CHAPTER 168

DESIGN CONSIDERATIONS FOR THE SAND ISLAND AND BARBERS POINT OUTFALLS

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INTRODUCTION

The design and construction of a major ocean outfall and diffuser system for disposal of wastewater effluents is a complex process involving an interplay of requirements originating from various disciplines. These include, among others, considerations of physical oceanography, mixing and dispersion, treatment processes, regulatory requirements, marine geology, economics and construction. The recently completed Sand Island Outfall and the newly designed Barbers Point Outfall are both on the southern coast of the island of Oahu, Hawaii, and are designed for treated sewage effluents from the densely populated portion of the City and County of Honolulu. In this paper, some design considerations of these outfalls will be examined. The emphasis in this paper is on the hydrodynamics, although other design aspects are also discussed briefly.

The design of a large submarine outfall must consider two basic objectives. First, the design must assure the physical integrity of the structure when subjected to the sometimes violent environment. Second, the mixing, dispersion and transport of the effluent must be such that environmental degradation is acceptably small and that water quality requirements are met. In addition, the design process also includes considerations of economics, overall system compatibility, and construction.

The Sand Island Outfall was constructed in 1975-1976 while construction of the Barbers Point Outfall began in 1976. The cost of the Sand Island outfall was 13.7 million.

DESCRIPTION OF THE DESIGN

The Sand Island Outfall is 84 inches in diameter and extends 12,500 ft offshore to a depth of approximately 230 ft. The last 3384 ft of the outfall (the diffuser section) contains 282 ports on the sides of the pipe varying in diameter from 3 to 3.53 inches. The Barbers Point Ocean Outfall is 78 inches in diameter and extends 10500 ft offshore to a depth of 200 ft. The last 1752 ft of the outfall contains 146 ports varying in diameter from 3.41 to 3.74 inches. The design ranges of flow are 32 to 194 mgd for the Sand Island Outfall and 14 to 112 mgd for the Barbers Point Outfall. Figures 1 and 2 show plan views of the two outfalls.

Considerations of forces from hurricane-generated waves and seismic loadings resulted in each pipeline being buried in a trench in the ocean bottom out to a depth of approximately 70 ft where it then gradually emerges from the sea floor and rests on the bottom, being anchored and protected by armor stones. The size and gradations of the stones and the cross sections of the ballast are chosen so that they are stable under the design wave or the design earthquake.

The offshore bathymetry beyond 70 feet depth showed rock and cemented coral outcrops dotting an underwater landscape of sand and coral rubble. The alignments of the outfalls were chosen to avoid these outcrops. The bottom slopes are also quite steep. The alignments of the diffuser sections are chosen to lie essentially on a level to ensure nearly uniform flow distribution along the diffuser for the full

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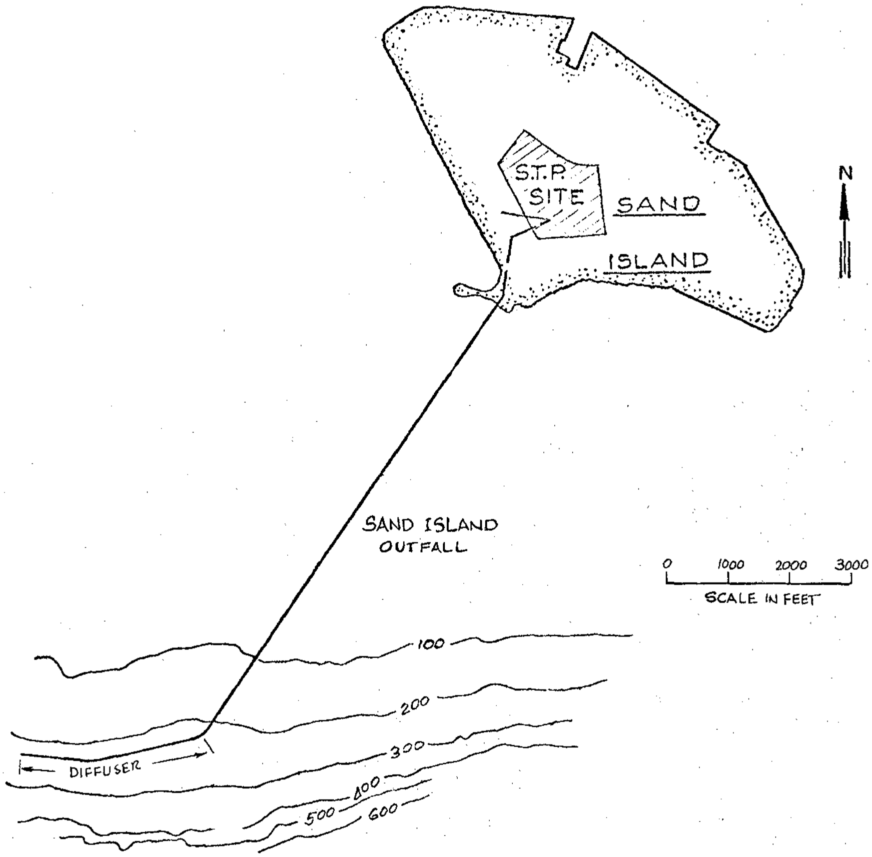


Fig. 1. Schematic Plan of Sand Island Outfall.

