

## SAN FRANCISCO'S SOUTHWEST OCEAN OUTFALL

by Y. Eisenberg<sup>1</sup>, M.ASCE  
and D. D. Treadwell<sup>2</sup>, M.ASCE

### ABSTRACT

The Southwest Ocean Outfall, with an overall length of 23,400 feet and a capacity of 450 million gallons per day, will be a major element of the Clean Water Program of the City and County of San Francisco, California, U.S.A. Offshore, the Outfall will cross one of the world's major active fault zones, the San Andreas.

Outfall construction started in 1981 and is scheduled to be completed by early 1985. The shoreward 3,000 feet is being built from a pile-supported trestle; offshore, the Outfall conduit sections will be placed using a barge designed and built specifically for the project. Oceanographic, coastal, geotechnical, and seismic conditions pertinent to design are presented along with discussions of specific Outfall design and construction features.

### INTRODUCTION

The Southwest Ocean Outfall is part of an improved system of collection, transportation, treatment, and disposal of sanitary and storm wastewater flows for the City and County of San Francisco. After passing through a system of transport lines, treatment plants, and tunnels, these flows will reach the Outfall, where they will be dispersed at a diffuser section located in the Pacific Ocean approximately four miles southwest of Lake Merced (Figure 1). About 8,700 feet offshore, the Outfall will cross the San Andreas fault zone, one of the world's major active faults.

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<sup>1</sup>Parsons Brinckerhoff, San Francisco, California.

<sup>2</sup>Woodward-Clyde Consultants, San Francisco, California.

The Outfall will be a single conduit composed of reinforced concrete pipe sections with an inside diameter of 12 feet extending about 23,000 feet offshore. The water depth at the Outfall terminus is about 80 feet. Throughout its length, the Outfall will be embedded in a trench excavated as much as 25 feet below the sea-floor. The design gravity flow rate of the Outfall system is 450 million gallons per day (about 700 cubic feet per second).

Starting in 1977, the project design team conducted various data acquisition and analysis programs (Belvedere et al, 1978; Treadwell et al, 1978; Murphy et al, 1979; Treadwell et al, 1980; Gilbert et al, 1981). The results of these studies were utilized in the planning, preliminary design, and final design efforts completed in late 1980.

The purpose of this paper is to describe the geotechnical, oceanic, coastal, and seismic conditions and their impact on the unique design features of this project. The first 18 months of Outfall construction are also described.

#### GEOTECHNICAL CONDITIONS

Prior to the studies and data acquisition programs associated with the Outfall project, very little information existed concerning geotechnical conditions offshore San Francisco. The offshore geotechnical investigations performed for the project included:

- o surf zone borings using a truck-mounted rotary drill rig on a self-propelled shallow-water work platform

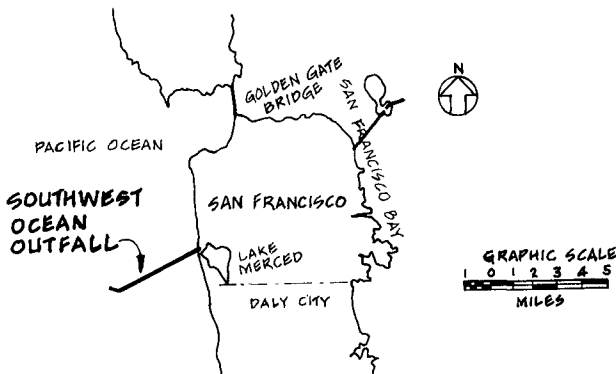


Figure 1 OUTFALL VICINITY MAP

- o offshore borings, vibratory corings, and cone penetrometer tests using a specially-equipped and modified drillship
- o marine geophysical surveys using an ocean survey vessel equipped with precision electronic navigation and fathometer systems as well as specialized seismic reflection, sonar, and magnetometer systems
- o test pit construction and monitoring using a derrick barge clamshell dredge and an ocean survey vessel

#### Offshore Soil Conditions

The offshore soils along the Outfall alignment are primarily dense to very dense fine sands. Within the surf zone, extending to about 4,500 feet offshore, the seafloor generally consists of a loosely consolidated layer of sand 2 to 8 feet thick, underlain by hard clayey silts and silty clays. These cohesive soils are underlain by dense to very dense sands with occasional lenses of fine gravel.

