CHAPTER 199

# MODEL/FIELD COMPARISON - COASTAL BUOYANT JET

Shuen-Wei Scott Tu (1), Member ASCE
Patrick J. Ryan (2), Member ASCE
Jeffrey P. Leighton (3), Associate Member ASCE

## ABSTRACT

Calibration and verification of a 1:75 scale undistorted hydraulic model is described. The model was used to simulate the waste heat distribution in shallow and semi-confined receiving waters. The study was carried out in the laboratory by analyzing the effect of several parameters in comparisons of model and field data. Because of the shallow receiving waters, it was found that the near-field bathymetry, bottom roughness and waves were the critical parameters in achieving a reasonable simulation.

## INTRODUCTION

In recent years, there have been numerous studies investigating the behavior of turbulent jets discharging waste heat or sewage into the environment. Extensive non-buoyant and buoyant jets study programs have been carried out for various outfall conditions. In general, they can be characterized as (1) free jets (where no bounding effect is present), (2) submerged jets (where the free surface effect is unimportant), and (3) surface jets (where surface effect is important, but bottom shear is excluded). Few attempts have been made to study the condition of surface jets issuing into rather shallow receiving water. Giger, Jirka and Dracos (1985) conducted a model study for a two dimensional turbulent horizontal jet in both deep and shallow waters. They observed noticeably different jet behavior for the "shallow jets" with a relatively large amplitude meandering motion. For the present study, extensive efforts were made to calibrate a physical model with a comprehensive set of field data. Several factors that affect the jet trajectory and mixing were identified.

## MODEL DESCRIPTION AND EXPERIMENTAL APPARATUS

The hydraulic model, constructed in 1975 (Wiegel et al., 1976), is an undistorted densimetric Froude model with a scale of 1:75 (Fig. 1). The model basin is 85 by 64 by 2.5 ft deep (25 X 19 X 0.8 m) and covers a prototype area of 6400 ft (1920 m) along the coast by 4800 ft (1440 m) normal to the coast. It is located at the Richmond Field Station of the University of California, Berkeley, California. The model studies were made under contract with the University, under the direction of Professor R.L. Wiegel.

(1) Research Engineer, Pacific Gas and Electric Company, 3400 Crow Canyon Rd., San Ramon, CA. 94583
(2) Chief Hydrologic Engineer, Bechtel Civil and Mineral Inc., P.O. Box 3965, San Francisco, CA. 94119
(3) Civil Engineer, Pacific Gas and Electric Company, 3400 Crow Canyon Rd., San Ramon, CA. 94583

The offshore current direction and strength can be controlled through a system of valves and pumps. Waves are produced by a piston type paddle. The water level can be programmed to follow a selected sinusoidal tide curve. The temperature measuring system consists of an array of probes (each with five thermistors spaced 4 ft apart (prototype) in the vertical direction) with supporting structures and booms to allow three dimensional movement for sampling. The time constant of the thermistors is approximately 0.3 seconds. Mean values obtained by averaging 20 instantaneous measurements over a period of 200 seconds were found satisfactory for achieving good repetition in the model.

## FIELD DATA

In late 1983, photos were taken of the unheated jet from an observation tower at 30 minute intervals. Analysis on these photos indicated that the jet appeared to head towards the north entrance at low tides and towards the west entrance at high tides (Fig. 2)

In late 1984, when the Unit 1 reactor was undergoing power ascension testing, an extensive prototype data collection program was initiated. The field data collection consisted of temperature measurements along five horizontal transects at four depths (Fig. 3), vertical profiles at various locations within Diablo Cove (the discharge cove), and surface temperatures in the offshore area (Leighton et al. (1986A), Leighton and Tu (1986B)).

Two representative power ascension field tests were chosen for model/prototype comparisons (Table 1). The first field test (corresponding to test 5-1 in Leighton et al., 1986A) included a condition of coflowing warm and cold jets from the discharge structure with 4000 cfs (114 $m^3/s$) total volumetric flow rate. The measured offshore current was 0.7 fps (0.21 m/s) towards the