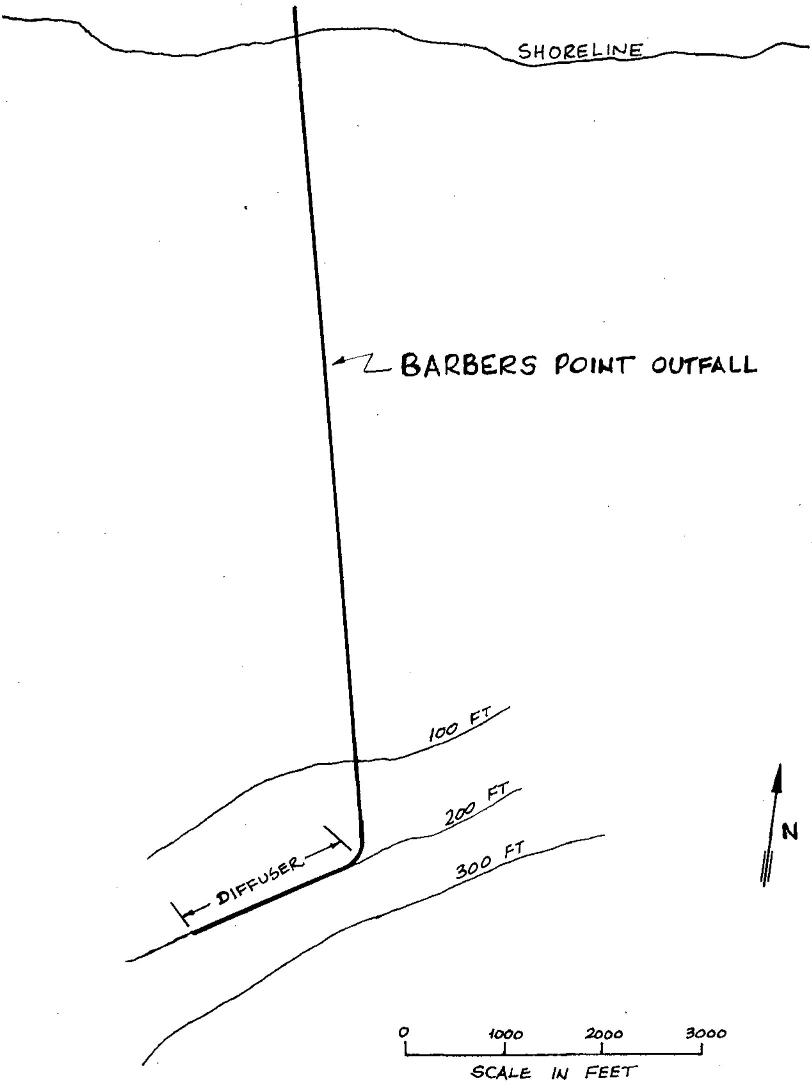


Fig. 2. Schematic Plan of Barbers Point Outfall.

range of discharges. The diffuser pipe sections were ballasted to prevent downslope rolling or sliding.

The lengths and depths of diffusers for the outfalls have been designed to ensure that the sewage effluent is diluted rapidly with ambient ocean water. Typical values of dilution are on the order of a few hundred. For part of the time, particularly during the summer, the diluted effluent plumes are submerged due to the existence of density stratification in the ambient sea. In the design process, however, high dilution was considered more important than submergence of the sewage field both from environmental as well ss from construction and economic considerations.

MIXING AND DISPERSION OF THE EFFLUENT IN THE OCEAN

Initial Dilution and Sewage Field Submergence

When sewage effluent is discharged through a submarine outfall diffuser, it undergoes basically three stages of turbulent mixing processes. First it rises as a buoyant plume, entraining (and mixing with) the ambient ocean water. This first phase of mixing carries the diluted effluent either to the surface or to a terminal level below the surface in the event there is sufficient ambient density stratification. The second phase of transport is thst of horizontal spreading. The sewage field, being either buoyant at the surface or more homogeneous at a submerged level, tends to spread out horizontally. This second phase of the establishment of a sewage field is followed by the third phase of dynamically passive turbulent diffusion and advection in the ocean. This last phase of mixing is dependent only on the ambient ocean turbulence and currents. Proper design of an ocean outfall diffuser must take into consideration all these processes although only the first is under the direct control of the design engineer.

One of the recent advances in the technology for ocean sewage disposal is the utilization of the natural ocean density stratification to achieve submergence of the sewage field. The sewage effluent, when mixed sufficiently with the denser seawater below the pycnocline, may not reach the surface since the much diluted effluent becomes denser than the surface seawater. The probability of submergence depends not only on the diffuser design but also on the natural density stratification in the ocean at the disposal site. In particular, if there is no density stratification between the depth of the diffuser and the surface, then the sewage field can never be made to stay submerged no matter how long a diffuser is used.

