PIPE MATERIALS STUDY
SAN LEANDRO TO HAYWARD

EBDA PROJECT NO. 57908

CLEAN WATER GRANT PROJECT C-06-0868-020

SEPTEMBER 1976

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**PIPE MATERIALS STUDY**

East Bay Dischargers Authority  
EBDA Project No. 57908  
Clean Water Grant Project No. C-06-0868-020

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SECTION 1

STUDY OBJECTIVES AND SCOPE

The objective of this study is to evaluate various presently available pipe materials for their suitability for use in the on-shore portion of the force main interceptor proposed to serve the East Bay Dischargers Authority. This study is to address the specific pipe sizes, hydraulic requirements and soil conditions applicable to the EBDA project. Considerations to be covered for each material are: field performance experience; ability to perform under conditions of differential settlement, high ground water and weak soils; ability to resist internal and external corrosion including very corrosive soils, some having pH values as low as 4.5; and water tightness.

An introduction provides a description of the specific requirements of this project and a summary of the recommendations of the Soils Study and the Corrosion Study as they affect installation and performance of pipelines.

A materials survey describes the various kinds of generally suitable pipe materials available, their physical properties and field installation requirements.

Costs have not been included in this study because the extraordinary soil conditions encountered have generated the necessity of requiring non-standard pipe design properties for which the various manufacturers contacted (except for concrete pipe) have been unable to cost out in time for this study. It is expected that these material costs will be available in the very near future providing, if the information received warrants further consideration, the necessary data for the issuance of an addendum to this study along with a cost effectiveness evaluation. It is not expected that the addendum will be available for issuance in time for the Oro Loma to Hayward bid openings but will probably be available for consideration for the remaining portions of the pipeline project.

Other considerations to be evaluated are: the alternative methods of jointing available for each material and the probable performance of these joints under expected conditions of differential settlement, and the alternative methods available for each material to resist joint separation at bends due to unbalanced thrust loads.

With the available evaluations described above, the final objective is to select for inclusion in the contract documents those materials deemed both functionally satisfactory and cost effective.
SECTION 2

INTRODUCTION

In this section the pipeline project scope and service conditions are discussed. Also the field conditions for the project are discussed to provide the framework within which the various pipe materials considered are to be evaluated.

2.1 Pipeline Project Scope and Service Conditions.

A major portion of the EBDA Phase I Project consists of constructing approximately 130,450 feet (approximately 25 miles) of on-shore force mains in sizes ranging from 39 to 96 inches in diameter. Lengths of each size, as shown in Table 1, indicate approximately 30 percent of the total in each of the 39, 48 and 60 inch sizes, 9 percent in the 96 inch size and a very small amount of 36 inch. Figures 1 and 2 show the force main plan and schematic diagram of the overall project.

Service conditions for the force main are conveyance of secondary treated sewage from Alvarado north and raw sewage south of Alvarado. That is, all of the 60 and 96 inch pipe and 11,500 feet of the 48 inch pipe will be in treated sewage service and all of the 39 inch and 28,200 feet of the 48 inch will be in raw sewage service.

TABLE 1

ON-SHORE FORCE MAIN PIPE QUANTITIES

<table>
<thead>
<tr>
<th>Diameter, inches</th>
<th>Length, feet</th>
<th>Percent of Total Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>150</td>
<td>0.1</td>
</tr>
<tr>
<td>39</td>
<td>40,800</td>
<td>31.3</td>
</tr>
<tr>
<td>48</td>
<td>39,700</td>
<td>30.4</td>
</tr>
<tr>
<td>60</td>
<td>38,500</td>
<td>29.5</td>
</tr>
<tr>
<td>96</td>
<td>11,300</td>
<td>8.7</td>
</tr>
<tr>
<td>TOTAL</td>
<td>130,450</td>
<td>100</td>
</tr>
</tbody>
</table>
TOTAL ON-SHORE LENGTH 130,300 FEET

TREATED SEWAGE — FLOW IN EITHER DIRECTION

RAW SEWAGE — FLOW TO NORTH ONLY

11,500’  11,300’  38,500’  28,200’  40,800’

48”  36”  50”  48”  30”

SAN LEANDRO PS

OUTFALL

ORO LOMA PS

HAYWARD PS

ALVARADO PS

NEWARK PS

IRVINGTON PS

SOILS REPORT, MAR. ’76
CORROSION STUDY, AUG. ’76

TENTATIVE PROFILE, JUNE ’76

ESTIMATED SOIL CONDITIONS

SHALLOW BAY MUD
CLAY
BAY MUD
CLAY
50% BAY MUD
30% BAY MUD & SOFT ALLUV
LITTLE BAY MUD OR SOFT ALLUVIAL

* 150 FEET OF 36 INCH NOT SHOWN FOR CLARITY.

ON-SHORE FORCE MAIN SCHEMATIC
Topography throughout the entire length of the pipeline is essentially flat with the ground surface elevation ranging from a few feet to 15 feet above sea level. The static lift at each pump station is essentially limited to the incremental depth required for wet well operation. 10 feet or less. The pipeline sizing given in Table 1 is based on a design hydraulic grade line at each pump station not to exceed 50 feet above the force main and a Manning's friction coefficient of .013. A unique design requirement of the portion of line from Alvarado to the Outfall junction is that the line be capable of conveying reclaimed wastewater in the opposite direction in the future, thus exposing both ends of these lines to the maximum hydraulic grade line. The portion from Irvington to Alvarado, which is to convey raw sewage, is not contemplated to have a future reverse direction use.

