CHAPTER 131

OIL SPREADING ON COASTAL WATERS

by

Young C. Kim*

ABSTRACT

The area of oil spread was measured in the laboratory and the predictable model was established in determining the spreading area of oil on coastal waters. The relationship between the oil slick and the Reynolds, Froude, and Weber numbers was examined and the influence of wind, currents, and waves on the spread area was investigated. The effects on the changes in water depth and the alteration of the net spreading coefficient on oil spreading capacity were also examined. Comparison between the existing field measurements and the laboratory work was made.

INTRODUCTION

The problem of oil spillage in the coastal zone has been one of great magnitude and concern to the public, to industry, and to the federal government, particularly in this period of ecological awareness. The Torrey Canyon disaster in 1967, the 1969 Santa Barbara Channel blowouts which discharged 336,000 gallons of crude oil, and recent accidental spills caused by collision of marine vessels are examples of major sources of spilled oil on coastal waters. When such a crisis of oil spill arises, there is an immediate need to determine how fast the oil will spread and how far it will go in a given time so that a reasonable plan for containment and collection of oil can be carried out.

*Professor of Civil Engineering, California State University, Los Angeles, Los Angeles, California, U.S.A.

The present study is focused on the problem when the volume of spilled oil is relatively small and the water depth is shallow as in the coastal zone. The objectives of the study are to investigate (1) the oil spreading phenomena on the shallow coastal waters with sloping bottom (2) the effects of wind, waves, and currents and their relative magnitude of influence on oil spreading (3) influence of beach slope, and (4) obtain a predictable equation for oil slick transport on the coastal waters.

THEORETICAL CONSIDERATIONS

This complex phenomena of spreading of oil on coastal waters should be considered under three possible conditions: the first, spreading of oil in tranquil water; the second, convection by winds, waves, and tidal currents; and the third, transformation of waves due to change in water depths. However, in nature the oil slick is greatly displaced either by strong winds and weak currents or relatively strong tidal currents.

Basic assumptions are needed to study this complex phenomena. It is assumed that the principle of superposition for fluid velocities due to wind, waves, and currents is still valid and that the viscosity and surface tension force predominate since the amount of spill is relatively small. All oil slicks are quite thin; hence oil is in hydrostatic equilibrium in the vertical direction. Lastly the properties of oil do not vary with time and evaporation, dissolution of the soluable components and biological degradation of oil are absent.

A dimensional analysis of the pertinent parameters involved in the problem is carried out and the area of oil spread including the effects of wind, tidal currents, waves, and change in depths is expressed as

$$\ell = h f \left[R, F, W, \frac{u}{U_w}, \frac{u}{U_c}, \frac{u}{U_{wi}} \right]$$

where ℓ is the diameter of oil spread, h is the water depth, R is the Reynolds number, F is the Froude number, W is the Weber number, u is the volume flow rate per unit area, and U_w, U_c, and U_{Wa} are the velocities of wind, currents, and waves respectively.

For the spreading of oil in tranquil water, Fay (1) describes the regimes of oil spreading as (a) the beginning phase in which only gravity and inertia forces are important, (b) an intermediate phase in which gravity and viscous forces dominate, and (c) a final phase in which surface tension is balanced by viscous forces. The final area of oil spreading in calm water in the tension regime is given as

$$\ell = \left(\frac{\alpha^2 t^3}{\rho^2 \nu}\right)^{\frac{1}{4}}$$

in which ℓ is the final area, α is the net surface tension, t is the time, ρ is mass density, and ν is the kinematic viscosity of the water. It is significant to note that in the inertial and viscous regimes, the rate of spread is proportional to one-fourth and one-third power of the volume released respectively, and in the surface-tension regime, the final area is independent of the released volume of oil.

The drift due to wind can be estimated because the turbulent shear stress at the water interface is the same in both the air and the water. Furthermore the velocity of water is approximately three percent of the wind velocity and the drift due to tidal currents can be estimated as the velocity of water itself. Hoult (2) assumed that the two-velocity vectors can be added when both wind-driven currents and tidal currents are present. The drift due to waves may not be the significant factor in the inertial regime; however, in the surface tension regime, the rate of drift may be influence by the waves as the water depth changes in coastal areas. For shallow water waves the situation is much more complex, particularly where the bottom is sloping. In water which decreases in depth in the direction of wave propagation, the phase velocity also decreases with distance. At the same time, the amplitude increases so that fluid velocity increases rapidly. For similar reasons, mass transport velocity increases rapidly and as breaking is approached, the phase velocity, instantaneous particle velocity, and net particle velocity approach each other in magnitude and direction.

EXPERIMENTAL INVESTIGATION AND DISCUSSION OF RESULTS

The tests have been conducted in a plexiglass tank 6 inches wide, 5 feet long, and 1 foot deep with adjustable bottom slope and water depths. Oil has been introduced at the upstream and oil velocity and arrival time have been measured by photocell technique. Three photocells were placed on the bottom 2 feet apart. Variation of water levels from 6 to 3 inches and the change of bottom slope of 2 to 5 percent were used. The tests were conducted in the following three situations: (a) oil spreading by wind, (b) oil spreading by waves, and (c) oil spreading by current.

