DESIGN OF AN INTERMITTENTLY OPERATED OUTFALL

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INTRODUCTION

The City of San Francisco, California, has a combined sewer system that presently overflows into the bay or ocean when it rains. Under the current wastewater management program being implemented, this combined flow of storm and sanitary wastes will be treated and discharged into the Pacific Ocean through a three-pipe outfall system. The system will dispose of the treated sanitary wastewater (dry weather flow) through a 2740-millimetre-(mm)-diameter, 6-kilometre (km) ocean outfall, and the mixture of sanitary wastewater and stormwater (wet weather flow) will be disposed of through two 2740-mm-diameter outfalls, 4 km long. The depth of the dry weather diffuser is approximately 24 m and the depth of the wet weather diffuser is approximately 17 m. The wet weather outfall will operate only when the rain exceeds 0.5 mm per hour. Rain exceeds this intensity about 4 percent of the time, or 350 hours per year. The peak wet weather flow is approximately 1800 megalitres per day (Ml/day)[3]. The average dry weather flow is 400 Ml/day and the peak dry weather flow is approximately 700 Ml/day.

This paper reviews the unique problems of an intermittently operated outfall located in an area of shallow water with loose bottom sediments on a coast subjected to high wave energy. The circulation of seawater through the dormant diffuser and the resulting reduction in hydraulic capacity by sediment intrusion and biofouling are identified as the most severe problems for the intermittently operated outfall. The features incorporated to reduce these problems are bottom-exiting risers, diffuser ports elevated above the seabed, four ports per riser with a dual valve system, and use of antifouling materials and a flushing system.

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[3]1 Ml/day = 1,000 cubic metres per/day (m^3/day) = 11.6 litres per second (lps)

BACKGROUND

San Francisco is undertaking an extensive wastewater management program to upgrade treatment and reduce the volume and frequency with which untreated effluent is discharged into both San Francisco Bay and the Pacific Ocean. This program involves construction of two secondary treatment plants for dry weather flow, and one chemically assisted primary treatment plant for the wet weather flow, several large storage and transmission facilities, and an ocean outfall system consisting of one dry weather and two wet weather outfall pipes. Figure 1 shows the basic configuration of the major elements of the wastewater treatment and disposal system.

The storage and transmission facilities will have the capacity to store excess combined sewage during most storms, thus limiting the number of overflows onto the beaches of the San Francisco peninsula. The chemically assisted primary plant will treat combined sewage in excess of that receiving secondary treatment. The combined sewage in storage will be processed as the storm flows subside. Once the transport and storage system is empty, the wet weather outfalls will be dormant until the next storm.

CONSTRAINTS

San Francisco's operating and site conditions make the design of the wet weather outfall considerably different from continuously flowing deep ocean outfalls. These constraints are reviewed below.

Dilution Requirements

The ocean outfall system must meet the requirements of the amended California Ocean Plan, which contains discharge regulations set by the California State Water Resources Control Board. These regulations do not contain specific requirements for dilution nor effluent criteria for biochemical oxygen demand (BOD) or coliform levels. The major provisions of the Ocean Plan include:

- Establish limits of receiving water quality, which the discharge does not violate
- Require that waste systems that discharge to the ocean will maintain the indigenous marine life
- Establish requirements for wastes that are discharged to the ocean