Preliminary profiles and hydraulic calculations indicate that the lines will operate as force mains flowing full through almost their entire lengths, with less than full flow taking place only immediately upstream from points of discharge at wet wells.

Provisions for surge control are being incorporated in the design. It is expected that actual positive and negative surge pressures will be limited to negligible increments above and below steady state conditions.

2.2 Field Conditions.

A definitive soils report along the proposed force mains has been completed for the section 33,500 feet long from the San Leandro Pump Station to the Hayward Pump Station (Ref. i). The soils report indicates a general condition consisting of a basement of clay with sand lenses overlain in part with bay mud and man-made fill. The man-made fills are relatively thin ranging from several feet to 10 feet and exist over approximately half the length in this section. Bay mud ranges up to 20 feet deep and exists over approximately 65 percent of the portion addressed in the report.

Soils reports are currently under way for the remainder of the pipeline from Hayward Pump Station south to Irvington. The preliminary evaluation of soil conditions south of Hayward Pump Station indicates generally similar conditions but with a trend toward less bay mud as the line progresses south. Between Hayward and Alvarado Pump Station, bay mud to 20 feet depth is expected for about 50 percent of the section. From Alvarado to Newark Pump Station, bay mud and soft alluvial material of corresponding strength are expected to be encountered over 30 percent of the section. South of Newark Pump Station to the southern terminus at Irvington Pump Station, some bay mud or soft alluvial is expected, primarily at creek crossings. These estimates of soil conditions are summarized in Figure 2.

Comparison of the tentative profile for the 60 inch main from Hayward to Oro Loma Pump Station (10,300 feet) within the 33,500 foot section covered by the available soils report indicates that the expected soil conditions will be in the following proportions:
Soil Condition                        Percent

Pipe invert and spring line
in bay mud                           24

Pipe invert on clay but spring
line in bay mud                       50

Pipe invert and spring line in
clay                                      26

100

This selected length of tentative profile also indicates that depth of pipe cover will range from 3 feet to 16 feet. The soils report states that ground water elevation should be regarded as between 100 and 105 (MSL Datum plus 100). The tentative profile shows that the pipe spring line will be below elevation 100 throughout and that the crown will likewise be below 105. Based on this sample length, all installation could be expected to be below groundwater with practically all pipe subject to saturated conditions to above the crown after installation. Since the section from Hayward to Alvarado Pump Station is estimated to have similar proportions of bay mud, the entire 60 inch section will probably encounter construction conditions similar to that indicated by the section tentatively profiled.

Figure 2 indicates that the 48 inch line from San Leandro to the Outfall will be generally free of bay mud conditions but that the 96 inch line from the Outfall to Oro Loma will be entirely in bay mud. Due to the 8 foot pipe diameter, the invert of the 96 inch would appear to be at or near the bottom of the mud throughout most of the section except for two reaches of about 1000 feet each where the mud extends to 20 foot depths.

The 48 inch between Alvarado and Newark is expected to be in mud or similar materials for about one third of this 28,200 feet run. The 39 inch south of Newark is expected to be free of mud conditions except at isolated locations.

The above described expected conditions by pipe size are summarized in Table 2. The summary indicates that approximately 10,000 feet of the 48 inch and smaller will be exposed to bay mud or similar conditions but that approximately 50,000 feet of these sizes should be free of the mud condition. On the other hand, the 60 inch appears to be evenly divided at 19,000 feet in each kind of exposure and the entire 11,300 feet of 96 inch in bay mud. All pipe, regardless of size, is expected to be installed below the ground water surface with the possible exception of some of the 48 and 39 inch which are in areas of slightly lower (elevation 98) ground-water conditions.

Surface improvements can impact pipe material suitability through requirements for trench width and backfill supporting strenth. Except for approximately 5000 feet of 48 inch pipe in San Leandro and approximately 2000 feet of 39 inch pipe in Newark, the proposed force main is not in or
### TABLE 2

**APPROXIMATE SOILS CONDITIONS BY PIPE SIZE**

<table>
<thead>
<tr>
<th>Pipe Size, inches</th>
<th>Expected Lengths, feet</th>
<th>Bay Mud</th>
<th>Clay or Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>39</td>
<td>Undetermined, Small Part</td>
<td>40,000+</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>9,700+</td>
<td></td>
<td>30,000+</td>
</tr>
<tr>
<td>60</td>
<td>19,500+</td>
<td></td>
<td>19,000+</td>
</tr>
<tr>
<td>96</td>
<td>11,300+</td>
<td></td>
<td>None</td>
</tr>
</tbody>
</table>
closely parallel to roads. The remainder of the force main is through unimproved areas except for crossings of roads, highways and railroads along the 25 mile route. Therefore, the predominant installation conditions for all sizes can be described as open and unimproved.

Studies of corrosion potential along the pipeline route are currently underway. One study on the San Leandro to Hayward Force Main has been completed indicating that typical conditions of concern throughout the alignment are: old garbage and debris dumps; proximity of the bay; parallel high voltage lines and/or crossing cathodically protected lines; and low pH conditions. (Ref. 2). Therefore, external as well as internal corrosion resistance will be a strong factor in pipe materials evaluation.

