular cross-section is the most efficient use of the material from a weight and cost standpoint and has the advantage of being almost self-buoyant if this was required.

If this was a detriment to the overall design, then the coating or protection of the tubular section would be very expensive compared to

an I-beam. The tubular section also does not readily lend itself to the attachment to the pipe as well as the I-beam section.

The attachment to the pipe would be made through the rubber only which has sufficient thickness and strength to carry the weight of the stiffener. Two fasteners at each location are probably more desirable than one to better distribute the load.

A doubler plate is required on the interior of the pipe to act as a back-up plate under the bolt heads for a better bearing surface. The edges of the doubler plate and stiffener ring in contact with the CWP should be radiused.

Some of the designs considered for the tubular stiffener sections are shown below. Figure 9 shows the stiffener tube with a stand-off plate welded to it for attachment. The tubular weldments would be made in a length consistent with shipment and then welded into an assembly at site. The particular design shows a single attachment with access to the nut through the side of the stand-offs. Figure 10 is similar except a floating anchor nut has been added to aid in the alignment of the parts.

FIGURE 9 -- STIFFENER RING

FIGURE 10 -- TUBULAR STIFFENER RING FLOATING ATTACHMENT

Figure 11 shows a configuration in which a dual attachment is made and also makes the attachment more accessible. This configuration is preferred due to accessibility and better load carrying capability.

The attachment holes through the pipe can either be punched or drilled to match the plates.

FIGURE 11 -- STIFFENER RING - DUAL ATTACHMENT

Figures 12, 13, and 14 show a configuration using an I-beam cross-section made from welding of a T-section to a base plate. Again this design has ready access to the attachment, is an all bolted construction and lends itself to being coated for protection from corrosion of the metal parts.

D. Circumferential Splice

1. General

As previously indicated, the sub-assembly sections would be made in lengths of 50'-75'. Therefore, on site assembly is required of the 66 sections with a circumferential splice. Consideration was given to both the fabric reinforced and the steel cable reinforced material.

Termination for the steel cables were evaluated using the following standard terminations as shown in Figure 15.

FIGURE 15 -- TYPICAL CABLE TERMINATION

SECTION A-A

FIGURE 13 -- STIFFENER RING - SPLICE

FIGURE 14 -- STIFFENER RING - CROSS-SECTION

The nicopress sleeve does not lend itself to the larger size cables, in addition would be much more difficult to perform since it would have to be done on site and alignment could be a problem. The ball and shank attachment would require machining a spherical seat on the attachment member which would significantly increase the cost of the attachment. This design would also require a thicker attachment member due to the size of the ball. The fork and eye end are standard terminations and the eye end would probably result in the least amount of material and the lowest cost in the attachment members.

Terminations for the fabric reinforced belting were considered and the sketches that follow show a "bead" joint termination used successfully on large sonar domes and the Minuteman Seal where the loads are similar to the loads on the CWP. This type is very expensive relative to the cable termination both in terms of making the termination and the attachment parts themselves. Since the metalcraft portion of the CWP design is a considerable portion of the cost, in the detail design stage a complete review and trade-off study should be made of this very significant item.

The following sketches depict various splice arrangements using various terminations.

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2. Circumferential Splice - Cable

Figure 16 uses a termination where the cable is molded into the belting material essentially as an endless cable. The cable would form a loop at each end layed back on itself. This configuration did not lend itself to production fabrication of the belt material and was considered much too expensive to consider further.

FIGURE 16 -- CABLE TERMINATION - WITHIN BELT

Figure 17 shows a termination using the nicopress sleeves which then would require outside cover strips to seal the area. The disadvantages of this configuration have been discussed, although a single advantage is that the load is carried directly from cable to cable without going through outside splice strips thereby reducing costs considerably.

FIGURE 17 -- CABLE TERMINATION - NICOPRESS SLEEVE

In Figure 18 the cables are terminated in a ball end fitting. Split rings would be machined to accept the ball fitting and could be assembled to the pipe sections. The field assembly would then involve welding of the rings or added exterior plates bolted through the split rings.

Figure 19 shows an attachment similar to Figure 18, except that the split rings incorporate outside flanges that in turn can be clamped together with a lug-fitting. This concept would eliminate any matching of holes in the field at the time of attachment of the ring sections. This configuration would be probably much more expensive due to the added machining involved.

FIGURE 18 -- CABLE TERMINATION - BALL END

FIGURE 19 -- HORIZONTAL SPLICE - LUG FITTING

A further refinement of the above concept is shown in Figure 20. This shows a locking key arrangement which again eliminates matching of holes in the field and minimizes the complexity of the joint structure. Again this concept would be heavy and costly.