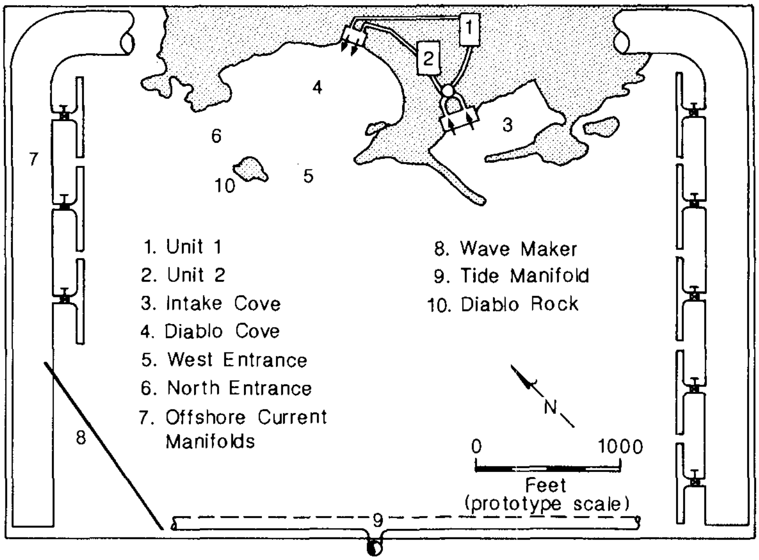



**Figure 1. Model Basin Layout**

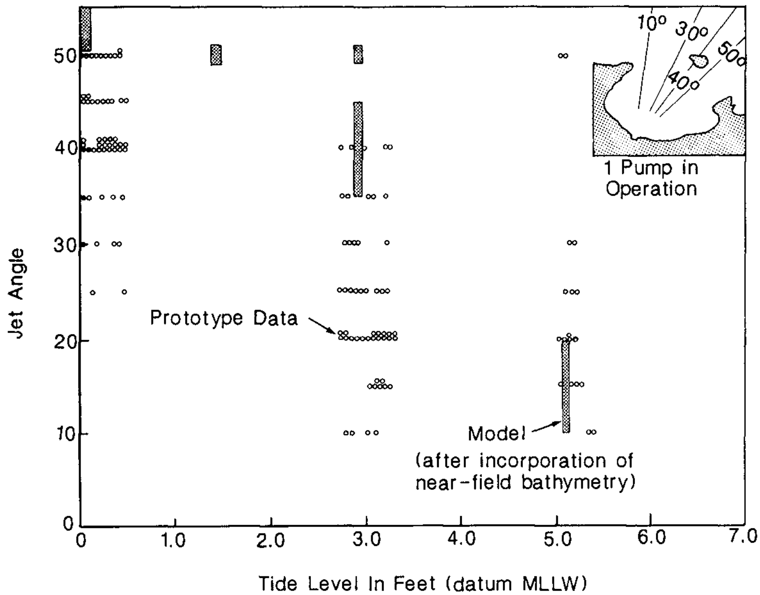



**Figure 2. Jet Trajectory Data for Model and Prototype**

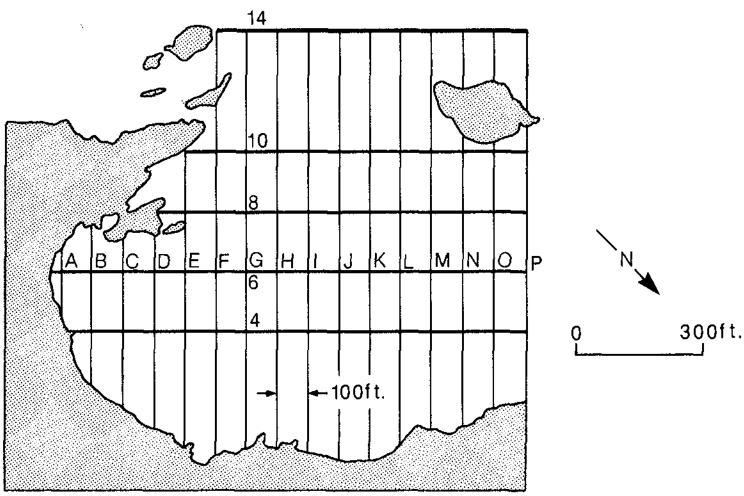



**Figure 3. Expanded View and Model Grid for Discharge Cove**

Table 1 Field Conditions

| | Case 1 (field test 5-1) | | Case 2 ( field test 6-3) | |
|---|---|---|---|---|
| | Unit 1 | Unit 2 | Unit 1 | Unit 2 |
| Discharge Flow Rate | 2000 cfs ($57\ m^3/s$) | 2000 cfs ($57\ m^3/s$) | 1200 cfs ($34\ m^3/s$) | 800 cfs ($23\ m^3/s$) |
| $\Delta T_0$ | ~18°F (10°C) | ~0°F | ~20°F (11°C) | ~20°F (11°C) |
| Tide | Mean Sea Level | | Low Water Level | |
| Offshore Current | Upcoast 0.7 ft./sec. (21 cm/s) | | Strong Downcoast 0.9 ft./sec. (27 cm/s) | |
| Waves | Sg. Ht. | Period | Sg. Ht. | Period |
| | 5 ft. (1.6m) | 7 sec. | 3 ft. (1m) | 11 sec. |

north (upcoast). The tides varied from 1.4 to 3.1 ft (0.4 to 0.9 m) with respect to Mean Lower Low Water (MLLW) datum over the two hour testing period. The second field test (corresponding to test 6-3 in Leighton et al.) consisted of two coflowing warm jets with a total flow rate of 2000 cfs ($57\ m^3/s$). The offshore current was 0.9 fps (0.27 m/s) downcoast (southerly). The tide ranged from -1.3 to -0.7 ft MLLW (-0.4 to -0.2 m).

## CALIBRATIONS

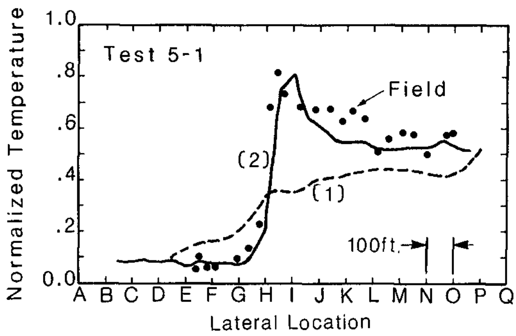
Three factors were found to significantly affect the model performance: (1) the near-field bathymetry, (2) the bottom roughness, and (3) waves.