Specific properties of the various soils encountered and recommended construction methods are given in the Soils Report for the San Leandro to Hayward section. The properties that impact performance of various pipe materials are (1) expected differential settlement, (2) passive resistance to horizontal thrust, (3) passive pressure to provide lateral support to the pipe wall, (4) liquefaction potential and forces, (5) buoyant forces, and (6) dewatering.

2.3 **Soils Report Recommendations** (Ref. 1).

Following are the Soils Report recommendations summarized for the two most prevalent soils conditions, bay mud and clay, assuming installation in unimproved areas with pipe installation and inspection in the dry. Note that these requirements are for pipe materials classified as "rigid" and a different design will be required for "flexible" conduits.

1. **Trenching**
   
   a) Bay mud requires 2:1 trench slopes where there is no fill overburden
   b) Clay requires 1/2:1 trench slopes

2. **Bedding and Backfill**

   For both clay and bay mud, compacted select materials from spring line to six inches below the bottom of the pipe. Refer to Figure 3 for material description and required compaction.

   For "flexible" conduits it is anticipated that the top of the Type B bedding material would extend up to approximately 0.7 D above the pipe outside invert and extend horizontally to the trench sides. Also the trench floor may need to be considerably wider than that for "rigid" conduits.

2.4 **Corrosion Report Recommendations** (Ref. 2).

   The Corrosion Study identified three types of pipe materials that
<table>
<thead>
<tr>
<th>MATERIAL TYPE</th>
<th>GRADATION REQUIREMENT</th>
<th>COMPACTION REQUIREMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Gravel or crushed rock</td>
<td>100 percent passing 3/4 inch sieve</td>
<td>95 percent</td>
</tr>
<tr>
<td></td>
<td>Less than 10 percent passing No. 200 sieve size</td>
<td></td>
</tr>
<tr>
<td>B Sand, gravel or crushed rock</td>
<td>2 inch maximum size</td>
<td>95 percent</td>
</tr>
<tr>
<td></td>
<td>2 inch maximum size</td>
<td>95 percent</td>
</tr>
<tr>
<td>Clayey or silty soils</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BACKFILL</td>
<td>6 inch maximum size</td>
<td>None</td>
</tr>
</tbody>
</table>

* Refers to ASTM D1557-70(C) test method
can provide the necessary resistance to deterioration:

Reinforced Concrete Pipe
Fiberglass Reinforced Pipe, "CorBan"
Reinforced Plastic Mortar Pipe, "Techite"

In addition, it was found upon review of the preliminary designs for the project that certain other pipe materials are proposed for short sections of pump station discharge mains, blowoffs, couplings, air relieves, and access manholes. Specific recommendations to provide effective corrosion protection for each of these types of pipes are listed as follows:

1. Reinforced Concrete Pipe - The pipe should be rigid thick pipe to avoid deflection and cracking conforming to ASTM C361 with extra thickness of concrete. The reinforced concrete pipe should be fabricated from Type V sulfate resistant cement and utilize non-reactive aggregates to provide a dense non-porous condition. The concrete cover over the cage steel reinforcing bars should provide a minimum thickness of cover of 2-inches.

All exterior surface sections of reinforced concrete pipe should be coated with a coal-tar epoxy resin concrete sealer to provide a thickness of 24 to 30 mils applied in two passes over the finished concrete surfaces. An appropriate coal-tar epoxy resin sealer is Amercoat No. 1972-B.

The pipe joints or cage steel shall not be bonded to form a continuous conductive condition. Measures to provide future impressed current cathodic protection should not be provided; instead each pipe segment will be protected by the thick concrete cover and coal-tar epoxy coating.

Pipe fittings fabricated of steel pipe sections should also be provided with a minimum 2-inch thick external concrete cover over any steel and receive the same type of coal-tar epoxy resin coating as recommended herein for the pipe itself.

Double "O" Ring gaskets of synthetic rubber should be provided. The synthetic rubber should have properties highly resistant to oxidizing acids such as sulfuric and hydrochloric acid, hydrocarbon greases and solvents, and bacterial organisms. A chlorinated sulfonated polyethylene, Hypolon, is a suggested material. This can be confirmed with the pipe manufacturer when receiving proposals.

Transition joints between reinforced concrete and
steel cylinder pipe should receive special protection. The transition joint should be of carbon steel. A coal-tar epoxy coating to provide a minimum 20 mil thickness applied in two passes should coat the steel. A flexible polysulfide grout, Thiokol, should be packed into the joint to provide a tight seal. The outside of the joint should be double tape wrapped with polyethylene or polyvinyl chloride tape to provide a minimum thickness of 30 mils. Tape can be similar to Scotchguard 50 or 51 or Polyken 930.

2. Fiberglass Reinforced Pipe - CorBan pipe is a reinforced fiberglass pipe that can be fabricated to meet individual structural and corrosion resistant conditions. CorBan pipe is offered with three classes of liner, that may use either an isophthalic or vinyl ester resin of thickness from 10 to 100 mils. The structural core is composed of isophthalic resin with fiberglass filament wound reinforcing. An outer weather resistant lining containing an ultraviolet absorber is generally provided for the external surface.