FIGURE 20 -- HORIZONTAL SPLICE - LOCKING KEY

A concept involving the use of a fork end fitting is shown in Figure 21. Load from the cable is transmitted to transfer plates through pressed in pins or bushings. The load in turn is transmitted to the outside doubler plates by the through bolts as shown. A variation of this concept would make the two transfer plates one piece and then have the outside doubler plates serve to seal the area. In all cases shown, provisions can be made to pump in sealant to seal the area after assembly.

FIGURE 21 -- HORIZONTAL SPLICE - FORK END FITTING

The last concept shown for the horizontal splice using cables is shown in Figure 22. In this case eye-end fittings are used which minimize the thickness of the joint. Doubler plates inside and outside with through bolts or tapped holes on the inside plate form the splicing members.

Table II summarizes the horizontal joint concepts, their advantages & disadvantages and GAC's recommendation for the preliminary design.

FIGURE 22 -- HORIZONTAL SPLICE - EYE-END FITTING

TABLE II -- HORIZONTAL JOINT SUMMARY

FIGURE NO.	PAGE NO.	CONCEPT	ADVANTAGES	DISADVANTAGES
16	32	Endless Cable	<ul style="list-style-type: none"> ° Eliminates Termination Fitting 	<ul style="list-style-type: none"> ° Does not lend itself to production belting fabrication ° Not adaptable to 1/2" diameter cable because of large radius required
17	33	Nicopress Sleeve	<ul style="list-style-type: none"> ° Direct load path between pipe sections ° No structural splice plates required ° No hole matching required 	<ul style="list-style-type: none"> ° Very difficult on site assembly ° Very low joint efficiency with 1/2" dia. cables
18	34	Ball End Termination	<ul style="list-style-type: none"> ° Split rings pre-assembled to pipe sections minimizes ship-board effort ° Eliminates hole matching at assembly of sections 	<ul style="list-style-type: none"> ° Machining of spherical seats to accept ball end fitting is very costly ° Ball end fittings are not standard for large dia. cable
19	34	Ball End Termination (Lug Fitting)	<ul style="list-style-type: none"> ° Split lug rings pre-assembled to pipe sections minimizes ship-board effort ° Eliminates hole matching at assembly of sections 	<ul style="list-style-type: none"> ° Machining of spherical seats to accept ball end fitting is very costly ° Ball end fittings are not standard for large dia. cable ° Lug fittings and split ring with flanges are very costly

TABLE II -- HORIZONTAL JOINT SUMMARY (Cont'd)

FIGURE NO.	PAGE NO.	CONCEPT	ADVANTAGES	DISADVANTAGES
20	35	Ball End Termination (Lug Fitting with Locking Key)	° Same as Figure 19	° Same as Figure 19
21	36	Fork End Termination	° Splice joints pre-assembled to pipe sections minimizes ship-board effort ° Eliminates hole matching at assembly of sections	° Machining of the transfer plates is costly
*22	37	Eye End Termination	° Low cost of metalcraft splice plates and minimizes quantity of metal parts	° Field alignment of holes through splice plates and eye ends

*NOTE: In the detail design phase of the cold water pipe development, GAC recommends additional work be performed to trade-off these and other concepts for the horizontal splice. For the preliminary design GAC chose the eye end termination (Figure 22) for the following reasons:

- (1) Adaptable to the large cable diameters required for the CWP.
- (2) Least overall cost for fabrication of the metalcraft parts.

3. Circumferential Splice - Fabric

A typical termination for a fabric reinforced structure, subjected to high loads is shown in Figure 23.

FIGURE 23 -- HORIZONTAL SPLICE - FABRIC REINFORCED BELT

In this concept the fabric layers in the belting must be separated and wrapped around a steel cable that serves to transfer the load from the fabric wraps to the splice plates. This type of construction makes a very reliable splice and has a high joint efficiency when properly designed. It is a costly type of construction compared to the termination of the cable belting material. The in-

creased cost includes not only the termination of the fabric ends, but also the substantial increase in the cost of the splice plates themselves. In addition, the joint would probably be suspect in long term loading.