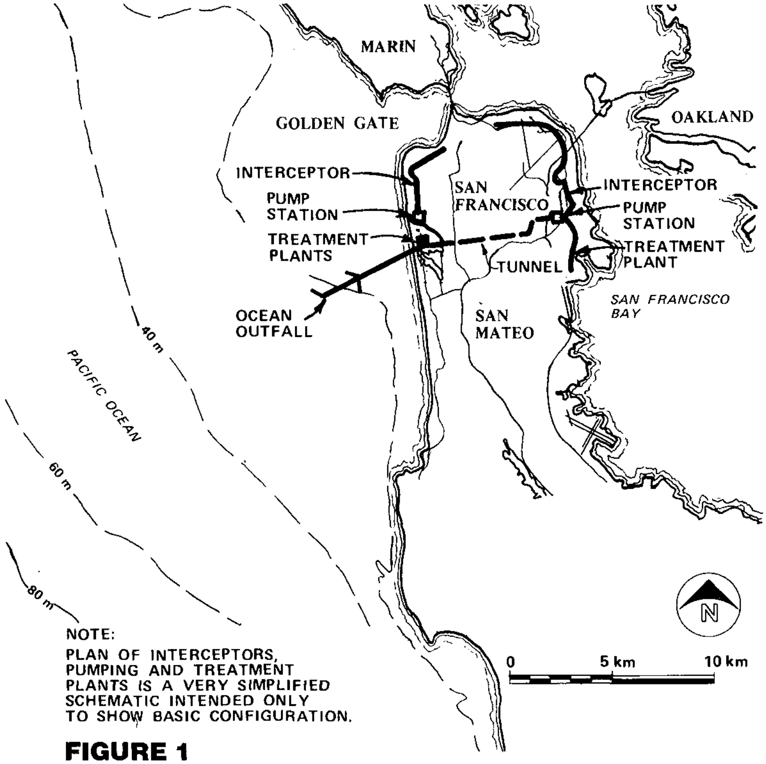

FIGURE 1
SAN FRANCISCO
WASTEWATER PROGRAM MASTER PLAN

The limitations on wastewater characteristics inelude 75-percent removal of suspended solids and limits on discharge of grease and oil, settleable solids, turbidity, pH, toxicity concentration, and toxic materials. There are receiving water limits on heavy metals, floating particulates, organics, dissolved oxygen, and radioactive and toxic substances. Maximum coliform concentrations are specified for beach and shellfish areas.

The discharge requirements for effluent concentration include a 6-month median as well as a daily maximum and an instantaneous maximum limit. Thus, by using the 6-month median, the wet weather dilution requirements are considerably less than the dry weather dilution. The target established for the dry weather diffuser is for better than 100:1 average initial dilution at least 80 percent of the time. The target for the wet weather diffuser is for greater than 25:1 average initial dilution at peak discharges. The relatively low target dilution for the wet weather discharge can be obtained in shallow water.

Operation Constraints

The wet weather outfall will operate about 350 hours per year during the wet season (December through April) and remain dormant during the rest of the year. Both dry weather and wet weather outfalls will operate at their maximum design flows several times each year. Whenever the wet weather outfall is not discharging, wave pumping through the diffuser ports will occur. Wave pumping, as used here, is the circulation of seawater through the diffuser with water entering the ports under the wave crest and exiting through the wave trough. If allowed to occur, this circulating seawater will introduce fouling organisms and sediment into the diffuser.

Site Constraints

The ocean floor, in the vicinity of the outfall, has a relatively flat slope for over 45 km from shore. Thus, no significant advantage can be gained by extending the outfall beyond the minimum depth required to obtain the dilution. The location of the outfall, 8 km south of the Golden Gate, is subject to intense winter storms as well as continuous wave action throughout most of the year. The ocean floor in the outfall area consists of loose sediments to a depth of up to 3 m; also an abundance of fine-grained sediment is discharged through the Golden Gate from the Sacramento and San Joaquin Rivers. The shallow water and the high wave energy cause sediments to be suspended except during the calmest days.

Over the life of the project, the elevation of the sea floor is predicted to vary from approximately 1 m above to 2 m below the present floor.

The low elevation of the onshore treatment site limits the head available for gravity flow to 7 m during high tide and high flow conditions.

Structural Constraints

The outfall is designed to account for wave and seismic forces and soil liquefaction. To protect it, the outfall will be buried in a trench, with approximately 3 m of backfill materials and armor cover over the pipes. Along the San Andreas Fault, which the outfall crosses approximately 3 km from shore, movement perpendicular to the pipe of up to 20 feet is possible. Special joints that provide for some movement and are easily replaced were designed for the fault zone.

ANALYSIS

The analysis and design of the outfall required close coordination between many engineering and scientific disciplines. No single solution was completely satisfactory to each discipline; judgment and compromises were required to fully develop the design. The analysis of several major elements is described below.

Dilution

The results of the dilution analysis indicated that the wet weather diffusers should each be approximately 420 m long, have 96 ports with a nominal diameter of 200 mm, and discharge with approximately 15 m of water above the port. Figures 2, 3, and 4 show the configuration of the outfall, diffuser, and risers.

Wave Pumping

Various methods of analysis and levels of refinement were made to estimate the volume of water that would enter the ports due to wave pumping. It was determined that large volumes of water would enter each riser under each wave crest. For instance, by using a simple orifice equation and an average head of the wave crest over the still water level, it can be found that over 1 cubic metre (m^3) of water will enter a riser under a relatively small wave.