Predicted dilution and submergence characteristics of the Sand Island Outfall is shown in Figure 3 for various density profiles as determined to be representative of typical conditions during the year (Figure 4). It may be noted that for a given flow, the submergence and dilution are inversely related, i.e., deep submergence is accompanied by lower dilutions. The analysis techniques used in obtaining these results are detailed in Refs. I, II, and IV. Blocking by currents were considered.

During the design process, a variety of different diffuser lengths and depths were investigated as to their performance in terms of initial dilution and sewage field submergence characteristics. For each combination of length and depth, a dilution vs. submergence graph such as shown in Figure 3 could be prepared. It is found that, as displayed in Figure 3, the dilution and submergence are interrelated. For deep submergence due to a strong ambient density gradient, the dilution obtained is low. Sometimes increasing the diffuser depth (for the same diffuser length) may actually decrease dilution if the increased depth places the diffuser in a region with stronger stratification. On the other hand, for the same diffuser depth, lengthening the diffuser always increases dilution. The choice of the diffuser design represents a compromise between achieving high dilution and submergence most of the time but without excessively deep submergence and hence too low dilution. For the case of deep submergence with attendant lower dilutions, the sewage field

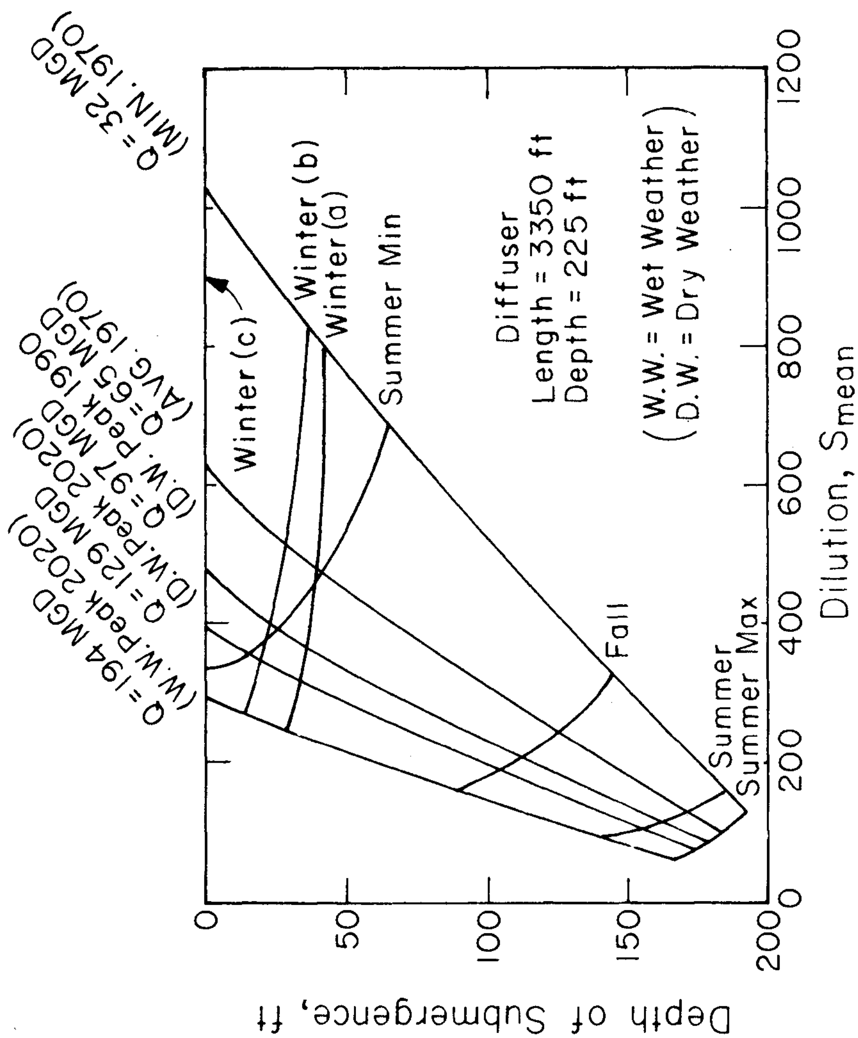


Fig. 3. Dilution and Submergence Characteristics for Sand Island Outfall.