In recognition of the external severe corrosion conditions as related to high brine, sulfates and sulfate reducing bacteria concentrations and probable presence of sulfuric acid, and petroleum solvents, a higher degree than normal of external protection is necessary. It will be very important to provide a stiff pipe to minimize deflections that could cause cracking and and exposure of filaments. The normal deflection allowance of 5% is considered excessive, and should be reduced to a maximum allowable deflection of 1%. This should be provided for pipe handling, transportation, placement and final installation.

It is recommended that the exterior coating of the pipe be formed of vinyl ester resin, Dow Derakane 411-50 or equal, of not less than 100 mil thickness, applied in two passes with a chopped strand fiberglass laminate of not more than 30% glass content. The coating shall be applied in such a manner that the minimum resin gel thickness over the plastic laminate reinforcing is 20 mils.

Either an additional external ultraviolet absorber 1/8-inch thick or a temporary protection of the resin coating shall be provided by the manufacturer to cover the acid resistant exterior coating described above.
The interior of this pipe shall also be provided with a protective lining of vinyl ester resin of 100 mil thickness to provide a maximum corrosion protection to the highly chlorinated wastewater effluent to be transported.

3. **Reinforced Plastic Mortar Pipe** - Reinforced plastic mortar pipe, Techite, is formed from a polyester resin, glass fiber, and sand. This pipe, similar to CorBan, can be fabricated to minimize deflection and with special protective linings and coatings.

It is recommended that the deflection allowed for this pipe be reduced from the manufacturer's suggested maximum of 4% to not more than 1% to provide a rigid non-cracking exterior surface. Again the key to successful corrosion protection is to provide a thick flexible coating over the structural fiberglass reinforcing. A vinyl ester or an alternative resin material of equal corrosion resistance to oxidizing acids, brine, solvents and bacterial decomposition should be used as a protective coating on the exterior of the pipe. The resin should provide a minimum of 100 mils thickness over fiberglass reinforcing. In addition, an ultraviolet or temporary protective shield coating should be provided for this pipe, similar to that recommended herein for the CorBan pipe.

The interior coating of this pipe should provide a minimum 100 mil thickness of resin gel coat over fiberglass. The resin should be a vinyl ester or equivalent thermosetting resin.

Rubber gaskets for the pipe should be resistant to sewage deterioration, a chlorophene rubber or equivalent to provide a high durability to organic solvents, oxidizing acids, and chlorine.

4. **Ductile Iron or Steel Pipe** - There are small sections of ductile iron and steel pipe utilized for blowoff, air vent, and related service. These should be protected by galvanizing or coating with an inorganic zinc primer with a coal-tar epoxy top coating followed by field wrapping with a double layer of half lapped polyethylene or polyvinyl chloride tape.

Bolts and nuts for ductile iron or steel pipe
SECTION 3
SPECIAL PROBLEMS

There are several special problems that are unique to the EBDA pipeline route that have an impact on pipe material suitability. These are differential settlement, thrust at the bends, pipe floatation or buoyancy, corrosion, water hammer force resistance, seismic activity and watertightness. Each is discussed in detail in the following paragraphs.

3.1 Differential Settlement.

This problem is acute because of the presence of soft low-strength bay muds. The main problems occur at the point of attachment of the pipelines to rigid structures and where a transition occurs between the bay mud and a firmer soil that affords little settlement.

Attachment of the pipelines to the firmly founded pumping stations will have to be designed with great care so as to prevent pull-out or outright breakage as the pipeline settles relative to the structure. To a lesser degree the same phenomena can be expected to occur at manhole locations. While the manholes will be supported by the pipe as opposed to independent support they will in effect constitute a point load tending to cause differential settlement. It is expected that vertical skin friction will help to mitigate the point load effect but careful design will be necessary to prevent differential settlement induced pipe shape distortion at nearby joints to a degree allowing leakage.

3.2 Bend Thrust.

Given the size of pipelines and the large flows under pressure, the thrusts developed at sharp bends can be expected to be large. Consequently a conventional concrete thrust block would be quite large and heavy, possibly requiring support to prevent sinking, and in turn introducing the problem of differential settlement between the rigid block and the floating pipeline. Because it is desirable that the pipeline act as a continuous flexible structure, it is deemed essential that the thrust should be taken up by the pipeline itself.

This can be accomplished by utilizing long radius curves consisting of a series of small bends or by restrained joint elbows. Regarding the former, long term creep analysis indicates that the creep will not exceed the allowable 1 inch joint pull out at 2-1/2 degree bends. In areas where both a vertical and horizontal long radius curve are needed the two should not be combined because of the complex and costly pipe barrel alignment required. The best method from an ease-of-construction standpoint, if sufficient self-contained joint restraint can be attained, would be single elbows per pipeline bend.
3.3 Flotation.

As previously mentioned most of the pipeline is subject to a high groundwater table throughout the year because of the proximity of the San Francisco Bay. In several areas the groundwater table is at the ground surface and in other areas the ground is flooded. Combined with this are the low unit weight bay muds. Thus, in these areas where shallow pipe cover will be used, the potential of pipe flotation during construction, during periods of non-use (due to construction scheduling), or during periods of short-term shutdown, is extreme.

