

# Wave Forces on a Test Pipe Exposed in an Ocean Trench

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## ABSTRACT

A special steel trench segment was placed within a dredged seabed cavity in 12 m of water offshore Honolulu. An adjustable-clearance pipe, mounted in the trench parallel to the wave fronts, was equipped with force sensors during episodes of appreciable swell. Wave-induced flow history was also measured. Three trench side slopes were involved, with three pipe clearances in each case. The data demonstrate the degree to which the horizontal and vertical peak forces on an exposed pipe of prescribed gap are diminished by sheltering it in trenches of varying side slopes.

## INTRODUCTION

### Application

There are very few locations along the world's ocean coastlines, inside the 50-m depth contour, where a pipeline can be allowed to simply lie on the bottom. A major risk concerns the furious water motion associated with storm waves (Seymour, 1989) or large swell (Rudnick and Hasse, 1971). A first level of protection can take the form of ballasting the pipe with rocks or stapling the line to the substrate (Grace, 1978). In the limit, the pipe can be placed in an excavated trench that is either left open or backfilled. In the open trench case, the pipe is stabilized for two reasons: 1) the difficulty of its moving up and out of the depression; 2) the reduced hydrodynamic loadings vis-à-vis the untrenched case.

The work reported upon by Skafel and Bishop (1990) was motivated by the desire to predict the wave and current forces imposed on pipes lying in open trenches underlying the Beaufort Sea. The general intent there, as well as for some installations in the North Sea (Mangor et al, 1984), is for pipes to be placed in dredged trenches that are then allowed to backfill naturally (Mortensen and Fredsoe, 1978; Niedoroda and Palmer, 1986). This is obviously far less costly than mobilizing heavy floating equipment for the task. The risk, of course, is that severe wave conditions may pass over the pipe before it is properly buried.

In some cases, pipes may be left exposed in open trenches by accident. This happened to the Scarborough, Maine, outfall while under construction (Jubenville and Arsenault, 1983). After a December 1982 storm destroyed the crane barge, the pipe lay uncovered and apparently undamaged until another barge appeared on station in March 1983 to begin backfilling.

### Approach Herein

The specification of the peak wave-induced force on an exposed pipe in a trench will be considered two steps removed from the maximum force imposed by the same undisturbed kinematics on that pipe at zero clearance over a flat seabed. First, multiplying factors ( $Q_G$ ) can be developed that relate the peak forces on two pipes over a flat bottom, one tight against the surface and the other at a specified gap. Second, multiplying factors ( $Q_T$ ) can be assigned that link peak forces for two pipes of the same clear-

ance, but one over a level substrate and the other in a trench.

This paper seeks to provide the second set of factors, and considerable detail will be provided later. The first set of factors, derived from ocean data taken by the writer and co-workers in 1987 and 1988, appears in Table A2 (Appendix A).

### Orientation

Herein, we consider exclusively a pipe in a trench that has received no infilled material. In addition, the pipe orientation is parallel to the wave fronts. Five research programs have apparently been run to date that involve wave forces on a pipe so exposed in an open trench. Table 1 contains details, and the symbols are defined as follows:  $D$  is the outside pipe diameter;  $h$  is the water depth;  $H$ ,  $T$ , and  $L$  are respectively the height, period, and length of a surface wave train;  $b$  and  $Z$  are the trench bottom width and depth below the bottom, respectively;  $U_{MAX}$  is the peak wave-induced undisturbed horizontal flow speed (beneath the crest);  $\phi$  is the angle of the trench side slope with respect to the horizontal.

## TEST SETUP

The test site for this project was in 12 m of water offshore Honolulu. A special 2-ton trapezoidal steel trench segment, 2.44 m long, was fabricated. It was placed in an excavated natural depression in the hard seabed, and connected to cemented studs. The trench boundaries were faired in with the natural sea floor. The trench axis was oriented so as to be parallel to the fronts of anticipated test waves. These are actually swell, generated in remote Southern Hemisphere winter storms, with travel times of roughly a week.

Three different trench cross-sections were possible (Fig. 1). The steel test pipe system, enclosed therein, was the same as described by Grace (1990) and referred to in Appendix A. The pipe itself, 324 mm in outside diameter and 2.29 m long, could be raised and lowered because bolttable end plates lay within vertical tracks. Pipe clearances ( $G$ ) of 13, 64, and 165 mm were used for all three trenches, with 318 mm being set in one case.

The central 1.22-m portion of the pipe was the force-determination segment. Electrical cables linked the pair of strain gage beam sensors, within the two flanking pipe lengths, to a recorder in a boat anchored overhead. The traces of the horizontal ( $F$ ) and vertical ( $P$ ) pipe segment forces were joined by the output of a ducted current meter. This was set 0.70 m above the seabed, about 2 m from one trench end wall and in line with the pipe. The flow meter height was the same as for the previous flat-bottom tests (Appendix A). A relatively high design natural frequency for the

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