### Near-Field Bathymetry

At the start of the calibration, some preliminary model runs using dye visualization had indicated the model jet exhibited a meandering motion (a condition similar to the description by Giger et al., 1985) and exited through the west entrance (Fig. 1) for all tidal levels. The tide-independent plume trajectory in the model was contrary to the observations of the field photo study (Fig. 2). It was found that major bathymetric features near the outfall (covering a prototype area of 100 by 150 ft (30 X 50 m)), absent in the model, were important. In the prototype, striations and rock ridges formed at an oblique angle of 20-30 degrees to the discharge centerline are apparent. During low tides, these rock ridges are close to the surface, and act as a series of vanes to deflect the jet away from the discharge structure centerline. The effect of the incorporation of this bathymetric feature into the model was dramatic and the jet trajectory at low tides was improved (Fig. 2). Nevertheless, the jet meanders in the model still persisted causing too much mixing between the two coflowing jets. The results are depicted as curve 1 in Fig. 4.

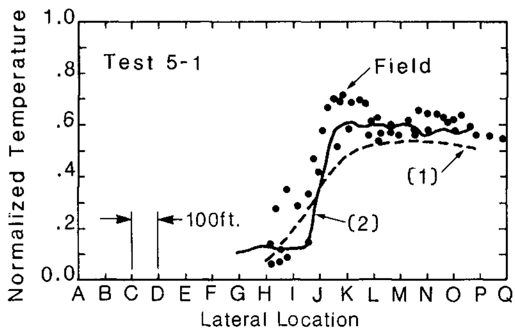
### Bottom Roughness

As a second step, 3/16" (5 mm) gravel was added to the model as random roughness to represent the presence of 1 to 3 ft (0.3 to 1 m) boulders in the prototype. The addition of the roughness greatly reduced the model jet meandering. In the region about 200 to 600 ft (60 to 180 m,



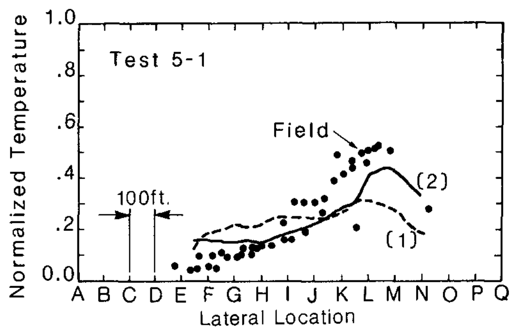

(1) Partially calibrated model - smooth bottom
(2) Final calibrated model

**Figure 4. Surface Temperature along Line 4**




(1) Partially calibrated model - no waves
(2) Final calibrated model - with waves

**Figure 5. Surface Temperature along Line 8**




(1) Partially calibrated model - no wave absorber
(2) Final calibrated model

**Figure 6. Surface Temperature along Line 14**

prototype scale) from the outfall, accurate bathymetric data were not available, and gravel was added in this wave breaking zone as a calibration tool. Model results now showed good agreement with the prototype data for areas within the first 600 ft (180 meters) from the outfall (see curve 2 in Fig. 4), but the agreement deteriorated offshore beyond line 8 (see curve 1 in Fig. 5).

### Waves

As the 3rd step, different wave conditions and the corresponding effects were investigated. Waves in the model had a marked effect on profiles in the discharge cove. It was found that model waves scaled relative to the prototype condition had relatively little effect on the inshore temperature profiles (except in extremely shallow areas in the south cove where waves are breaking), but appeared to improve line 8 and line 10. Shown in Figure 5 are two temperature profiles simulated with and without waves. However, on line 14 at the west mouth of the discharge cove, model temperatures still showed poor agreement. It appeared that waves, which were observed breaking and dissipating energy near the seaward side of Diablo Rock (Fig. 1) were actually being reflected in the model. Wave absorption material (horse hair) was put in place in this area to absorb the wave energy. The improvement is shown in Figure 6.