A thin veneer of loose surface sands was encountered along the entire alignment. This layer is typically 2 to 4 feet thick, but in localized areas is as much as 6 to 8 feet thick. Beneath the surface layer, the sands increase in density with depth, from medium dense to very dense.

From about 11,000 feet offshore and westward, the surface sands are underlain by medium stiff to stiff, moderately overconsolidated silty clays which grade to clayey and sandy silts at greater depths. The top of the clays appears to vary from 15 to 35 feet below the seafloor, based on the borings and geophysical data. The relatively level surface of these cohesive soils apparently represents an ancient shoreline.

#### Offshore Faults

Offshore fault zones located in the project vicinity are the San Andreas, Pilarcitos, and Seal Cove (Figure 2). The latter were found to be westward of the Outfall, thus efforts were focused on defining the width and orientation of the San Andreas fault zone at the Outfall alignment.

Between the surf zone and the San Andreas fault zone is a series of tightly-folded, thinly-bedded sediments. These sediments may be correlative with similar outcrops seen on the shore. The limbs of the folds dip approximately 10 to 20 degrees; the fold axes plunge to the northwest, and the width of the geological structures decreases toward the fault.

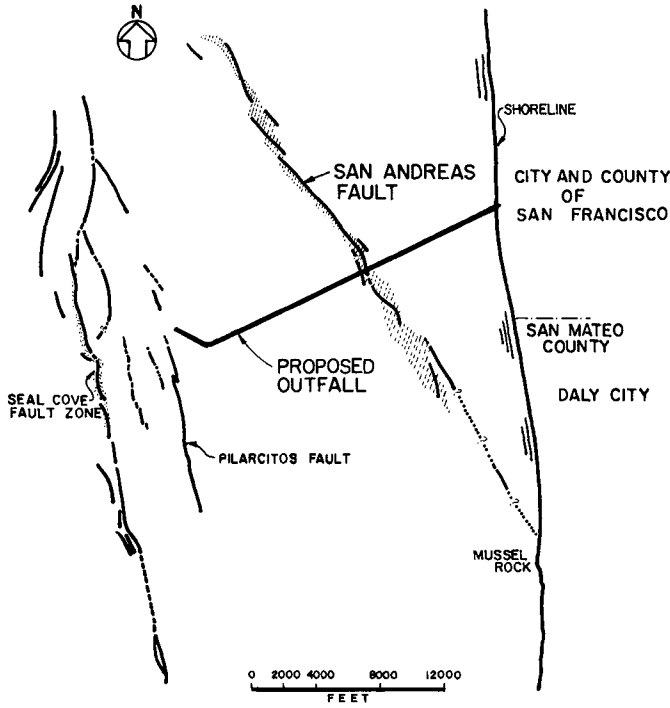


Figure 2 OFFSHORE FAULTS IN PROJECT AREA

In the vicinity of the Outfall alignment, the trace of the San Andreas fault is represented on the geophysical records by a blurred zone which does not show internal structure across the zone. This zone marks a transition between tightly-folded sediments to the east and relatively horizontally-bedded sediments to the west.

Along the Outfall centerline, the San Andreas fault zone was determined to be approximately 400 feet wide. The strike of the fault zone is approximately N39°W, which is 12 degrees west of perpendicular to the Outfall alignment.

#### OCEANOGRAPHIC CONDITIONS

A major factor in the design of the Outfall was the development of an understanding of the oceanographic conditions (e.g., wind, wave, current, tide, and water quality) likely to be encountered in the Gulf of the Farallones. These data were acquired and criteria developed through a variety of offshore sampling and analysis programs and reviews and evaluations of wave and storm records.

#### Monitoring Programs

A 13-month physical oceanographic monitoring program was conducted in 1977-78. Endeco current meters were installed and retrieved on a monthly basis from four fixed locations and two roving locations within the survey area (velocity and direction data were internally recorded every half hour by the meters). Density profiles and water quality samples were also taken on a monthly basis. In-situ measurements were taken of temperature and conductivity using an Inter-Ocean Model 513 CTD at selected depths and locations. The results of the measurements were converted to sigma-t (density) values.

Water quality samples were taken at selected locations and depths in the offshore project area. The water quality parameters analyzed were temperature, dissolved oxygen, conductivity pH, total coliforms, fecal coliforms, total suspended solids, settleable solids, turbidity, ammonia, nitrate, total phosphorous, chlorophyll, phaeophyton, and sulfide. The density profiling and water quality sampling programs were performed in cooperation with CH2M-Hill, Inc., the sanitary and hydraulic subconsultant to the design team.