V. MANUFACTURING SEQUENCE

A. General

GAC has established a manufacturing sequence for the CWP. The 5 steps are shown in Figures 24 and 25. The plan was used to determine what special tooling would be required, time sequencing of operations and what in-process-testing is required. As a result of this breakdown a cost baseline and schedule was determined. All of the operations required for the manufacture of a 30' dia. cylindrical section are routinely accomplished in one form or another on many present production contracts. As such the cost of development and implementation of the manufacturing sequence should be minimal except for the cost of special tooling specifically required for the CWP.

B. Manufacturing Sequence

Step 1 is the manufacture of the basic conveyor belt material. This would be accomplished at the Goodyear Tire & Rubber facility at Marysville, Ohio. The continuous lay-up of the belt material 6' wide would be accomplished until a roll approximately 1500' long is assembled. The material is step cured in a nominal cure length of 34 ft. Separators would be added at specific points in the belt material at

FIGURE 24 -- CWP FABRICATION PLAN STEPS 1 THRU 3

SECTION END CURE

STEP 5

FIGURE 25 -- CWP FABRICATION PLAN STEPS 4 & 5

the length of the pipe segments to aid in the removal of the elastomer where the cables are terminated.

The basic belt material can be manufactured at a rate of 500 ft per day. Assuming that the final design does not exceed a 1" thick belt and 1/2" cable diameter, there is no cost or time involved in special tooling or revision to the equipment to manufacture the basic material.

Step 2 involves cutting the 1500' long belt into predetermined lengths and removing the elastomer in preparation for application of the cable terminal. In addition the edges of the belting would be trimmed in preparation for making the longitudinal seam. Step 3 shows the application of the fitting for termination of the cable.

Step 4 is required to re-encapsulate the cable in elastomer after the fitting is installed. It is assumed that the elastomer would have to be removed further back from the end of the cable than the fitting end. If not, this step could be eliminated. In the detail design an attempt would be made to do so.

Step 5 is the final assembly of the cylindrical pipe section. This step would involve a large press for application of pressure and heat to make the longitudinal seam. It is estimated that this operation would require 4 hours per seam, and would be the pacing item in an overall manufacturing schedule.

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C. Special Tooling

The following is the special tooling required for the above manufacturing sequence, noting that there is none for the basic belt material with the design as it is at the present.

1. Swaging Machine (1 required) for termination of the cables (Step 3).
There are off-the-shelf machines available at a relatively reasonable cost. The machine would be modified to give it mobility.
2. Curing Molds (7 required) for the curing of the end section after application of the cable termination (Step 4).
3. Slitting Tool (1 required) to prepare edge of belting material for the vertical seam (Step 2).
4. Vertical Seam Curing Press (1 required) (Step 5).

VI. TESTING

Based upon the configuration of the basic design, GAC has analyzed the development and production type tests that would be required for the development and production of the CWP.

GAC suggests that the development and production type testing for the CWP would include the following.

A. Development Tests

1. Cable Material

Tests should be conducted to verify the stress/strain curve for the

recommended cable to be used; in addition, the weight of the material would be verified.

2. Joint Tests

GAC recommends that tests be conducted on the following basic joints of the CWP.

- ° Longitudinal Seam -- This involves testing of the vertical seam and to verify that the seam design is capable of carrying the loads of the basic material, to establish the efficiency of the seam and determine seam width.
- ° Cable Termination -- Tests should be conducted to establish the efficiency of the cable termination so that the efficiency factor of the joint can be included in the design analysis. This would be a tensile type test.
- ° Horizontal Seam -- Tests should be performed to verify the adequacy of the design and again to determine the efficiency of the particular design. These would be a tensile test of the configuration.
- ° Stiffener Ring Attachment -- Similar to the horizontal seam, tensile tests should be performed to verify this attachment.

B. Production - In-Process Testing

In reviewing the production type testing, GAC would perform the following tests on the end product.

1. Conveyor Belting

a. Each mix of the basic elastomer would be tested to verify its physical properties.

b. Elastomer to Cable Adhesion (Material Evaluation)

Tensile tests would be performed to verify proper adhesion of the elastomer to the cables.

c. Cable Tensile

Each lot of cables would be tested to verify the cable strength and stress/strain curve for the cable.

d. Elastomer to Cable Adhesion (End Product Verification)

Samples would be taken from each end of each roll of conveyor belting material to verify that proper adhesion of the cable to the elastomer is maintained.

2. Subassembly

a. Vertical Seam

Tensile tests would be performed on samples cured with each seam cure.

b. Cable Termination

Tensile tests would be conducted on a sampling basis to verify the efficiency of the cable termination and to demonstrate that it equals or surpasses the efficiency used in the development analysis.