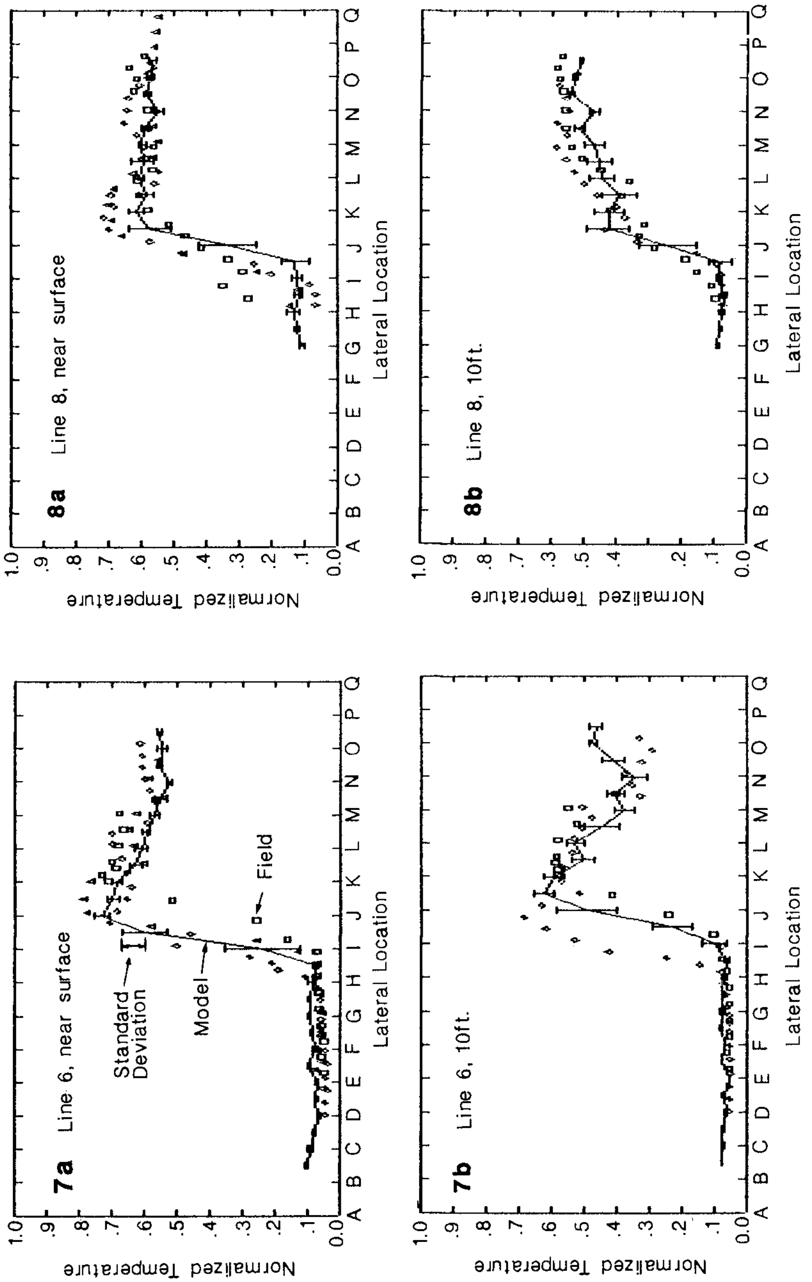
## MODEL SIMULATION RESULTS

The final model results are shown in Figures 7-10 for field test 1 and in Figures 11-14 for field test 2. In each figure, the normalized temperature is defined as the ratio of the excess temperature above the ambient to the discharge temperature rise. Figures 7-10 (case 1) and Figures 11-14 (case 2) showed the temperature distribution along transect lines 6,8,10 and 14 at two water depths respectively (i.e., near the surface and 10 ft (3 m) below the surface). Figure 15 (case 1) and Figure 16 (case 2) depict vertical profiles at two locations - one in the north portion and the other in the south portion of the discharge cove (see Fig. 3 for reference coordinates) for both cases. For case 2, inshore line 6 (Fig. 12) shows a marked temperature drop at the surface near the south cove. It was found that breaking waves at low tide in the shallow area in the south cove formed by a number of rock pinnacles produce significant mass transport and pump cold water into the area. During a sensitivity test, placing some wave absorbing material near these wash rocks significantly reduced this discrepancy.