On a less frequent basis, surface drifter and drogue studies were also performed. Surface drifters were plywood blocks painted a bright orange on both sides. Several drift block batches, from two to four in number (500 to 100 drift blocks each) were released in serial order during each drifter study. Ten-foot square windowshade drogues were also deployed, with releases during the three distinct

oceanic seasons, to measure current speeds and trajectories and eddy diffusivity.

#### Tides, Currents, and Wind

In the project area, tides vary over about an 11-foot range (about 8.05 feet above to 2.45 feet below MLLW), based on over 60 years of records at the Presidio tide gage near the Golden Gate Bridge. It is also expected that the sea level will rise about 6 inches in the 75-year design life of the Outfall.

Current velocity and direction were determined from the results of the oceanographic field data collection program. It was found that currents in the project area are dominated by the tidal influence and generally move toward the Golden Gate during a flood tide and away from the Golden Gate on an ebb. Currents greater than 1.0 knot occur less than one percent of the time.

Analyses of the current meter, drogue and drifter data indicated a net long term drift to the northwest (away from the shore). Winds are primarily from the west (toward the shore) and average 15 to 25 mph in warmer months and 10 mph in cooler months.

#### Waves

Determination of both normal and extreme wave conditions in the project area consisted of estimation of wave conditions offshore, in deep water, and transfer of these data to the nearshore. Extreme storm wave characteristics were developed based upon the selected design storm. The 8-hour design storm contained 3,141 waves with a significant wave period of 12 seconds; wave periods were expected to be primarily in the range of 7 to 14 seconds.

The design significant wave height at the diffuser location (80 feet of water) was predicted to be about 38 feet for the 100-year storm. For the 200-year storm, the significant wave height is expected to exceed 47 feet. The wave-induced currents at the seafloor are expected to be about 11 to 12 feet per second.

#### OUTFALL DESIGN

The Southwest Ocean Outfall is ultimately to be the terminus for all of San Francisco's sanitary and storm wastewater. Until recently, the existing combined wastewater disposal system caused severe pollution in San Francisco Bay and the surrounding shores. Every rainfall exceeding 0.02 inches per hour in intensity caused the system to overflow and discharge raw sewage into the Bay; on average, this used to happen about 80 times a year. The

Clean Water Program, of which the Outfall is an important part, is designed to remedy this condition.

The Outfall consists of a single 12-foot diameter pipe weighing about 3 tons per linear foot extending about 4.5 miles into the Pacific Ocean to a water depth of 80 feet. The Outfall's capacity is 450 million gallons per day by gravity; this capacity may eventually be increased to 590 million gallons per day by adding a pumping station. It is scheduled to be completed in the spring of 1985 and for the first 5 to 10 years will be utilized to only about 30 percent of its capacity, while the remainder of the system is completed.

The location of the Outfall was selected so as to carry the effluent into deeper water as quickly as possible within the otherwise relatively shallow continental-shelf. Also, the diffusers had to be placed at a sufficiently remote distance from the Golden Gate to avoid the likelihood of tidal currents carrying the effluent into San Francisco Bay.

The Outfall has been designed to resist or accommodate all environmental forces or displacements anticipated during the design life of the system. Where significant damage appears unavoidable, such as across the fault zone during a major rupture, provisions have been made to limit the extent of damage and to facilitate required repairs. Provisions have also been made to permit the operation of the Outfall system on an emergency basis during the repair period.

#### Seismic Design Criteria

The centerline of the Outfall lies across the San Andreas Fault, one of the world's most active and violent earthquake fault zones (Figure 2). Based on review of historical seismicity, a design Richter magnitude of 8+ was selected for the project with a peak ground acceleration of 0.6g, transient displacement of 20 inches, and a peak velocity of 30 inches per second.

Based on review of the famous 1906 event, it was concluded that the Outfall could be subjected to a relative horizontal displacement of 16 to 20 feet and a relative vertical displacement of 3 to 4 feet. Additionally, a relative fault creep movement of about 6 inches can be anticipated during the 75-year design life of the project.