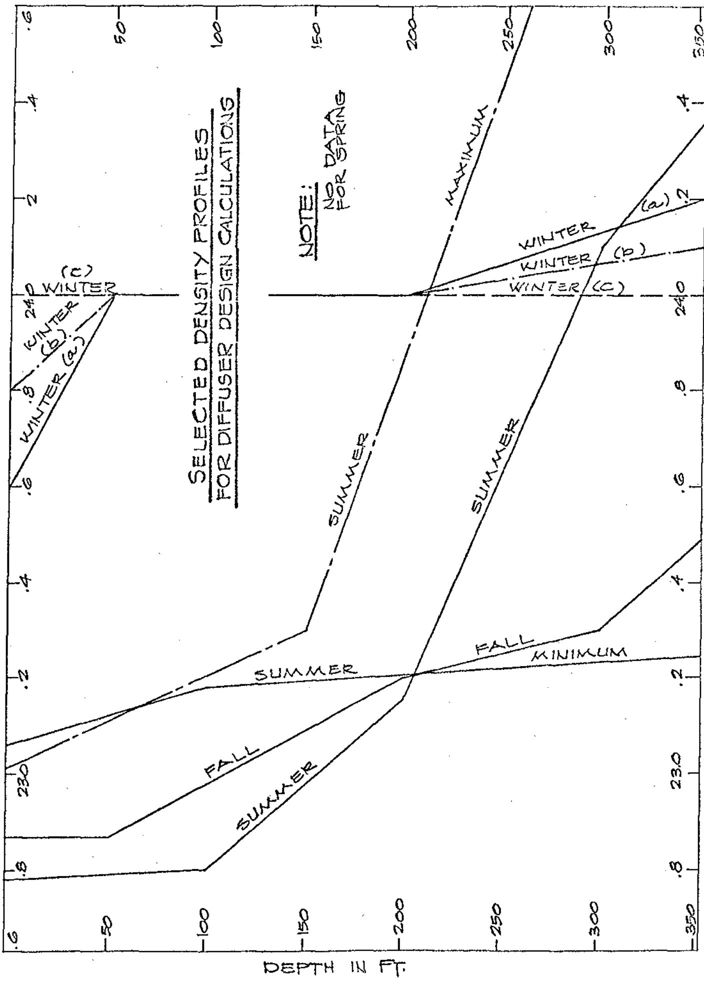


Fig. 4. Design Ocean Density Profiles for Sand Island Outfall.

would be subjected to somewhat slower natural assimilation and potentially higher impact.

Subsequent Transport and Diffusion

The advective transport of the diluted sewage effluent in the ocean environment was investigated by utilizing current meter measurements at the site in combination with statistical analyses, resulting in estimates of the probability of reaching shore as functions of time. Available ocean current data were obtained and analyzed to obtain streaklines for the sewage field advected according to the measured currents. The streaklines were then analyzed to obtain the statistics of transport to two lines designated reef line and recreation line. The reef line is a piecewise linear line which is essentially tangent to the offshore extent of the coral reef. The recreation line is displaced 1000 ft seaward of the reef line. These lines and an example segment of the streakline are shown in Figure 5 for the Sand Island Outfall location. The result of such an analysis is shown in Figure 6 where the probabilities of transport to either of the two lines are shown as a function of time of travel. It is seen that there is little chance of reaching the reef line in less than four hours. Since the bacterial dieoff rate tends to be very rapid in the tropical waters off Hawaii, health hazard due to sewage discharge from the new outfalls is very low.

During the subsequent transport of the sewage field following initial dilution, it will continue to mix with seawater by virtue of turbulent diffusion. This is generally a much less effective means of mixing for typical large plumes. For example, in four hours travel time, the additional mixing achieved by turbulent diffusion is only about a factor of two. For the Sand Island Outfall it is found that the probability of transport to shore within four hours is virtually nonexistent. The probability of transport to shore in 24 hrs is no more than a few percent under tradewind conditions and only 10 to 30% during periods interspersed by Kona storms. Results for the Barbers Point Outfall are similar.

INTERNAL HYDRAULICS

The basic premise of a long multiport diffuser is to distribute the sewage effluent over a large area to ensure the availability of large quantities of diluting sea water so that the initial dilution is sufficiently high (on the order of 200 or 300 to 1). Thus it is necessary that the diffuser be designed in such a manner that effluent is discharged nearly uniformly through the many ports.

The quantity of effluent flowing in the diffuser pipe decreases along the diffuser toward the seaward end due to the continual discharge. On the other hand, the flow velocity in the pipe should be maintained sufficiently high to prevent gross deposits of grease or sludge. This fact necessitates decreasing the diffuser pipe diameter toward the seaward end and the provision of a flap gate at the end which can be opened for occasional flushing if and when required.

A hydraulically well-designed diffuser should also be such that i) the pumping head requirements be reasonable, ii) no sea water intrusion occurs, and iii) remain hydraulically insensitive to age. These considerations lead to a choice of relatively small port sizes so that the port densimetric Froude number is relatively high, and certainly larger than two; and to bell mouthed ports which minimize clogging and whose discharge coefficients are high and will remain constant.

In the hydraulic design of the San Island and Barbers Point Outfall diffusers, these requirements were all taken into consideration. In addition, the effect of the density difference between the sewage effluent and sea water, coupled with any change in elevation along the diffuser introduces density head differences which must be taken into account in the hydraulic analysis.