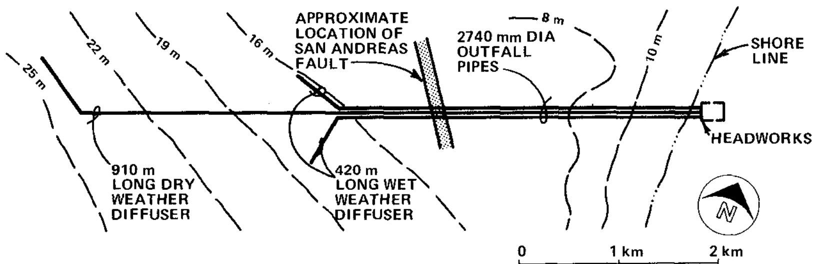

FIGURE 2
SCHEMATIC OUTFALL CONFIGURATION

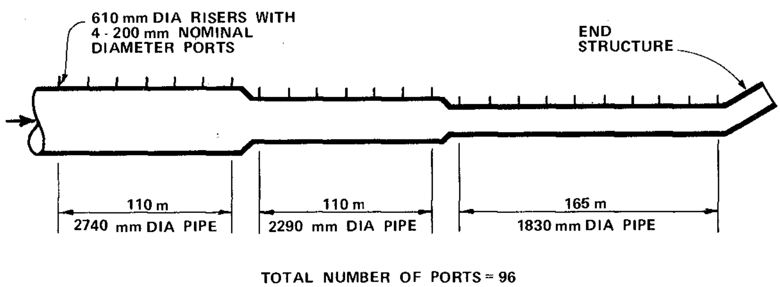

FIGURE 3
WET WEATHER DIFFUSER CONFIGURATION

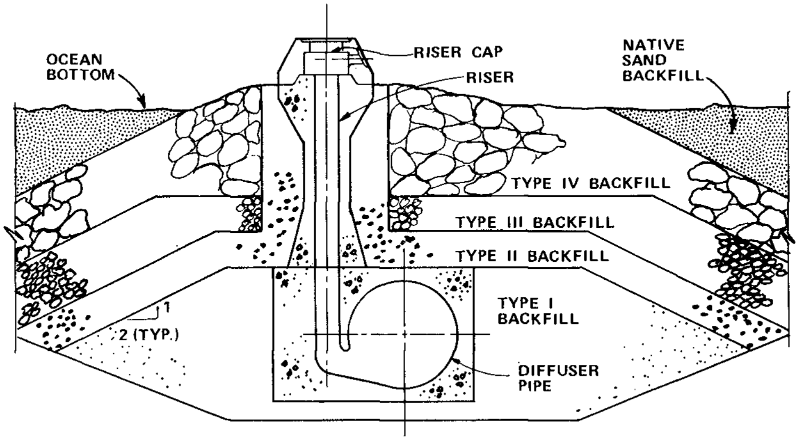

FIGURE 4
TYPICAL SECTION OF WET WEATHER RISER

Sediment Intrusion

The volume of sediment that enters the diffuser depends upon the concentration of sediment in suspension. This concentration in turn depends upon the bottom currents, the wave conditions, and the height of the port above the seabed. The trapping efficiency of the port and riser also affect the volume of sediment entering the diffuser. The trapping efficiency is defined as the percent of sediment entering the ports that is deposited in the diffuser. Various assumptions on concentration were made using sediment trap and water sample data. With the high trapping efficiency it was found that the diffuser could fill with sediment during a single storm.

Biofouling

Biofouling organisms were identified and methods of controlling them were examined. It was concluded that the diffuser would be an ideal habitat for certain organisms if seawater circulated through the diffuser. Unless circulation of seawater could be eliminated, fouling growth several inches thick could be expected inside the outfall. Other methods of control that were investigated included washing the newly settled, but poorly attached, fouling organisms off the structures with high velocity flushing water, use of antifouling materials, or discharge of small quantities of freshwater in the diffuser. None of these methods appeared satisfactory on close examination.

Various types of antifouling materials, including NOFOUL[1] rubber, various copper-nickel alloys, and aluminum bronze alloys were studied. Coupons of these materials were placed in the seawater at Monterey Bay, in bay water in the San Francisco Bay, and alternated between bay water and treated sewage effluent. These test coupons provided information on the rate of leaching of these compounds when alternately exposed to treated sewage effluent and seawater.

Flushing

Removal of sediments from the diffuser by flushing was analyzed. The diameter and length of the outfalls require a large volume of water for minimum flushing. There is no source of freshwater for flushing other than secondary treated sewage effluent. Various storage facilities were examined for storing the treated effluent flushing water,

[1] Manufactured by B.F. Goodrich, Akron, Ohio.

including the tunnel storage system, the primary sedimentation basins at the wet weather treatment plantsite, and a separate storage reservoir built above the plantsite. The use of the sedimentation basins in the primary treatment system located near the headworks provides the most economical storage for flushing water. Samples of sediments, in suspension in the water column, were trapped in a nest of sediment traps, located near the wet weather diffuser. The sediments in suspension are a nonplastic silty fine sand with a mean diameter of 0.16 mm. This material is finer than the fine sand on the seafloor.