In the case of a light weight pipe material special consideration must be given for controlling flotation, such as concrete encasement. Point anchoring such as with concrete saddles or augers is not recommended as it would reduce pipe flexibility, induce point stressing and differential settlement and restrict freedom of movement.

3.4 Corrosion.

As previously mentioned, corrosion studies of the entire pipeline are not yet complete except for the San Leandro to Hayward Pump Station portion (Ref.-2). The completed study is considered indicative of the general corrosion problem.

Detailed interpretation of the corrosion problem is available in the report but, to summarize, the study indicates a generally highly corrosive condition with a degree of variability associated with whether the pipe is in bay mud, native clay and sand, garbage fills or rubble fill areas. Over 50 percent of the San Leandro to Hayward pipeline route is located in or adjacent to garbage fills with the attendant problem of active anaerobic decomposition. Portions of the pipeline are subject to tidal fluctuations causing alternate aerobic and anaerobic cycles. The above reported corrosion conditions of the soil are classified as very severe to ferrous and concrete piping materials and corrosive to some extent to polyester and fiberglass piping materials as well. In addition ground currents will be induced by the nearby high voltage transmission systems and existing cathodically protected pipelines.

Recommendations for corrosion control with regard to specific pipe materials are discussed in the following section of this study.

3.5 Water Hammer.

A special consultant, Mr. John Parmakian, analyzed the entire EBDA Phase I Project force main for the potential and control of water hammer. His recommendations are (1) that either standpipes or quick-opening/slow-closure valves be used to control surge and column separation with the former preferred for 100% reliability and (2) that the pipe design vacuum be approximately equivalent to 2 atmospheres (approx. 30 psi) for surge control by standpipes or 3 atmospheres (approx. 45 psi) for surge control by quick-opening/slow-closure valves. While these
designs for vacuums at first appear to be high it must be kept in mind that pipeline failure risk must be absolutely minimal as the entire force main system is being built without redundancy and that very large masses of water will normally be in motion.

Standpipes are preferred because of their inherent maximum reliability due to requiring no external aid to function. Valves can and sometimes do fail. Initial study indicates that the largest standpipes would be approximately 20 feet in diameter and 50 feet high. The final approval for the recommended standpipes is currently under consideration with KBDA.

3.6 Seismic.

The primary seismic concern for on-shore pipelines is damage induced by liquefaction of the backfill, bedding and/or foundation soils. Liquefaction can occur in loose, saturated, uniform grain-size granular soils during seismic activity resulting in increased buoyant forces because the liquefied material acts as a heavy viscous fluid (Ref. 1). Following the seismic activity ground subsidence could also occur.

Liquefaction can be mitigated using gravel or crushed rock for bedding and side backfill and sandy, silty clayey soils for the remainder of the trench backfill. If such a backfill system is deemed necessary it would be helpful in reducing the buoyancy potential because of the higher unit weight than that of bay mud.

3.7 Watertightness.

Minimal leakage is necessary on the on-shore portion of the pipeline because a large portion of the line will be below the existing groundwater table at all times. This condition will tend to allow the leakage to build up in place rather than percolate downward. It is recommended that the specifications limit the allowed leakage to 100 gallons per day per inch diameter per mile of pipe.
SECTION 4

PIPE MATERIALS SURVEY

In this section candidate types of materials which were considered are introduced and discussed in detail sufficient to allow comparison and selection of the most suitable pipe material(s). Comparison of the candidate pipe materials will be made on the basis of their individual physical properties, experience and expected performance under the previously described field conditions and special problems.

4.1 Candidate Pipe Materials.

For the required size range of 36 inch through 96 inch and design working pressure up to 75 feet or 33 psi, the following materials are available over a portion or all of the size range.

1. Reinforced concrete pressure pipe (RCPP)
2. Reinforced concrete cylinder pipe (RCCP)
3. Prestressed concrete pipe, embedded cylinder type (PCPE)
4. Pretensioned concrete cylinder pipe (PCCP)
5. Cement mortar lined and coated steel pipe (CMLC)
6. Reinforced plastic mortar pipe (RPMP)
7. Fiberglass reinforced plastic pipe (FRPP)
8. Asbestos cement pipe (ACP)
9. Ductile iron pipe (DIP)
10. Corrugated steel pipe, asphalt lined and coated (CSP)

Pipe materials are designated as "rigid" or "flexible" conduits for design purposes. Rigid conduits are those whose materials allow essentially zero deflection under loading and transfer very little of the imposed loading to the surrounding soil envelope. Examples of rigid conduit materials are RCPP, RCCP, PCPE and PCCP. Flexible conduits are those whose materials allow relatively large deflections (up to 5 percent) under loading and transfer a proportional amount of the imposed loading to the surrounding soil envelope (Ref. 3). Examples of flexible conduit materials are CMLC, RPMP, FRPP, ACP, DIP and CSP. Normally the choice of materials depends on the trade-offs between the lightweight thin wall flexible conduits requiring very strict backfilling and trenching against the heavyweight thick wall rigid conduits requiring relatively less stringent backfilling and trenching. In the case of the EBDA Project additional considerations are the low strength in situ soils, the highly corrosive conditions and the high flotation potential.