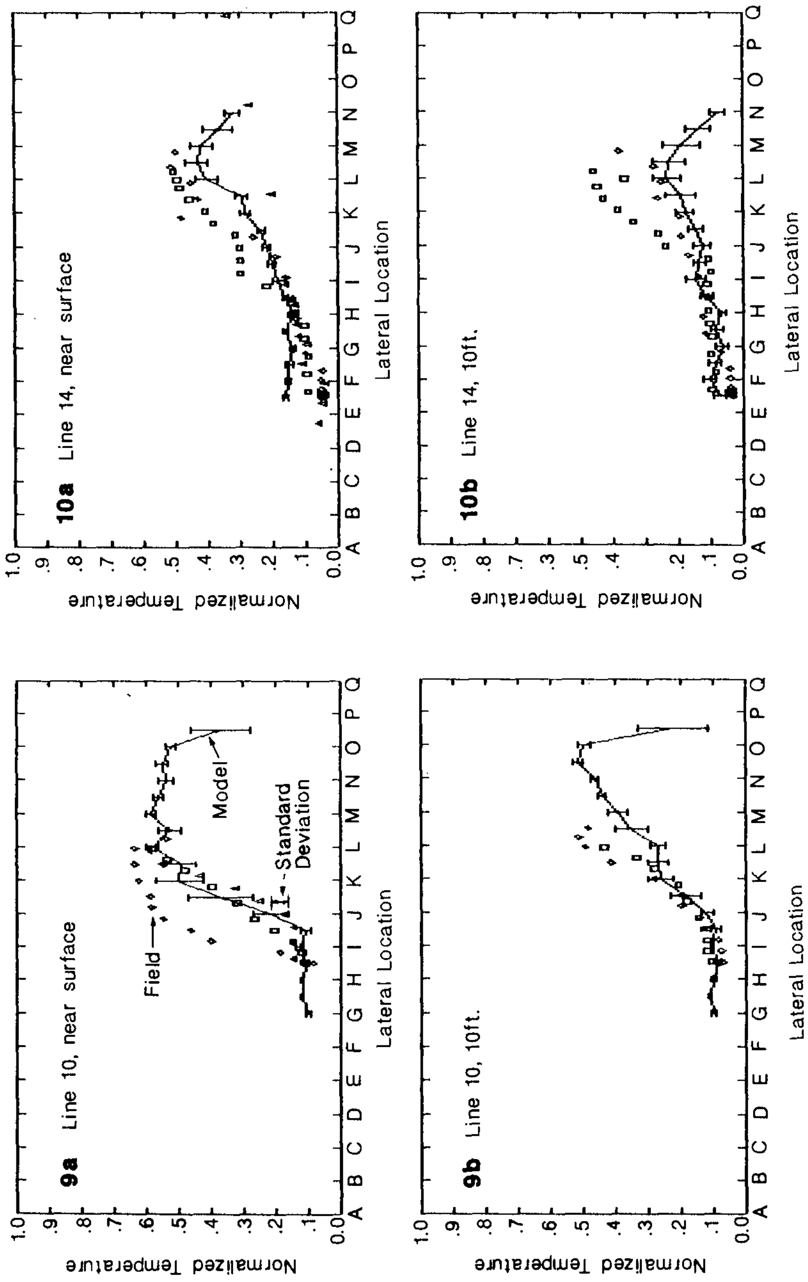
Offshore surface plume behavior was investigated for case 2 and a similar test condition (case 2A). The two field tests examined had similar discharge and environmental conditions, i.e., low tides, low waves and low winds. Both tests had a downcoast (southerly) offshore current, with case 2A having a speed 10% higher than case 2, resulting in some difference in the plume bending (Fig. 17). Both cases were simulated (6-3 026 for case 2 and 6-3 027 for case 2A). The higher cross current model test (6-3 027) was produced with slightly higher waves in comparison to the lower current test (6-3 026). Both model tests showed good agreement with the corresponding prototype data for the plume trajectories (Fig. 17). The isotherm area comparison between model and field exhibited satisfactory results as shown by Figure 18. The isotherm contour configurations for the model test 6-3 027 and field test (case 2A) are shown in Figure 19, and are remarkably similar.

## CONCLUSIONS

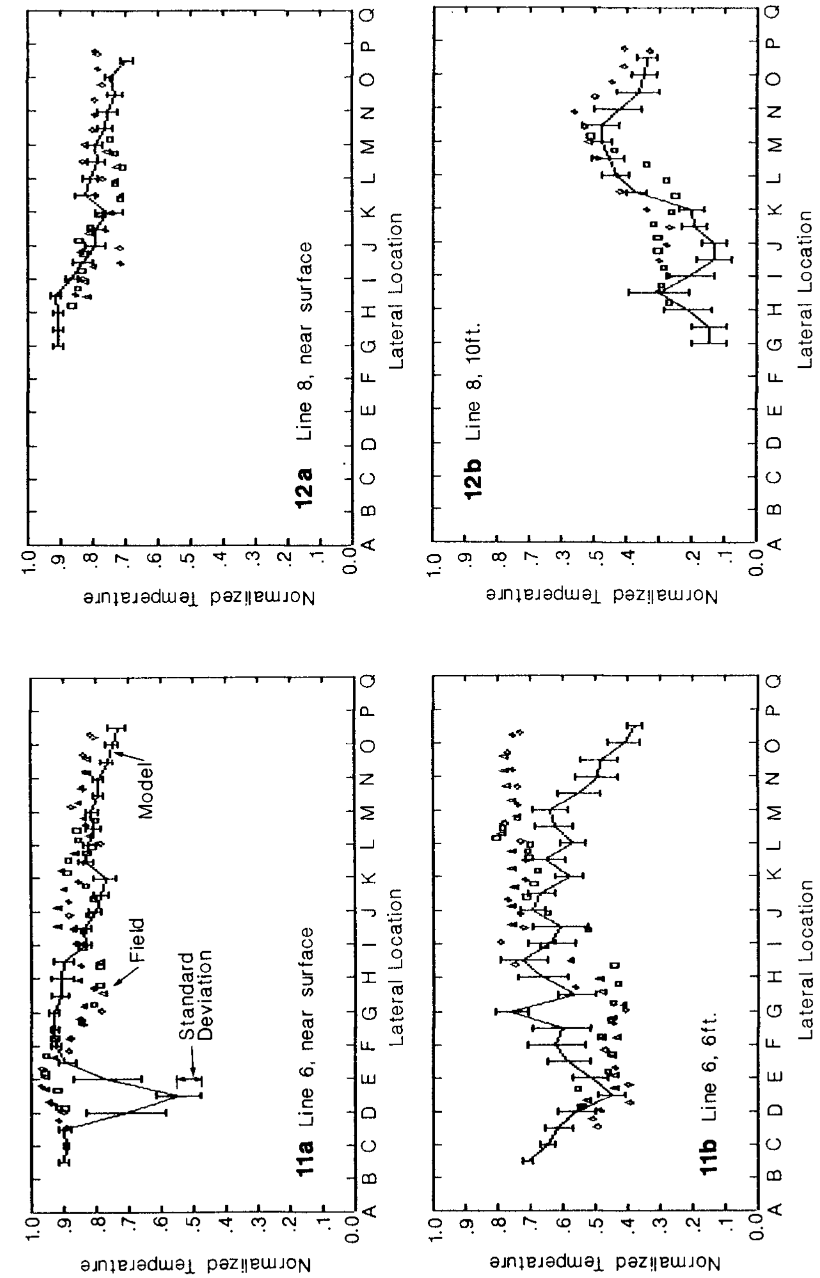
It appears that the bottom shear has a great impact on the behavior of a shallow water jet. The near-field bathymetry affects the jet trajectory, and random roughness inhibits the development of the jet meandering. Waves also play an important role in the interfacial mixing between two coflowing jets. In shallow areas where waves are breaking and are difficult to scale in a small scale model, material to absorb the wave energy can be used to improve model/field agreement.