#### Earthquake Joints

Conduit sections with special earthquake joints (Figure 3) will be placed longitudinally at 20 feet on center across the fault zone (400 feet) and the two bands on each side, a total length of 1200 feet. The earthquake joints were

designed to absorb the following anticipated transient forces and movements:

- o longitudinal pipe tension = 150 tons
- o total joint extension = 12 inches
- o total joint contraction = 5 inches
- o total joint deflection = 2.4 degrees
- o gasket pressure = 300 psi
- o internal water pressure = 10 psi

A joint consists of two neoprene gaskets sliding on teflon surfaces, the outer one being for testing purposes only. The locking device is made up of four Dywidag rods, fusion epoxy coated and encased in PVC conduit, with crushable closed cell urethane foam reinforced with nylon behind the rod washers. When the joint reaches its expansion or contraction capacity by crushing the urethane foam, it then transfers the force and movement through the pipe to the next joint, and then to the following joint(s) until the entire motion is absorbed.

#### Backfill Configuration

The backfill configuration (Figure 4) was designed to provide protection for the Outfall conduit for the design life of 75 years. The lowest layer of gravel (Type I) was selected to furnish proper bedding of highly pervious material providing rapid pore pressure redistribution during periods of earthquake-induced shaking and potential liquefaction. The second layer of gravel (Type II) is a graded filter course to minimize infiltration of the natural sands into the Type I backfill. The armour stone layers are for wave defense, with Type IV placed on top of Type III in the surf zone and diffuser areas only.

#### Diffusers and Manholes

At its outer extremity, the Outfall contains 85 diffuser units (Figure 5). Each diffuser consists of structural unit with a riser containing an 18-inch diameter conduit connecting the pipe invert to the diffuser riser cap which protrudes several feet above the seafloor. Each cap contains eight 4-inch diameter ports through which the effluent is diffused to the ocean. The risers are connected to the pipe bottom in order to minimize the likelihood of sediment accumulation and possible constriction of the pipe cross section and capacity. Surprisingly, the lateral forces caused by fishing nets dragged along the seafloor which may snag on the diffuser caps proved to be potentially far greater than the seismic