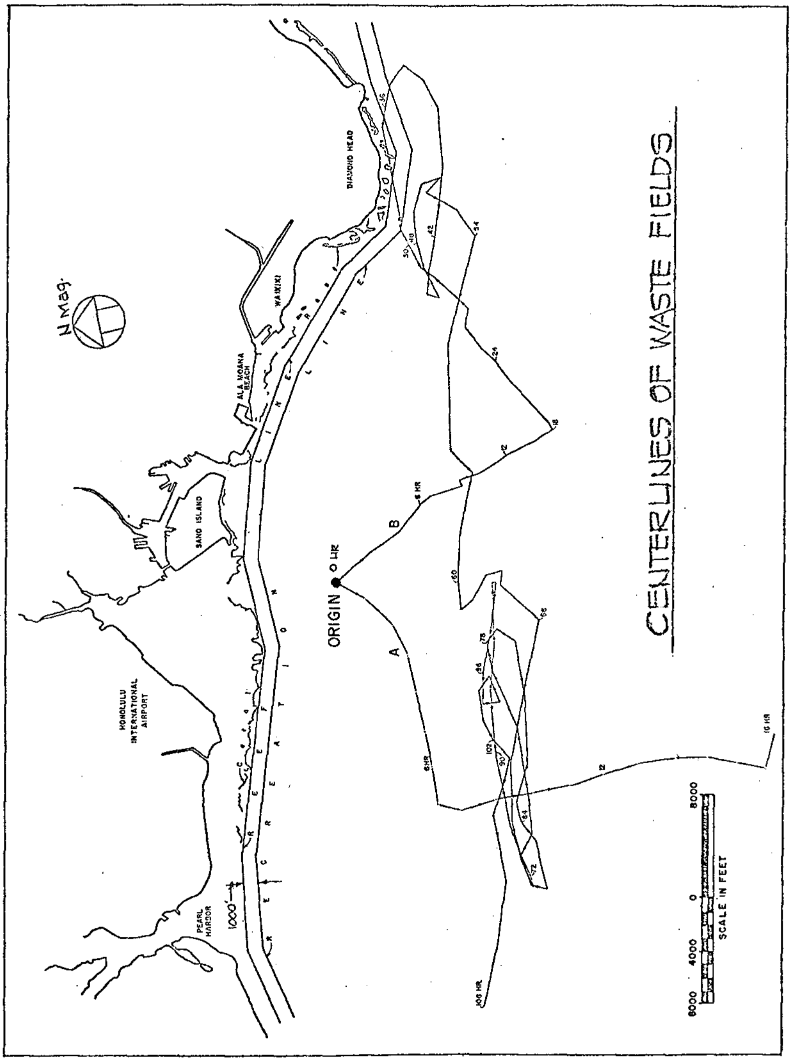
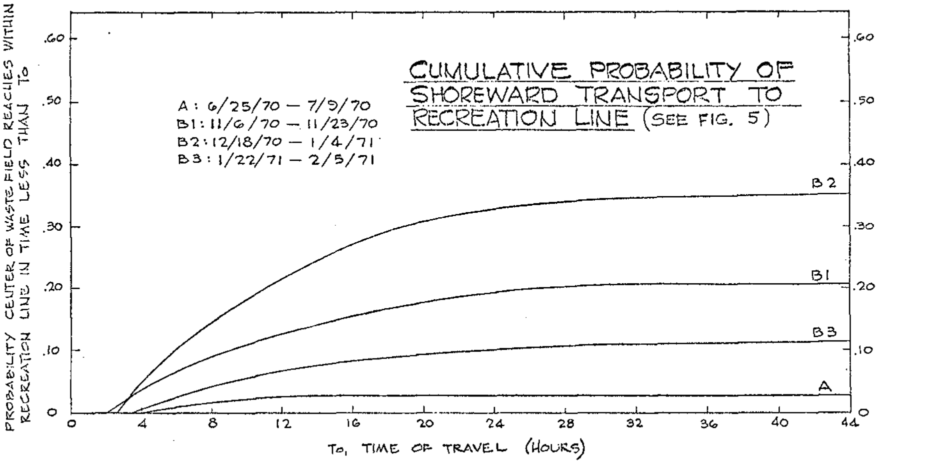


Fig. 5. Definition Sketch and Example Streaklines for Evaluation of Ocean Transport (Sand Island Outfall).