VII. SCHEDULE

As a result of the study, the schedule shown in Figure 26 and 27 was defined for the development and production phases of the Cold Water Pipe.

FIGURE 26 -- SCHEDULE FOR COLD WATER PIPE DEVELOPMENT

FIGURE 26 -- SCHEDULE FOR COLD WATER PIPE DEVELOPMENT (CONTINUED)

FIGURE 27 -- SCHEDULE FOR COLD WATER PIPE PRODUCTION

The nine month development program was considered as non-recurring while the nine month production follow-on was considered as recurring effort.

Preliminary Design Review (PDR) is achieved two months after receipt of order (ARO). During PDR, discussions will concentrate on such things as design concepts, material requirements, fabrication techniques, development testing and tooling for support of the production program. The main design and analysis considerations include the belting materials, vertical and horizontal splicing techniques, stiffener subsystems and interface requirements. Test fixtures will be designed and fabricated so that basic materials, fabrication techniques, joint construction and interface requirements can be investigated and design concepts verified. Sufficient tooling must be ordered to ensure an acceptable production flow. Tooling presently contemplated include swaging machines to attach special terminals to the belting cables, curing molds to cure interface joints, slitting tools to prepare belt edge and facilitate fastening techniques and curing press to fabricate the vertical seams. To expedite production it will be necessary to execute an advance material release (AMR) five months ARO. In addition, plant make-ready will take place during the three months prior to the end of the development phase. The development program will culminate in the critical design review (CDR), where detail design drawings and fabrication procedures will reflect the results of development tests and tooling decisions. The last month is dedicated to update of the CDR data with considerations toward production improvement and definition of the major potential problem areas.

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A nine-month production program is attainable provided sufficient tooling and extra work shifts are planned. The manufacturing and inspection time frame on Figure 27 is predicated on the rates, number of shifts and number of tools therein defined. The assumptions are reasonable and within the state-of-the-art. Sufficient testing of the raw materials and typical fabricated parts will be conducted throughout the production program to monitor materials and techniques and thus ensure an acceptable cold water pipe. The manufacturing rates and inspection tests may be modified as the program progresses; however, the initial assumptions are based on experience and judgements of specialists in this technical discipline.

VIII. COST DATA

A. General

GAC generated a cost breakdown for the steel cable reinforced conveyor belt construction for the cold water pipe. The basis for the estimate was the following baseline design:

- ° 1/2" dia steel cables at 2.5" spacing, 1" thick belting material.
- ° 30' dia cylinders, 75' long. (Figure 25)
- ° I-beam stiffener rings at 6' spacing (Figure 12).
- ° Horizontal splice - using eye end fittings (Figure 22).
- ° Pipe is 3280 ft long.
- ° No finish is included on metal parts.

For these costs see page 4-47 of Reference No. 1

- ° Metal craft material is A36 STL with Titanium hardware.
- ° Estimate is for CWP for one (1) CWP system (30 ft in dia., 3280 ft lg)

The following was the basis for the estimate:

- ° Delivery is F.O.B. Akron, Ohio.
- ° Costs are based on 1979 rates - no inflation included.
- ° No costs are included for field assembly or field support.

For these costs, see page 4-46 of Reference No. 1

- ° All costs are at selling price (S/P) level
- ° Cost information is budgetary.
- ° No contingency is included. GAC recommends 15-20% be added.

B. Development Estimate (Non-Recurring)

The estimate for the development portion includes the following:

- ° Management
- ° Analysis
- ° Design
- ° Testing
- ° Procedures
- ° Tool Design
- ° Tool Manufacture & Checkout
- ° Moves and Alterations
- ° Data Submittal

C. Production Estimate (Recurring)

Production estimate includes the following:

- ° Management
- ° Fabrication of 1 system - 3280' long, including stiffener rings, horizontal splice materials and attachment hardware.

- ° Quality Assurance and Inspection
- ° In-Process Testing
- ° Data Submittal

The fabrication flow plan shown in Section V of this report is the basis for the estimate prepared herein.

D. Particulars

Some significant particulars about the cost breakdown or basis are as follows:

1. To show the cost sensitivity of the conveyor belting material, the following table is presented.

TABLE III
CONVEYOR BELT COST VERSUS DESIGN

<u>Belt Thickness</u> <u>(inches)</u>	<u>Cable Diameter</u> <u>(inches)</u>	<u>Cable Spacing</u> <u>(inches)</u>	<u>Cost</u> <u>Ft² *</u>
.75	.25	6.0	X
.75	.25	3.0	1.07X
.75	.25	1.0	1.34X
1.00	.50	6.0	1.41X
1.00	.50	3.0	1.61X
1.00	.50	2.5	1.70X

There is approximately 314,880 ft² of belting required for one (1) pipe. For information purposes the cost of the elastomer is 67% of the total cost of the belting material and neoprene is approximately 50% more expensive than SBR (Styrene-Butadiene Rubber) elastomer, the standard belting elastomer.