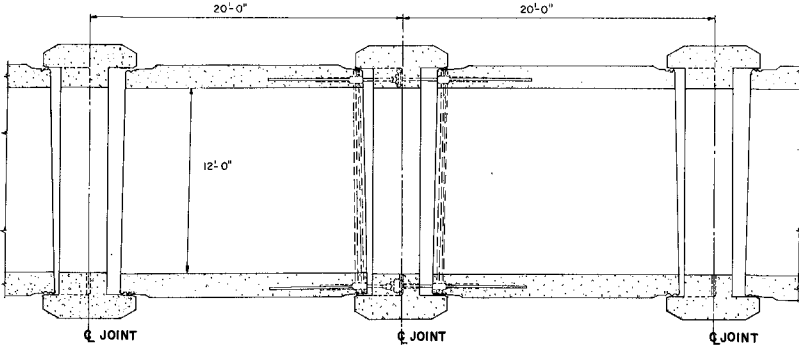


Figure 3 EARTHQUAKE JOINTS

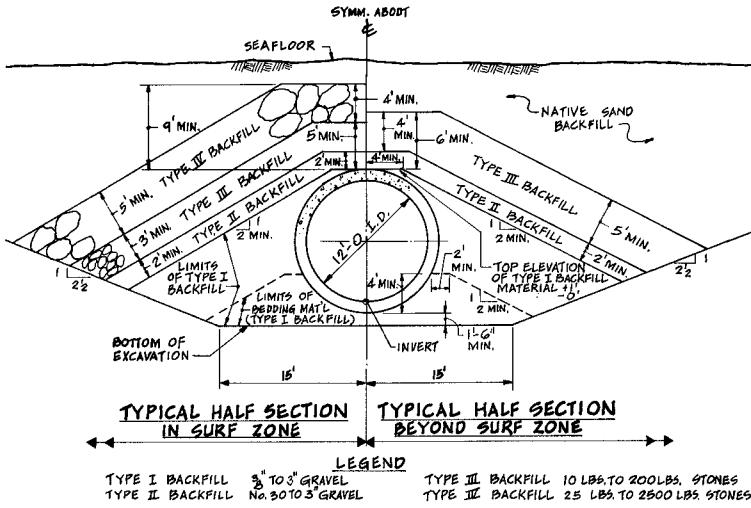


Figure 4 BACKFILL CONFIGURATION

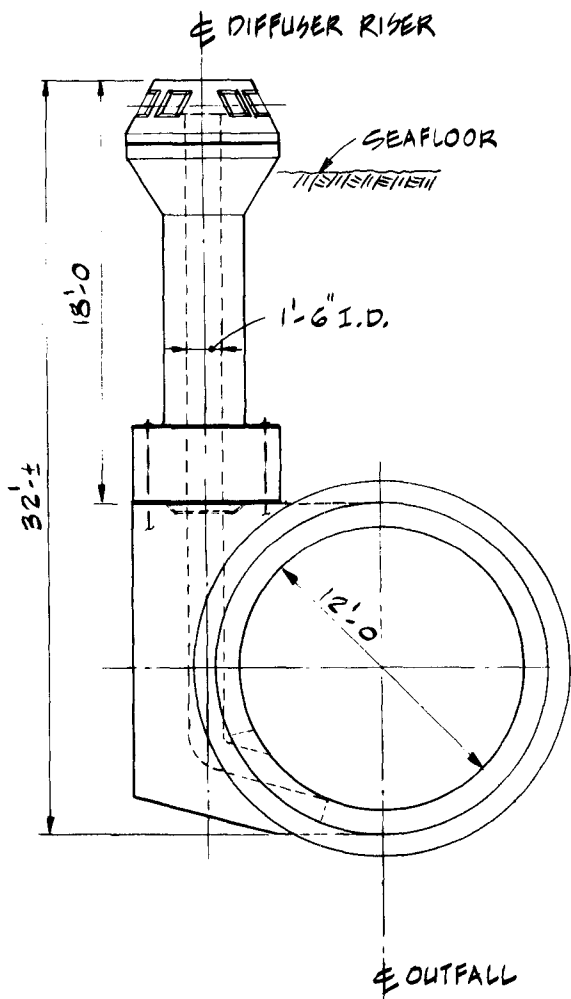


Figure 5 DIFFUSER UNIT

or wave forces and thus became the design load. Also, erosion or accretion of the seafloor in the diffuser area is not expected to exceed 3 feet in 75 years, based on historical records.

Access manholes were designed at a maximum center-to-center spacing of 500 feet. This spacing allows for the timely rescue of a tethered maintenance/repair diver inside the Outfall conduit. The manholes essentially consist of 42-inch diameter holes at the top of the Outfall pipe with reinforced concrete gasketed covers. A special marker is connected to the manhole cover and protrudes some 5 feet above the seafloor. The manhole cover is backfilled in a manner similar to the pipe itself. No access chimneys were designed to ease entry into the pipe, since it was felt that they were unlikely to survive the hostile seismic and wave environment. Access to the manholes will therefore require excavation and backfilling equipment in order to remove and later replace the backfill material above the manhole cover.

#### Emergency Features

Two emergency features have been incorporated into the Outfall design to respond to the possibilities of flows exceeding design capacity or a rupture of the conduit; these are the emergency overflow structure and several emergency diffuser units.

The emergency overflow structure consists of a 10-foot diameter pipe and spillway structure connecting the onshore headworks to Ocean Beach. It is anticipated that the emergency overflow structure would be used during rare periods of major flooding or in case the Outfall conduit should break near shore for any reason. The effluent discharge on the beach would continue until the flood flows abated or until repairs were completed.

Should a major slip occur along San Andreas fault zone in the project area, the Outfall conduit will almost certainly break. To mitigate the impact of this possibility, provisions have been made to excavate and expose two or more manholes on the shoreward side of the break, remove their covers, and then install emergency diffuser units (Figure 6). These units will act to diffuse the effluent about 1.5 miles offshore during the conduit repair operations.

#### OUTFALL CONSTRUCTION

The contractor has now (December 1982) finished the surf zone trestle (Figure 7) which extends about 3,000 feet into the ocean to a water depth of about 38 feet. The 32-foot wide deck of the trestle stands about 28 feet above the water. Its main supporting members are 24-inch diameter