4.1.1 Reinforced Concrete Pressure Pipe (RCPP). This product is a reinforced concrete pipe without a steel cylinder and without prestressing or pretensioning elements. The pipe wall consists of concrete with a steel bar reinforcing cage. The design and manufacture are covered by the following standard specifications:
AWWA C 302  
ASTM C 361  

Trade designations for this pipe by Ameron and the Concrete Pipe Division of U.S. Pipe are both listed as Reinforced Concrete Pressure Pipe.

This material is a made-to-order product available throughout the entire required size range of 36 through 96 inches. Available joints include single and double O-ring gasketed types entirely of concrete or made with steel spigot and bell rings. End bevels are available for both kinds of joints at 2°30' and 5°00' angles.

Lengths are 20 to 24 feet maximum in sizes through 60 inch but the 96 inch size would probably be limited to 16 feet due to highway weight restrictions.

Pipe wall designs are available for heads up to 150 feet combined with various D-load crushing strengths.

Typical leakage specifications for this material are 125 to 150 gallons per inch diameter per day per mile.

RCPP is classified as a rigid conduit for determination of safe support of external loads.

4.1.2 Reinforced Concrete Cylinder Pipe (RCCP). This product is a reinforced concrete pipe with a steel cylinder but without prestressing or pretensioning elements. The pipe wall consists of concrete with a steel bar reinforcing cage and a thin embedded steel cylinder. The design and manufacture are covered by AWWA Standard C 300.

Ameron regards RCCP and RCPP as variations of "Reinforced Concrete Pressure Pipe." The Concrete Pipe Division of U.S. Pipe designates RCCP as "Reinforced Concrete Cylinder Pipe" (not to be confused with Ameron's "Concrete Cylinder Pipe" which is PCCP).

The available size range includes 36 through 96 inches. Available joints include single and double O-ring gasketed types made with steel spigot and bell rings welded to the embedded cylinder. End bevels are available at 2°30' and 5°00' angles.

Lengths are 20 to 24 feet maximum in sizes through 60 inch but the 96 inch size would probably be limited to 16 feet due to highway weight restrictions.

Pipe wall designs are available for heads up to 150 feet combined with various D-load crushing strengths.

Typical leakage specification for this material is 25 gallons per inch diameter per day per mile.
RCCP is classified as a rigid pipe for determination of safe support of external loads.

4.1.3 Prestressed Concrete Pipe, Embedded Cylinder Type (PCPE). This product has a pipe wall that consists of an unreinforced concrete core with an embedded steel cylinder which is circumferentially wrapped with prestressed steel wire protected by concrete mortar. The design and manufacture are covered by AWWA Standard C 301. This standard also covers another variation of this type designated as lined cylinder type. This lined cylinder type is not included as a separate type since it has not been available in California and is for use in sizes up to 48 inch only.

PCPE is identified by Ameron as "Prestressed Concrete Pipe" and by the Concrete Pipe Division of U.S. Pipe as "Embedded Cylinder Prestressed Concrete Pipe."

PCPE is available throughout the required size range of 36 through 96 inches. Available joints include steel spigot and bell rings welded to the ends of the core cylinder provided with either single or double gasket rings. End bevels are available at 2°30" and 5°00.

Lengths are 20 to 24 feet maximum in sizes through 60 inch but the 96 inch size would be limited to 16 feet maximum due to highway weight restrictions.

Typical leakage specification is 25 gallons per inch diameter per day per mile

PCPE is classified as a rigid pipe for determination of safe support of external loads.

4.1.4 Pretensioned Concrete Cylinder Pipe (PCCP). PCCP consists of a steel cylinder with a pretensioned reinforcing rod wrap, cement mortar lined and coated. The steel cylinder and the pretension rod wrap share in resisting the hydrostatic forces. This product is covered by the following standard specifications:

AWWA C-303
Federal Spec. SS-P-381a

Trade designations for this pipe are: by Ameron, "Concrete Cylinder Pipe" and by Concrete Pipe Division of U.S. Pipe, "Shot-cote Pretensioned Concrete Cylinder Pipe."

The standard specifications cover sizes only up to 42 inch. Both Ameron and U.S. Pipe provide special design for sizes through 72 inch. Through 42 inch the resultant pipe is regarded as "rigid" for shallow depths of cover. Beyond 42 inch, flexibility is considered and becomes an element in design so that projected installation conditions as well as hydrostatic pressure are design elements.
Standard joint details are for a single rubber gasket but double gasketed joints can be provided. Bevels at the ends can be provided at any required angle from 0 to 5 degrees.

4.1.5 **Cement Mortar Lined and Coated Steel Pipe (CMLC).** CMLC consists of a steel cylinder designed to resist all of the hydrostatic forces with a cement mortar lining and coating primarily to provide protection against corrosion. The lining is unreinforced and the coating is reinforced only to prevent cracking of the mortar. Some added stiffness is an incidental result of the lining and coating.

The design and manufacture of CMLC pipe is covered by the following standard specifications:

AWWA C 200 and C 205
Federal Specifications SS-P-385a.

The trade designation for this pipe by Ameron is the same as this paragraph heading and by the Concrete Pipe Division of U.S. Pipe is "Hi-Flo Steel Pipe, Cement-Mortar Lined and Coated."