For the sediment flushing system to be effective, the flushing water must have sufficient velocity and volume to erode and transport the deposited sediment. Very little information is available that is applicable to large diameter outfalls and diffusers. A relationship of shear intensity parameters and transport parameters based on conduit data, flume data, and river data presented by Graf-Acaroglu(1) was used as a guide in developing a method of predicting the amount of sediment that could be flushed from the diffuser pipe. Using parameters for the outfall pipe diameter and Manning's flow equation, the Graf-Acaroglu relationship reduces to:

$$C = 1.03 \times 10^{-5} d^{-1.02} D^{-1.84} V^{4.04}$$

Where D = the diameter of the diffuser pipe in feet
d = the grain size in millimetres
V = velocity in the diffuser pipe in feet per second
C = sediment concentration by volume

This equation was used to estimate the flushing characteristics in the outfall diffusers as a function of the sediment grain size and the effluent velocity through the diffusers. The analysis and computations are complicated because of the continually changing effluent velocity as it is discharged through the diffuser ports and it is transported through the tapered sections of the diffuser. A computer program was written to perform the calculations for flushing the diffuser and record the mathematical calculations.

This analysis indicates the upstream end of each tapered section would be the first to scour clean. Part of the sediment removed from these upstream sections would be discharged out of the first riser pipe, and part of it would be deposited in the downstream sections. After the upstream section was clean, the cleaning process would progress downstream. A very simple hydraulic model was used to verify the concepts developed from the Graf-Acaroglu relationship. The results of this model study gave reasonable verification to this method of predicting the success of the flushing process.

Flushing with the end gate open and end gate closed were analyzed with the computerized hydraulic model. With the end gate open, a 90-minute flushing period will remove 0.6 m^3 of sediment per metre of diffuser, or approximately 240 m^3. With the end gate closed, a 90-minute flushing period will remove less than half of this amount of sediment from the diffusers. With the end gate closed, the first sections of diffuser will be cleaned out, but the remainder of the sediment will be transported to the end of the diffuser, plugging the last few sections.

DESIGN FEATURES

The design features that were incorporated into the diffuser to protect it from the seawater circulation problems caused by wave pumping are discussed below. A double check valve system is considered the primary defense against seawater circulation. However, because of the severe site and operating conditions, the diffuser was designed with several safety features in case the check valve system does not work properly.

Double Valve System

After it was concluded that some sort of valve system was necessary to reduce wave pumping, many ideas were evaluated. These ideas varied from using manufacturers' standard check valves to complicated, remote-controlled valves that could be opened when the wet weather flow began and closed when it stopped. Because of the harsh environment, it was decided that the valve should be as simple as possible with few moving parts.

The final system consisted of a "poppet" valve over the riser and rubber flap valves over the ports, as shown on Figures 5 and 6. The poppet valve consists of a flat copper nickel plate, centered over the riser pipe with four guide legs. This plate rises when the outfall is flowing and closes under its own weight when the flow has stopped. It is provided with rubber gate seats. Each port is covered with a heavy rubber flap valve that is reinforced with a metal plate, which opens under flow and closes when the flow stops.