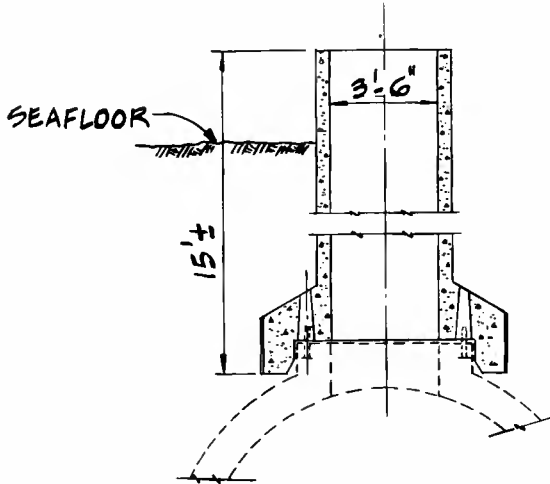


Figure 6 EMERGENCY DIFFUSER



Figure 7 SURF ZONE TRESTLE

pipe piles at 30 feet on center for the first 2,000 feet of trestle; 30-inch diameter piles were used for the outer 1,000 feet of trestle. The trestle carries tracks for movement of cranes, material carts, and a pipe laying gantry (Figure 8).

#### Surf Zone Construction

The Outfall pipe is presently being installed from the gantry in a protected trench (Figure 9). Ordinary interlocking sheet piles spaced 24 feet apart were used for the first four hundred feet; they were jettied and driven with some difficulty due to the hard material encountered just below the top loose sands. The contractor then employed three-legged wave barriers 20 feet long by 12 feet wide consisting of three pipes connected by steel plates with interlocking connections to the abutting wave barriers and weighing about 10 tons each (Figure 10). These are placed in position during relatively calm seas and pin piles are driven through the wave barrier piles to secure them in place. After the completion of the excavation, pipe laying, and backfilling in a given section, the pin piles are loosened and pulled and the wave barrier modules are transported to new positions (Figure 11). The present pipe laying rate is 2 to 3 units per day.

The pipe being installed from the gantry was produced in a pipe plant near the beach (Figures 12 and 13) and consisted of about 120 units weighing about 90 tons each. The other 900 or so conduit sections, including the special earthquake sections and the diffuser units, are being manufactured at Rio Vista, about 60 miles up the Sacramento River from San Francisco.

#### Offshore Construction

A 13,000 ton capacity barge (Figure 14) was built in Portland, Oregon specifically for this project at a cost of about U.S.\$15 million. It was launched in mid-September 1982 and is presently being outfitted and rigged. It is scheduled to arrive at the site in early 1983 and to commence offshore operations beyond the end of the trestle shortly afterwards. The barge is 420 feet long, 98 feet wide and 25 feet high. It has a draft of 10 to 12 feet, depending on the weight of its cargo, and a 500-ton capacity crane with a 200-foot boom. Excavation, pipe laying, and backfilling will be performed off the barge at an anticipated rate of two pipe lengths (48 feet) during each 24 hour day.

#### ACKNOWLEDGEMENTS

The prime consultant for the Outfall is Parsons Brinckerhoff. Woodward-Clyde Consultants is principal subconsultant for geotechnical, seismic, coastal, and



Figure 8 PIPE GANTRY



Figure 9  
PLACING CONDUIT IN  
SHEETED TRENCH



Figure 10 WAVE BARRIERS



Figure 11 TRANSPORT OF WAVE BARRIERS



Figure 12 CASTING YARD



Figure 13 CONDUIT SECTIONS





Figure 14 BARGE DURING CONSTRUCTION

oceanographic aspects of the project. Principal subconsultant for hydraulic and sanitary design is CH2M-Hill, Inc. Cost estimates and special studies on constructibility are provided by H. V. Anderson Engineers.

In addition to the authors, the project management team includes P. H. Gilbert and G. J. Murphy of Parsons Brinckerhoff, G. E. Hervert of Woodward-Clyde Consultants, and P. B. Hall and L. E. Hanson of CH2M-Hill, Inc. The special joint system was designed by Robert Warshaw of Parsons Brinckerhoff; the senior geotechnical engineer was the late O. H. Gilbert, Jr. of Woodward-Clyde Consultants.

Guidance concerning seismic design and constructibility of the Outfall system was provided by the Seismic Advisory Board. This panel of consultants, under the chairmanship of T. R. Kuesel of Parsons Brinckerhoff, included H. B. Seed, B. C. Gerwick, Jr., B. A. Bolt, and J. W. Johnson of the University of California, Berkeley, G. W. Housner and N. H. Brooks of the California Institute of Technology, and the late N. M. Newmark of the University of Illinois.

The contractor, Ocean Beach Outfall Constructors, is a joint venture headed by Morrison-Knudsen of Boise, Idaho. R. R. Vlach is project construction director and W. Hirvela is project construction engineer. Construction management services are being provided by Deleuw-Greeley-Hyman under the direction of George Kline.

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