Up to 42 inch size, this product has sufficient stiffness to be regarded as a rigid conduit for nominal depths of cover. Beyond 42 inch concerns for stiffness become important and, unless the internal pressure is extremely high requiring a very thick cylinder, the design approach becomes similar to pretensioned concrete cylinder pipe. Unlike PCCP, this product is not offered in larger sizes as a special design.

Standard joint details are for a single rubber gasket but double gasketed joints can be provided. Bevels at the ends can be provided at any required angle from 0 to 5 degrees.

4.1.6 **Reinforced Plastic Mortar Pipe (RPMP).** This material consists of a structural wall composed of thermosetting resin reinforced with sand, chopped glass strand and wound glass filament. A resin rich liner layer is provided for corrosion resistance. There is no standard specification for a pressure pipe of this general type. (There is an ASTM specification D 3262 for gravity flow type pipe in sizes 8 inch through 48 inch.) Pressure pipe of this type is manufactured by Amoco in sizes 8 through 60 inch under the trade name "Techite" and by Owens/Corning in sizes 24 through 78 inch as "Fiberglass Flowtite Sewer Pipe."

The Amoco product has been offered for this project in sizes through 96 inch based on a proposed revision of ASTM 3262 and is also offered with double ring gasketed joints in 66" through 96". Joint lengths are 20 feet and the deflection per joint is 1°40' for 39", 1°24' for 48" and 2° for 60".

RPMP is classified as a flexible pipe for determination of safe external loads.
4.1.7 Fiberglass Reinforced Plastic Pipe (FRPP). This product consists of a structural wall composed of closely spaced continuous glass filaments wound on a mandrel under tension in a thermosetting polyester resin. There may be in addition to the cylindrical structural wall, circumferential reinforcing ribs of the same material. A resin rich liner with a glass surfacing veil and chopped strand protects the structural cylinder on the inside. An external resin rich layer is provided for external protection. There are no inert filler materials.

There is no single standard specification for the total product. The product is designed to order to suit the particular hydraulic, external loading and soil properties for the specific project. The largest and most experienced purveyor of FRPP is CorBan Industries. The CorBan specification contains the requirement that the filament reinforcing be wound at a helix angle of not less than 74° and that no chopped strand or filler be permitted. It also requires that bell ends be fabricated integral with the pipe cylinder. These requirements distinguish the CorBan product from that manufactured by Owens/Corning under the trade name Fiberglass Flowtite Pressure Pipe. The Owens/Corning product is made with a 90° winding of glass filament and chopped strands and has a bell added after the pipe is finished. The two products are sufficiently different that they should be regarded as different alternative materials. The trade name is suggested for attachment to the generic description to distinguish the two: FRPP C/B of CorBan and FRPP O/C for Owens/Corning.

FRPP C/B has been fabricated in sizes up to 144 inch for pressures up to 70 psi. Normal lengths are 60 feet.

Available joints include bell and spigot for internal or external resin and fiberglass sealing and bell and spigot single or double ring gasketed. The single gasket permits a deflection of 3° and the double gasket, 2°. End bellwals are not available as a standard item.

Typical leakage specifications are 50 gallons per inch diameter per mile per day or less.

Supporting strength calculations are based on flexible conduit theory.

4.1.8 Asbestos Cement Pipe (ACP). This material is available as pressure pipe only to size 36 inch at present. It is possible that 42 inch size may be made available in 6 month to a year.

4.1.9 Ductile Iron Pipe (DIP). This material is available only to size 36 inch. Cast iron pipe, which was manufactured in larger sizes through 54 inch, is no longer produced in any size.

4.1.10 Corrugated Steel Pipe (CSP). This material is normally offered for pressure service up to 30 feet but is being used in two recent jobs at pressures up to 40 feet. This would apply only to a corrugated product with welded seams and is not applicable to riveted or folded seams. Leakage criteria proposed by Armco Metal Products Division for their HEL-COR pipe with smooth-
flow lining is 100 gallons per inch of diameter per day per mile at 30 feet of head using their hugger O-ring sealed coupling band.

The above described Armco product would consist of galvanized steel plate with helical corrugations and a welded helical seam, asphalt coated and asphalt lined to fill the interior corrugations to a smooth bore. Their asbestos bonded galvanized steel is not available in HEL-COR pipe, only in radial corrugated with riveted seams and not suitable for pressure service.

CSP is available in sizes through 96 inch in 24 foot lengths.

Recent pressure applications using CSP are (1) a power plant cooling water intake, fresh water service, in Oregon using 2000 feet of 96 inch at 40 feet (Bechtel Corp.) and (2) a temporary (5 year) sewer bypass in Sacramento using 36 inch at 30-40 feet head (Brown and Caldwell).

CSP is classified as a flexible pipe for determination of safe external loads.

4.2 Joints.

Because of the poor field conditions pipe joints are especially important in the EBDA project. The major concerns are thrust control, flexibility, and field testing. Slip-on joints are preferable because of their relative flexibility. However, thrust control is most easily solved with restrained joints such as flanged or welded or harnessed joints. From a field testing standpoint the double gasket bell and spigot joint is preferred because testing can be done at the joint eliminating the need for filling the pipeline as done in a conventional hydrostatic field test. Metallic joints would not be acceptable due to the corrosion problem.