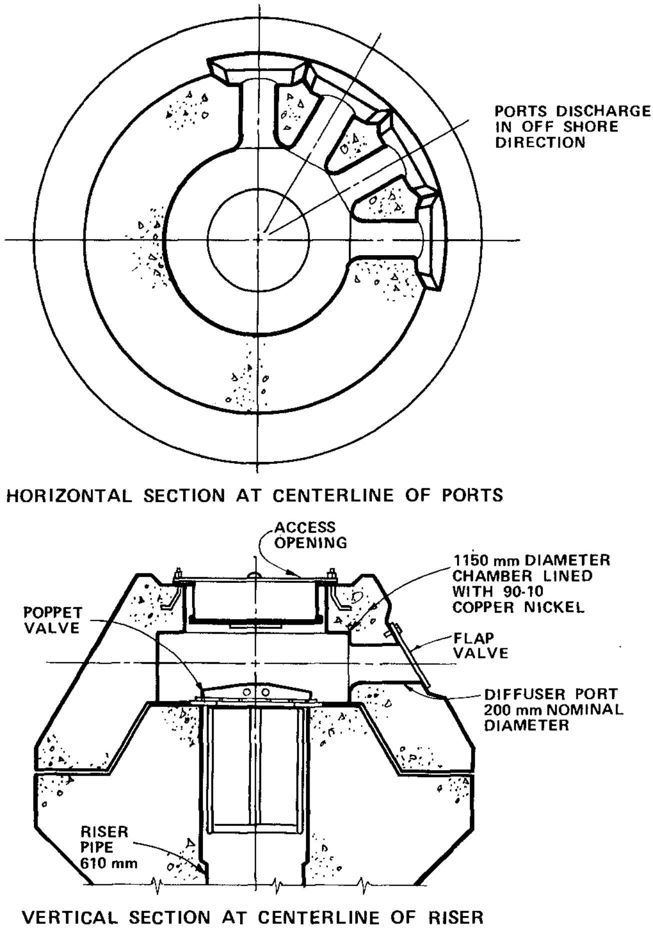

FIGURE 5
WET WEATHER RISER CAP AND VALVES

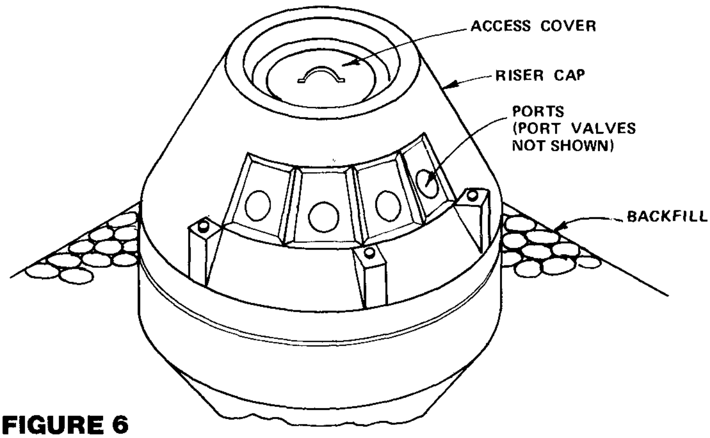

FIGURE 6
ISOMETRIC DETAIL OF WET WEATHER RISER CAP

Four hydraulic models were used as tools to develop and refine the design. The wave tank facilities at Oregon State University, Corvallis, Oregon, were used to study a 4:1 scale model of the riser cap and valves under wave action. While the combination of the flap and poppet valve greatly reduces the flow of seawater into the riser, waves cause some fluttering of the valve, which may allow some backflow of seawater. This fluttering is caused by wave forces, orbital velocities, and differential pressure on each flap valve. The fluttering can be reduced or eliminated by adding weights to the flap valves, but this increases the headloss across the valves. The headloss across the riser cap and valve system was 0.9 m under the maximum design flow of 1800 Ml/day.

Bottom-Exiting Risers

The wet weather risers are designed to exit from the invert of the diffuser pipe as shown on Figure 4. The main purpose of this configuration is to improve the effectiveness of flushing to remove sediments.

Multiport Riser

Normally, the diffuser ports are simply holes located in the sides of the diffuser pipe. However, with the buried diffuser, a riser pipe had to be used to bring the effluent from the buried pipe to about 1500 mm above the sea floor. Since the risers are exposed to damage by wave forces, anchors, and fishing gear, they must be structurally designed to resist these forces. The structural requirements control the external shape and size of each riser, regardless of the riser diameter. Such a riser is expensive and difficult to construct. In order to reduce the number of risers, two, three, and four ports per riser were studied and tested. In the final design, four ports were designed for each riser as shown on Figure 4.

Hydraulic modeling of the plume behavior was performed at the California Institute of Technology, Pasadena, California. Modeling consisted of comparisons of two, three, four, or eight ports per riser. Confirming tests were performed on the four-port-per-riser system, as finally designed. The four ports are located close together, in one quadrant, and positioned to discharge offshore, as shown in Figure 5.

Antifouling Materials

To reduce fouling, the riser cap was lined with copper nickel; the metal parts of the valves are copper nickel. The rubber valve seals, gaskets, and valve hinge are NOFOUL rubber. NOFOUL rubber is a chloroprene rubber impregnated with tributyltin oxide.

Height Above the Seabed

The highest concentration of suspended sediments occurs near the bottom. In order to reduce the concentration of sediment in suspension around the ports and to provide some protection from port burial caused by the fluctuating elevation of the seabed, the ports were located approximately 1500 mm above the seabed.

Flushing System

The sedimentation tanks for the proposed primary treatment system furnish storage for approximately 72,000 m^3 of effluent for flushing the outfall. These tanks will be filled with secondary treated effluent and then discharged through the outfall. To be effective, the velocity of the flushing water must be at least 2 metres per second. It is estimated that this water, when flushed through the diffuser with the end gate open, will remove approximately 240 m^3 of sediment.

ACKNOWLEDGEMENTS

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