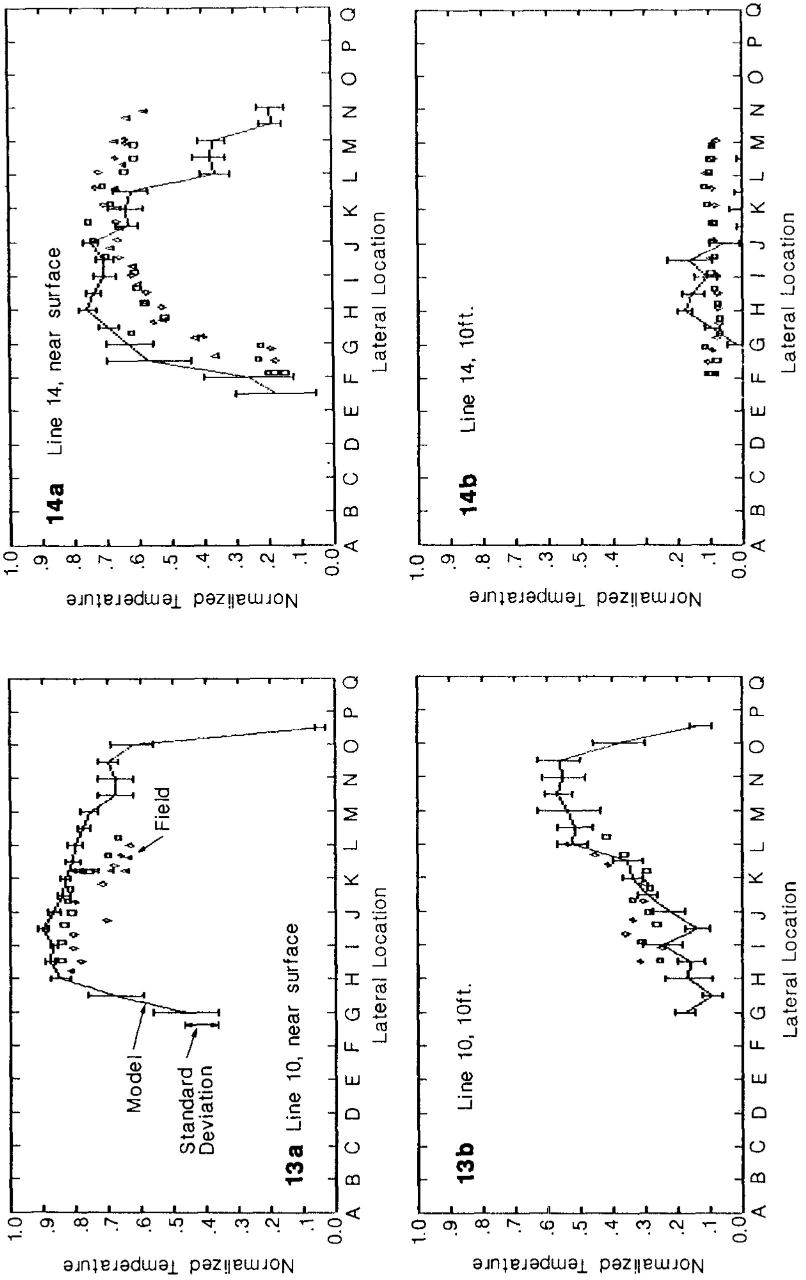

**Figures 7 & 8. Comparison of Model and Field Temperature Profiles**



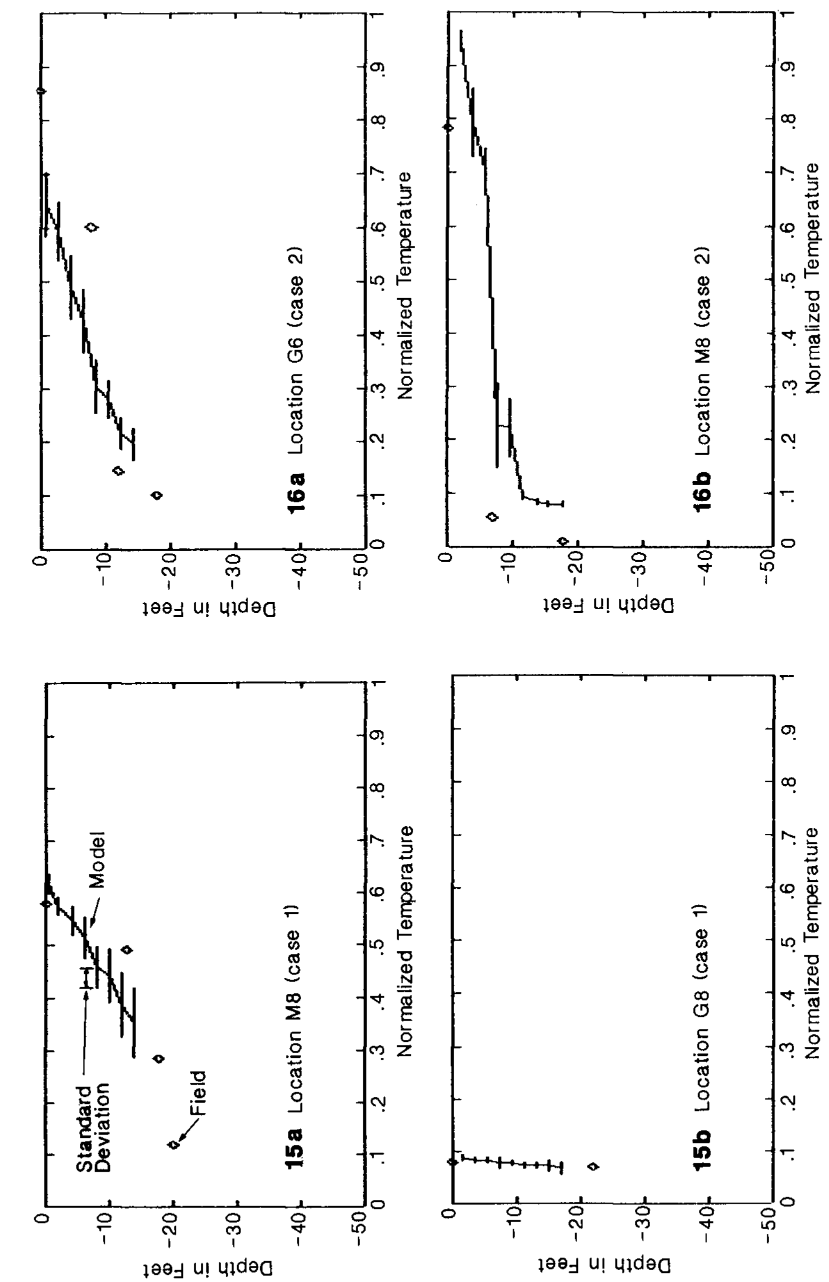

**Figures 9 & 10. Comparison of Model and Field Temperature Profiles**




**Figures 11 & 12. Comparison of Model and Field Temperature Profiles**




**Figures 13 & 14. Comparison of Model and Field Temperature Profiles**




**Figures 15 & 16. Comparison of Model and Field Vertical Temperature Profiles**

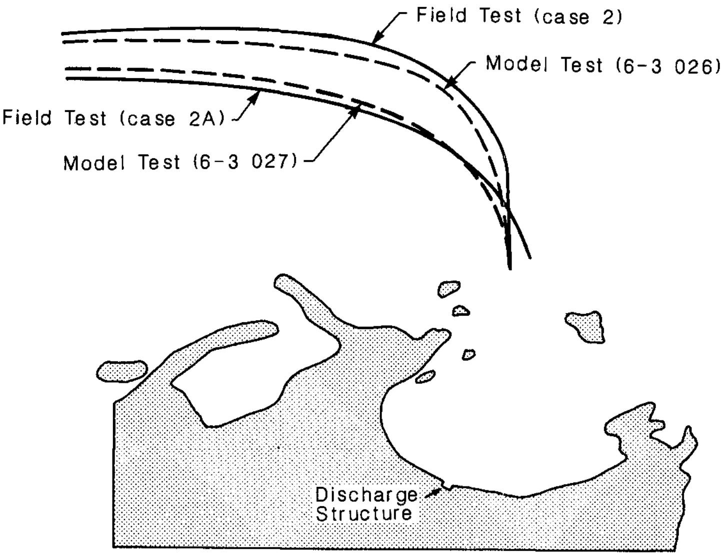



**Figure 17. Comparison of Offshore Plume Trajectory between Model and Field data for Case 2 and Case 2A**

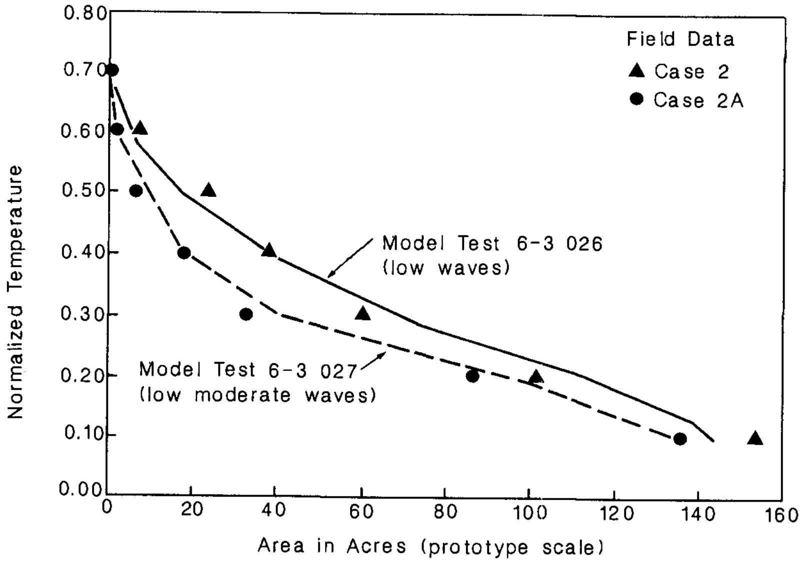