For straight runs the double gasket bell and spigot joint is recommended. For bends utilizing long radii and small deflections to control thrust the same joint is recommended. For bends using a few or one sharp deflection the harness welded joint available with FRPP or RPMP is recommended because of its resistance to corrosion.

4.3 Corrosion.

Many of the candidate pipe materials can be immediately eliminated because of the severe corrosion conditions expected on this project. Those pipe materials to be eliminated on this basis include RCCP, PCPE, RCCP, CMTG, DTP and CSP. All of these are essentially steel pipelines requiring prohibitively expensive cathodic protection. Cathode protection introduces a liability question where crossing existing cathodically protected lines because the potential exists for the EBDA pipeline cathodic protection system to overwhelm the existing pipeline's systems.

To meet the corrosion protection requirements RCPP will be required to have a minimum of 2 inches cover over the rebar and the exterior coated with 30 mils of coal-tar epoxy. FRPP and RPMP will be required to be designed to allow no more than 1 percent deflection for protection of
the structural fiberglass reinforcing and have a 100 mil thick external and internal flexible coating of vinyl ester or equal alternative resin. For additional requirements see Ref. 2.

From a corrosion economics and impact standpoint the recommended candidate pipe materials are concrete-to-concrete joint RCPP, FRPP, RPMP and ACP.

4.4 Buoyancy.

The easiest buoyancy control method is pipe weight. From a total pipe integrity standpoint RCPP has a clear advantage.

Calculations of needed buoyancy off-set cover for standard RCPP, FRPP and RPMP, without any buoyancy control aids such as concrete saddles or encasement on tie-down augers, show that in bay mud with empty pipe and groundwater table at ground surface, RCPP needs 0 to 0.3 D cover, FRPP needs approximately 1.5 D cover and RPMP needs slightly less cover than FRPP. With proper design however, such as concrete encasement, light weight pipe materials such as FRPP and RPMP can be expected to compare with RCPP in required buoyancy off-setting cover depths.

Buoyancy control for FRPP and RPMP has not been fully resolved in time for this report mainly because of the severe corrosion problems requiring extensive economics analysis for trade-offs to meet the flexible conduit deflection requirements and control of buoyancy.

4.5 Conclusions.

Based on the preceding only RCPP, FRPP, and RPMP type pipe materials are considered viable candidates for the EBDA Phase I Project force main pipelines.

RCPP with concrete-to-concrete double gasket joints furnished with 2 inches minimum rebar cover and 30 mils coal-tar epoxy external coating with 2-1/2 degree beveled spigots for bends is recommended for the first 10,000 foot section of 60 inch diameter force main between Oro Loma and Hayward Pump Station. This project is due for Contract Drawings and Specifications submittal on September 30, 1976. Because of timing FRPP and RPMP should be still considered for inclusion in this first portion of the EBDA Project in the form of an addendum if the problems of buoyancy and minimal deflection can be resolved satisfactorily. FRPP and RPMP do have a somewhat superior potential for satisfactory service under the highly corrosive field conditions and should be given careful consideration. However, we must consider the extent and field experience of the installed pipe of this type and size, and whether or not satisfactory service life has been demonstrated.
SECTION 5

SUMMARY

5.1 Findings.

The following existing conditions were found after extensive field and office investigations had been completed.

1. The soil strength is generally quite poor consisting predominantly of bay mud, old bay clay, garbage fills and rubble deposits.

2. The soil is classified as highly corrosive, chemically and biochemically, and subject to stray currents induced by adjacent power transmission lines.

3. There are a number of existing cathodically protected pipelines that must be crossed by the EBDA force main.

4. The groundwater table is generally quite high posing an all year long buoyancy problem.

5. Conventional thrust blocking is not applicable due to the poor soils.

6. Water hammer must be mitigated to a greater degree than normal due to the vital function of this single conduit resulting in the requirement for pipe materials and design to withstand two to three atmospheres of vacuum pressure depending on the surge protection system to be used.

5.2 Recommendations.

Based on this study the following recommendations are offered.

1. That reinforced concrete pressure pipe (RCPP) with concrete-to-concrete double gasket joints, 2 inches minimum rebar cover, 30 mils coal-tar epoxy external coating and 2-1/2 degree spigots for bends, be furnished for use in the first 10,000 feet of 60 inch diameter force main between Oro Loma and Hayward Pumping Stations.

2. That fiberglass reinforced plastic pipe (FRPP) and reinforced plastic mortar pipe (RPMP) be further considered as an alternative to RCPP for the remainder of the EBDA Phase I Project Interceptor force mains, if and when the designated product suitability for this project is demonstrated. This would include solutions to the 1% deflection requirement, flotation resistance, corrosion resistance, cost-effectiveness, and proof of long term experiences in
the production and installed service life of this size of force main under similar installation conditions.

3. That single gasket bell and spigot joints be used for pipe sizes 39 inches and less in diameter and that double gasket bell and spigot joints be used for pipe sizes 48 inches and more in diameter.

4. That allowable leakage should not exceed 100 gallons per day per inch diameter per mile.
SECTION 6

REFERENCES

The following references were used for specific documentation of this study:


The following references were used to provide background information for this report:


2. CorBan Industries, Design Standards for Burial of Large Diameter Fiberglass Reinforced Plastic Pipe, Date Unknown.