CUMULATIVE PROBABILITY OF SHOREWARD TRANSPORT TO RECREATION LINE (SEE FIG. 5)
A : 6/25/70 — 7/9/70
B1 : 11/6/70 — 11/23/70
B2 : 12/18/70 — 1/4/71
B3 : 1/22/71 — 2/5/71
PROBABILITY CENTER OF WASTE FIELD REACHES WITHIN RECREATION LINE IN TIME LESS THAN To
To, TIME OF TRAVEL (HOURS)
B2
B1
B3
A

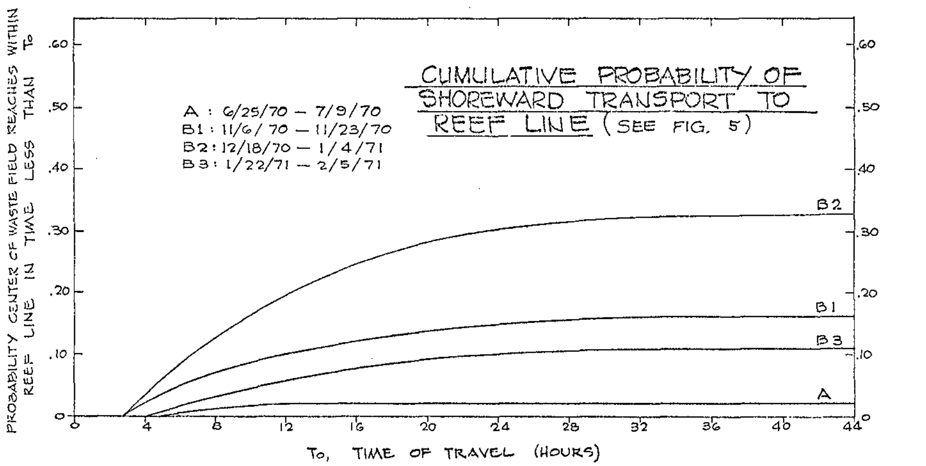

CUMULATIVE PROBABILITY OF SHOREWARD TRANSPORT TO REEF LINE (SEE FIG. 5)
A : 6/25/70 — 7/9/70
B1 : 11/6/70 — 11/23/70
B2 : 12/18/70 — 1/4/71
B3 : 1/22/71 — 2/5/71
PROBABILITY CENTER OF WASTE FIELD REACHES WITHIN REEF LINE IN TIME LESS THAN To
To, TIME OF TRAVEL (HOURS)
B2
B1
B3
A

Fig. 6.

The hydraulic analysis of a multiport diffuser is basically a problem in manifold flow. The procedure for the hydraulic calculations has been documented by Rawn, Bowerman and Brooks (1951) and is used in the design. It should be noted that if the diffuser is not placed along a constant elevation, then the phenomenon of density head makes it impossible for the discharge to be uniformly distributed along the diffuser for all flows. In the particular case of the Sand Island Outfall diffuser, the design is such that the discharge is essentially uniform for medium flow rates. At high flow rates, representing the more critical case from the point of view of submergence and dilution, the deeper ports are the ones discharging more.

Figure 7 shows the distribution of port discharge in the pipe along the diffuser for the Barbers Point Outfall for a friction coefficient (Manning n) of 0.015. This is shown as an example. A range of values of the friction coefficient were evaluated in the design process.

While the diffuser pipes in the Sand Island and Barbers Point Outfalls are reduced in steps to maintain a reasonable flow velocity along the pipe, some deposition may still accumulate in the diffuser particularly towards the end. Thus the ends of these diffusers are equipped with flat gates which can be opened to let the flow flush out the system (at most only once every few years, and perhaps never). When the diffuser is operated in this manner, a significant portion of the flow is discharged through the end of the diffuser. However, the bulk of the flow still occurs through the many ports along the diffuser. Figure 8 shows the calculated velocity in the diffuser pipe for the Barbers Point Outfall diffuser when operated in the flushing mode.

OTHER DESIGN CONSIDERATIONS

It is not posaible in this brief technical paper to treat all the facets in the design of a major ocean outfall structure. The reader is referred to the two design reports (Ref. I and II) for further details.

In the design process, consideration was also given to: a) geophysical factors such as nature of the ocean bottom and subbottom, and earthquake forces; b) physical factors such as storm waves, currents, and tsunami forces on the structure; c) system hydraulics and pumping requirements; d) economic factors.

The Barbers Point Outfall system also includes a 9166-ft land outfall between the Honouliuli Treatment Plant (elev. 32 ft) and the shoreline. During all but the higher flow rates, the land outfall will not flow full. The vertical alignment chosen for the land outfall consists of a hydraulically steep portion near the plant followed by a mild portion. In this way, critical flow in the land outfall is avoided. Excess energy is dissipated by friction and a hydraulic jump near the upper end of the land outfall. The chosen alignment assures that 1) the hydraulic jump is never more than a few hundred feet downstream of the change in slope, and 2) a long reach of tranquil flow exists before the pipe flows full to avoid significant air entrainment.

CONSTRUCTION OF THE SAND ISLAND OUTFALL

Construction of the Sand Island Outfall began with excavation of the 15-foot deep and 13-foot wide trench at the end of the trestle, 2,500 feet offshore and in water 20 feet deep. The contractor (Morrison-Knudsen) laid pipe downhill to the end of the diffuser. When the trestle was finished, a double bell connection was made at the end of the trestle and pipe was then laid back to the junction box on shore.