* - Cost will be supplied to the Government only -- upon request.

2. The cost for 4-ply nylon fabric reinforced belting material is fairly close to the cost of the steel cable belting material. The manufacturing costs using fabric are estimated to be an order of magnitude larger.

3. Materials & Quantities

- ° 44 pipe sections -- 75' long.
- ° 40,000 cable terminations.
- ° 704 vertical splice joints
- ° 1,408 panel end moldings.
- ° 250,000 bolts.
- ° 43 horizontal splices -- 276,000#.
- ° 550 Stiffener Rings -- 2,177,500#.

E. Cost Breakdown

Table III shows the cost breakdown both non-recurring and recurring and also shows percentage of total for comparison purposes.

The actual cost data will be supplied to the Government only -- upon request.

TABLE IV

COST BREAKDOWN @ S/P - 1979 DOLLARS

<u>CATEGORY</u>	<u>ITEM</u>	<u>DOLLARS</u>	<u>PERCENT</u> <u>SUB-TOTAL</u>	<u>TOTAL</u>
<u>Non-Recurring</u>				
	Eng. & Dev.		45%	
	Tooling		55%	
			100%	6%
<u>Recurring</u>				
	Management		2%	
	Belting Mat'l		20%	
	Misc. Mat'l		6%	
	Mfg. (Ass'y)		7%	
	Stiff. Rings		55%	
	Horiz. Splice		10%	
			100%	94%
Grand Total				100%

IX. ASSEMBLY & INSTALLATION

GAC is not familiar with the facilities and handling equipment anticipated for the assembly and installation of the CWP. GAC presumes a large and comprehensive study would be performed in this area.* An attempt was made to present a concept to show how GAC feels the CWP sections can be handled and to generate ideas for the installation contractors.

A typical assembly scenario for the pipe could be as follows:

- A. Upon receipt of the unit at the assembly site, the cylinder section would be removed from the rail car using the lifting provisions provided by the manufacturer for loading of the unit and moved to the assembly area. An inflation tube either already installed in the unit or installed at the site would be inflated to round the cylinder section into shape and the end attachment rings installed (Figure 28, Step 1).
- B. A spreader bar assembly would then be attached to one of the rings and either with or without the inflatable cylinder the unit could be rotated to a vertical position and lowered between interior and exterior scaffolding for attachment of the reinforcing rings (Figures 28 and 29, Steps 2 and 3).
- C. The unit could then be removed and rotated to the horizontal position, supported on cradles under the reinforcing rings for water shipment to the site.

* See Section 4.4 of Reference No. 1.

- D. For final assembly at the site, the first section would be vertically hoisted and lowered for mating to the ballast and screen assembly. (Figure 29, Step 4).
- E. The unit would then be lowered through the moon pool and supported by support lugs attached to the end rings (Figure 30, Step 5).
- F. The spreader bar would be removed, attached to another section, and the section lowered to mate to the previous section (Figure 30, Step 6). The process could be repeated to complete the 44 attachments required. An interior work platform could be supported from above or a floating island platform with rubber bumpers could be inserted within the cylinder if work was required from both sides of the joint or the joint could be designed so that all work would be exterior.
- G. For assembly on shore, the sections could be placed horizontally and supported by the reinforcing tubes, cradles and dollies. As the assembly of each section is completed, the assembled section could be moved on the dollies for towing to the water.

END RING INSTL

STEP 1.

HOISTING OF SECTION
(UP-RIGHTING)

STEP 2.

FIGURE 28 -- CWP - ASSEMBLY AND INSTALLATION - STEPS 1 AND 2

REINF RING INSTL.
STEP 3.

BALLAST/SCREEN ATTACH

STEP 4.

FIGURE 29 -- CWP - ASSEMBLY AND INSTALLATION - STEPS 3 and 4

STEP 5.

STEP 6.

FIGURE 30 -- CWP - ASSEMBLY AND INSTALLATION - STEPS 5 and 6

X. MISCELLANEOUS INFORMATION

During the course of the study program, GAC provided or generated information requested by the contractors studying the various designs for the CWP. The following items were prepared.