**Figure 18. Comparison of Surface Plume Areal Spread between Model and Field Data for Case 2 and Case 2A**

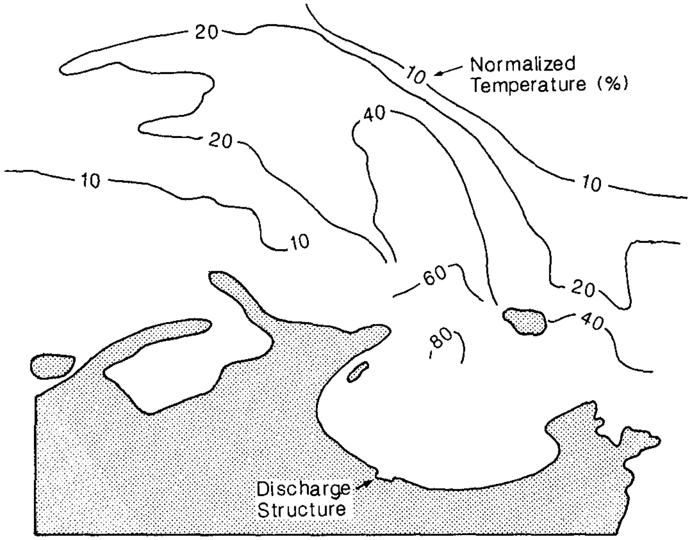



**Figure 19a. Offshore Plume Configuration for Model Test 6-3 027**

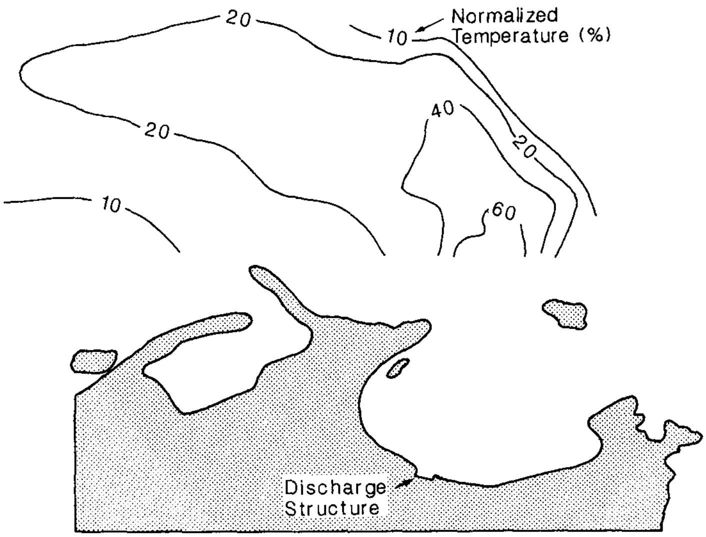



**Figure 19b. Offshore Plume Configuration for Field Test Case 2A**

REFERENCES

GIGER, M., JIRKA, G.H. and DRACOS T.H., (1985), "Meandering Jets in A Shallow Fluid Layer", Proc. Fifth Symposium on Turbulent Shear Flows, Cornell University, Ithaca, New York.

LEIGHTON, J.P., TU, S.W., PETROCCITTO, A.A. and EASTMAN, L.K., (1986A), "Characterization of Receiving Water Temperatures During Power Ascension Testing of Unit 1 of Diablo Canyon Power Plant", Report 420-85.748, Department of Engineering Research, Pacific Gas and Electric Company, San Ramon, California.

LEIGHTON, J.P. and TU, S.W., (1986B), "Field Studies of Buoyant Jet in Coastal Waters", ASCE, 20th International Conference on Coastal Engineering, Taipei, Taiwan, Republic of China, 9-14 November, 1986

WIEGEL, R.L., HARMS, V.W., SAFAIE, B., CUMMING, J.D., DELLA, R.P., LEIDERSDORF, C.B. and YOUNG, C., (1976), "Report of Model Study of Cooling Water System of Pacific Gas and Electric Company Nuclear Power Plant Located at Diablo Canyon, California", Supplement Report No. 8 to Environmental Report Units 1 and 2 Diablo Canyon Site; also Report No. HEL 27-2, Hydraulic Engineering Lab., University of California at Berkeley, California.