Starting from shore, the material on Sand Island was easy to dig since it was old fill material. Along the trestle, hard coral rock was encountered which made it very difficult to drive the two rows of sheet piling extending 2,500 from shore. Beyond the trestle, the bottom slopes gradually downward to where the pipe from the trench exits onto the ocean floor. This trench soil was highly variable,

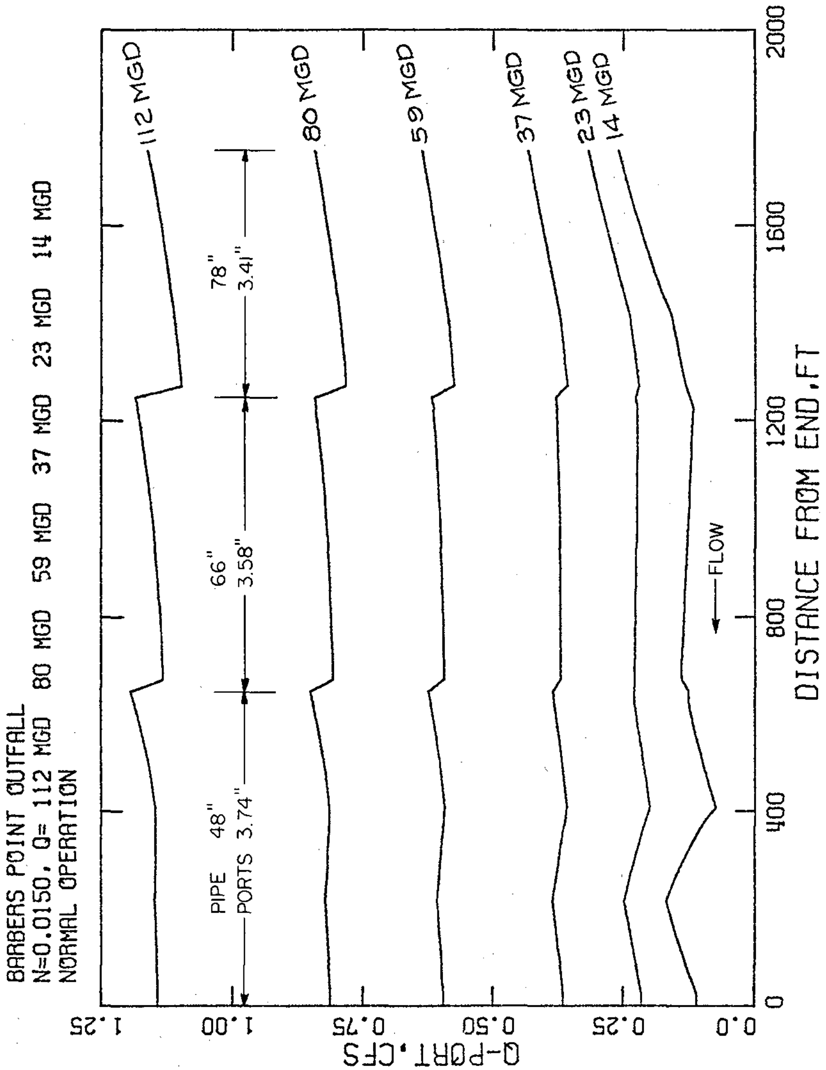


Fig. 7. Distribution of Port Discharge Along Diffuser of Barbers Point Outfall.