A. Underwater Repair Of The CWP

Actual installations of wire reinforced sonar domes on surface ships indicate adequate durability against normal sea environment conditions. There are instances where ships have struck or scraped piers, piling and other underwater obstructions causing certain damage to the wire reinforced domes. Various repair procedures and materials have been developed and are in use for the underwater repair of these damages on the wire reinforced domes. Goodyear provided procedures for the underwater repair of pits, cuts, or gouges in the elastomer portion of the sonar domes as defined in the NAVSHIPS 0967-447-2310 Technical Manual, "Installation, Operation, Maintenance, Repair, and Storage With Illustrated Parts List, AN/SQQ-23 (Pair) Sonar Dome Assembly and Related Parts" (15 Oct. 1972 Goodyear Tire & Rubber Co). In addition, underwater repairs of damaged reinforcement wire of a section of a sonar dome were conducted under NAVSEA cognizance at the Naval Coastal Systems Laboratory, Panama City, Florida. These techniques are described in Goodyear Aerospace Corporation Document, GAC 19-1077, "Manual For The Emergency Underwater Repair of Rubber Sonar Domes and Windows". The actual techniques used may or may not be directly applicable to the CWP, but the technology exists to provide adequate repairs for a CWP.

B. Coating of Metal Parts For Salt Water Protection

In response to questions concerning the covering of metalcraft parts with elastomer for salt water protection, GAC sees this as a very feasible approach and well within the state-of-the-art. Many small parts have a molded elastomeric coating, but this approach would not be feasible for the large structures of the CWP, but a typical example of a large structure with elastomeric coating is the interior lining used in tank cars. In this case the car is used as an autoclave (pressure and heat) to vulcanize the uncured material applied to the inside of the car. The application of the elastomer in the case of exterior coating simply involves application of the uncured elastomer to metal parts and curing the material in an autoclave where pressure and heat can be applied. The size of the metal parts are within the capability of existing autoclaves. There are also spray-on air-cure protective materials available.

C. Anti-Foulant Material

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 its 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, that is, 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 31 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

FIGURE 31 -- FOULING RESISTANCE OF MA852 VERSUS THICKNESS

* .25" thickness will be good to resist fouling for ~ 120 months (10 yr)

.62" thickness will be good to resist fouling for ~ 360 months (30 yr)

yet to make long term projections, but short term data indicates that 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. We are continuing to analyze our data to improve antifouling predictions.

Please note that all of the aforementioned data was obtained statically, that is, the material was not subjected to open-sea turbulence. 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 probably would not settle.

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D. Sealing Compound

A search was made of applicable sealing compounds to be inserted into the horizontal seams after assembly, to protect the cable ends and terminals.

Two very likely prospects were recommended by Products Research, Inc. of Glendale, California. They are PR 1539 or Rubber 3095 (Products Research Code Numbers).

They both exhibit the following characteristics per Products Research:

- ° Adheres well to neoprene and metals.
- ° Salt water resistant.
- ° Cure under water.
- ° Good resistance to pressure
- ° Infinite life span.

XI. CONCLUSIONS AND RECOMMENDATIONS

As a result of this study program and the work performed by TRW* under contract to DOE/NOAA, GAC finds the following conclusions and recommendations.

A. Conclusions

- ° Reinforced elastomer CWP can be designed to survive the environmental conditions.
- ° Wall construction and assembly techniques are well within the state-of-the-art and are performed daily in the production of conveyor belting.

* See Reference No. 1

- ° The elastomeric CWP concept is adaptable to larger diameters of CWP construction.
- ° The flexibility of the elastomeric CWP should be an asset in the deployment of the system.

B. Recommendations

1. The development of the elastomeric CWP should proceed to further evaluate the concept.
2. Development tests of the elastomeric concept should be started so that the true potential of the system can be realized.
3. Material testing of the elastomeric design should proceed with the following:
 - ° Cable load/elongation characteristics
 - ° Tensile strength of vertical seam
 - ° Tensile strength of cable termination
 - ° Tensile strength of horizontal seam
 - ° Verification of stiffener ring attachment
4. A detail study and trade-off analysis should be initiated of the design of the stiffener rings which are principal cost impact of the overall design.

REFERENCES

1. TRW Report D02715 Cold Water Pipe Preliminary Design Study - Final Report.
2. Material Engineering, December 1978 (1979 Materials Selector).

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FINAL REPORT
OTEC ELASTOMER COLD WATER PIPE
PRELIMINARY DESIGN STUDY
FOR
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