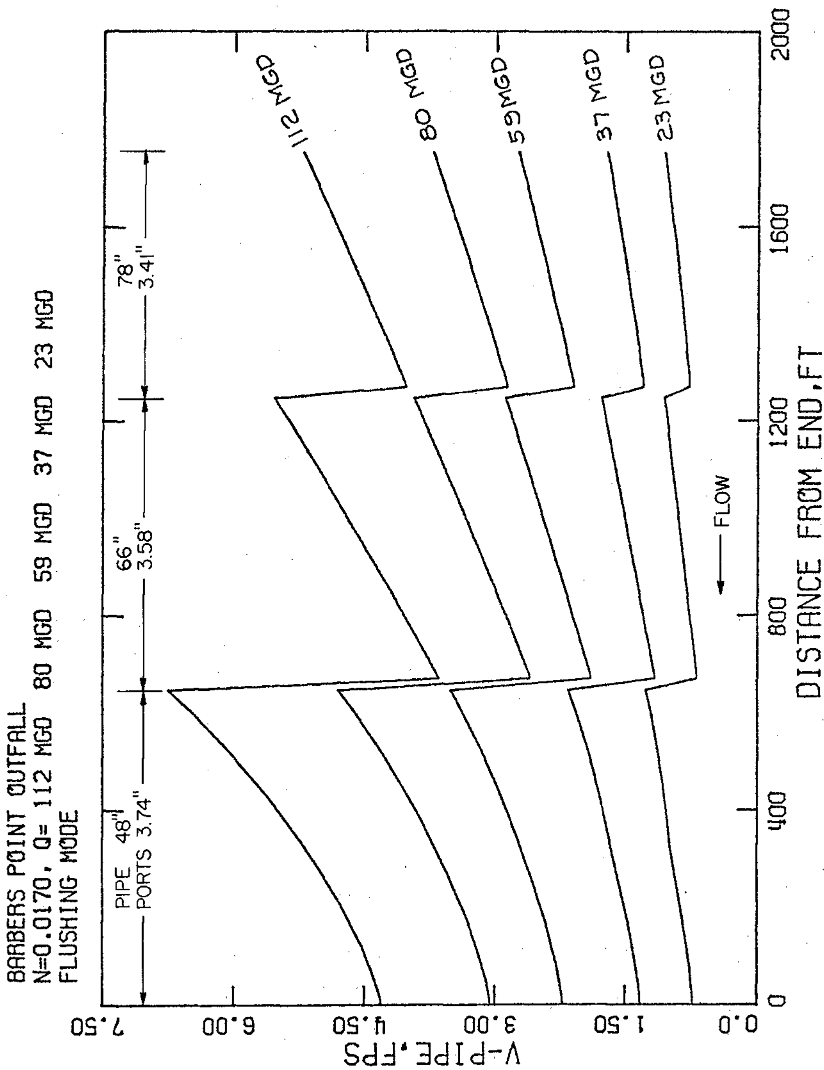


Fig. 8. Distribution of Velocity in Pipe Along Diffuser of Barbers Point Outfall.

changing often from sand to coral of varying hardness. The contractor used 500 lb. charges of dynamite (in 25-pound sacks) repeatedly along the trench, using many charges in the process. The trench excavation was especially difficult in the deeper sectors. Beyond the trench sections, the pipe was placed directly onto the ocean bottom and the work moved quickly to completion, with rock protection being used to stabilize the pipe all the way to the flap gate at the end.

The construction site is on the leeward side of the island so the contractor had a relatively calm working area. Several Kona storms interrupted the work and, on many occasions, the summer swells from the southern hemisphere stopped work because of the difficulty of loading pipe from the pipe barges onto the pipelaying barge. The contractor had allowed 3 months of downtime for weather and sea state and used up most of it during the 18-month period of construction.

The trestle was 2,500 feet long and made of steel H-pipes and beams. High speed carriers moved on the two rails to carry cranes and supplies of sheet piles and pipe. The heavy double bell section proved very difficult to connect to the pipe spigot already in place, because of the water swells in the shallow 20-foot depth. It is interesting to note that the contractor for the Barbers Point Outfall (almost identical to this one) plans to make his connection in much deeper water where the wave forces should be minimal at the joint location.

The pipelaying barge, called the "Davy Crockett", has been used on a number of outfall jobs. It is a converted World War II Liberty Ship, rigged with large anchor winches on each quarter (see Figure 9). The large crane in the center picks up the pipes and places them in a magazine until ready for laying. It then picks one of them up with a so-called "horse", places it on the ocean bottom and pushes it home into the bell of the previous pipe. Figure 9 also shows the complex pipe placing structure, called the "horse", which can pick up a pipe section and then stand on the ocean floor with its 4 legs near the previous pipe in place. Hydraulic controls, moving in 3 dimensions, carefully insert the spigot into the bell of the previous pipe. Once in place the pipe joint is tested with hydrostatic pressure. It is then rocked into position before the horse relaxes its grip on the pipe and is withdrawn. A diving bell is located near the joint. The contractor's diver is on one side, observing the joint make-up and talking by wire line to the horse operator up on the barge. The other side of the bell has a City Inspector, also observing and reporting on the adequacy of the underwater work. In some parts of the excavated trench, the trench width was so wide that the "horse's" legs were too narrow and it had to be extensively modified to straddle the trench.

Many barge loads of heavy armor stone were put in place to protect the pipe from the 46-foot design wave which was predicted as possible during the next 50 years. The initial design called for a thick concrete blanket over the pipe throughout the trench length because large rock was not available. After the job began the local quarry operator decided to make the investment in the equipment required to produce well-graded rock in five different classes ranging in nominal diameter from 1/2-foot to 2-1/2-foot. Divers controlled the placing of rocks around and on top of the pipe in the trench. Smaller size stones were placed near the pipe. This was later topped with armor stone varying up to 2-1/2-foot nominal diameter. The armor stones are of strong basalt with a specific gravity of 2.6. The well-graded mix was not easy to achieve. The City Inapectors sampled batches of these stones at random at the quarry. Each batch was separated. Then each stone of the batch was weighed and set aside into the five weight categories to validate the gradation. It proved to be a very tedious but worthwhile specification, ensuring well-graded armor protection for the pipe.

ACKNOWLEDGMENTS

The outfalls described herein were designed by the R. M. Towill Corporation under contracts for the City and County of Honolulu. The first two authors

Fig. 9. Pipelaying Barge Used in Construction of Sand Island Outfall.

(R. C. Y. Koh and N. H. Brooks) were engaged as special hydraulics consultants by the Towill Corporation for the projects. The authors acknowledge their contributions as well as others involved in the project.

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