Dimensionless velocities, oil velocity to wind velocity, vs. Reynolds number and the bottom slope were plotted as shown in Figure 1. Comparison has been made by superimposing the results obtained by Keulegan and O'Brien in the flume tests. The following comments are of particular significance from the plot. The experiments show that the oil velocity on the water surface is basically the same as the water particle velocity and that the oil velocity induced by the wind is independent of density and viscosity of oil. Moreover, both velocities, velocities of oil and water, tend to increase with the wind velocity and water depth. The relative velocity lies between 2 to 4 percent as the Reynolds number varies from 10^3 to 10^5. It can be seen that oil velocity is nearly 3 percent of the mean wind velocity for low Reynolds number and is less than 4 percent of the mean velocity at Reynolds number greater than 10^4. The tests also show that at Reynolds number greater than 10^5, u over U ratio tends to be constant. A comparison of measured oil slick size to experimentally obtained oil spreading length in a sloping channel has been made and plotted in Figure 2. Case (1) is the displaced length of oil when the wind and waves were superimposed and case (2) is the displaced length of oil when the currents and waves were superimposed. Obviously oil slick transport on the coastal water is greatly influenced by the wind rather than currents on the shallow water.

CONCLUSIONS

The findings of the study reported here may be summarized as follows:

1. When a small volume of oil is spilled in shallow coastal waters, the rate of spread is much greater than in deep water. Any assumption that oil spreading on the coastal water is the same as in tranquil water gives too conservative an estimate of spreading length.
2. Oil spreading in shallow coastal water is greatly influenced by wind, waves, and currents. Moreover, the currents induced by waves can not be neglected in shallow coastal waters.
3. Assuming that the concept of superposition is valid, the oil slick velocity due to wind and waves seems to be greater than the velocity due to waves and currents.
4. Effect of changing depth or beach slope has very little influence on oil slick velocity in coastal waters. Particularly, for wind generated waves, the changing depth has no influence on the velocity of oil spreading.
5. There is a need for more scientifically controlled investigation on oil slick transport, particularly in the determination of true wind, waves, and current velocities. Further research is needed in developing more realistic solutions to the three-dimensional oil spreadin- phenomena.

REFERENCES

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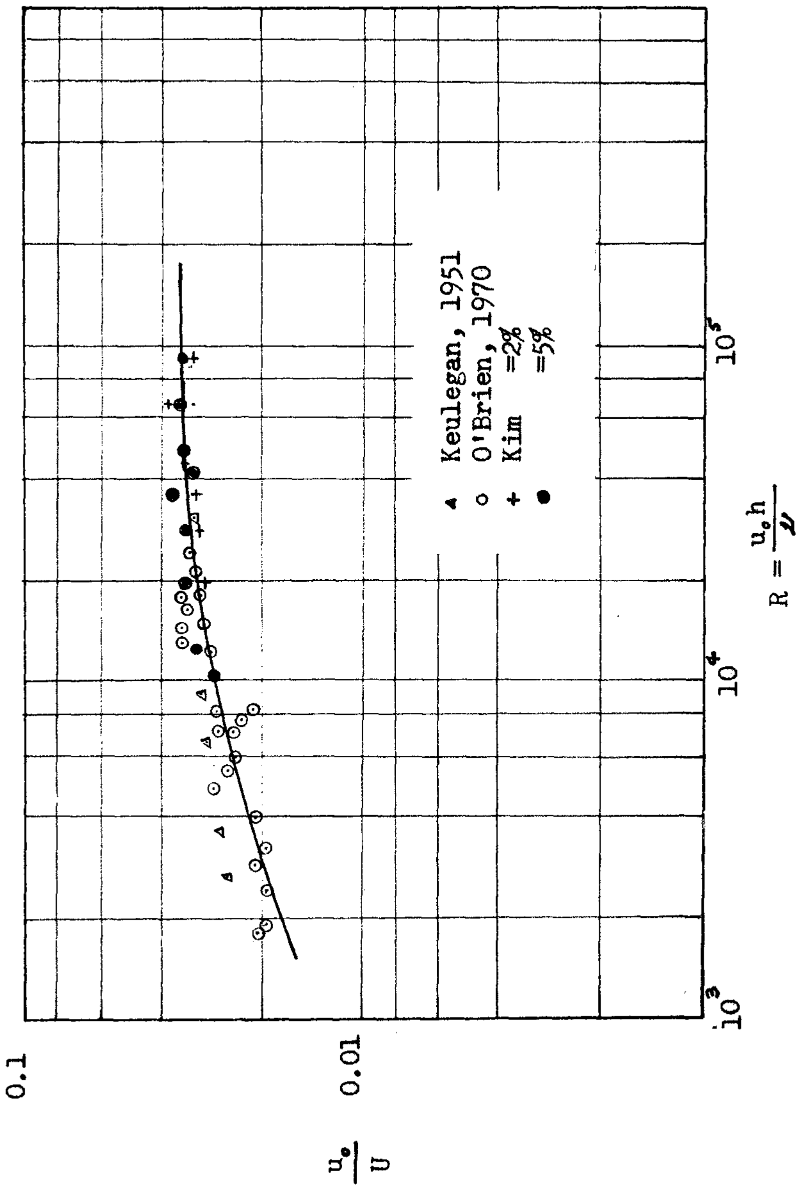

Fig. 1- $\frac{u_o}{U}$ vs. Reynolds Number and α

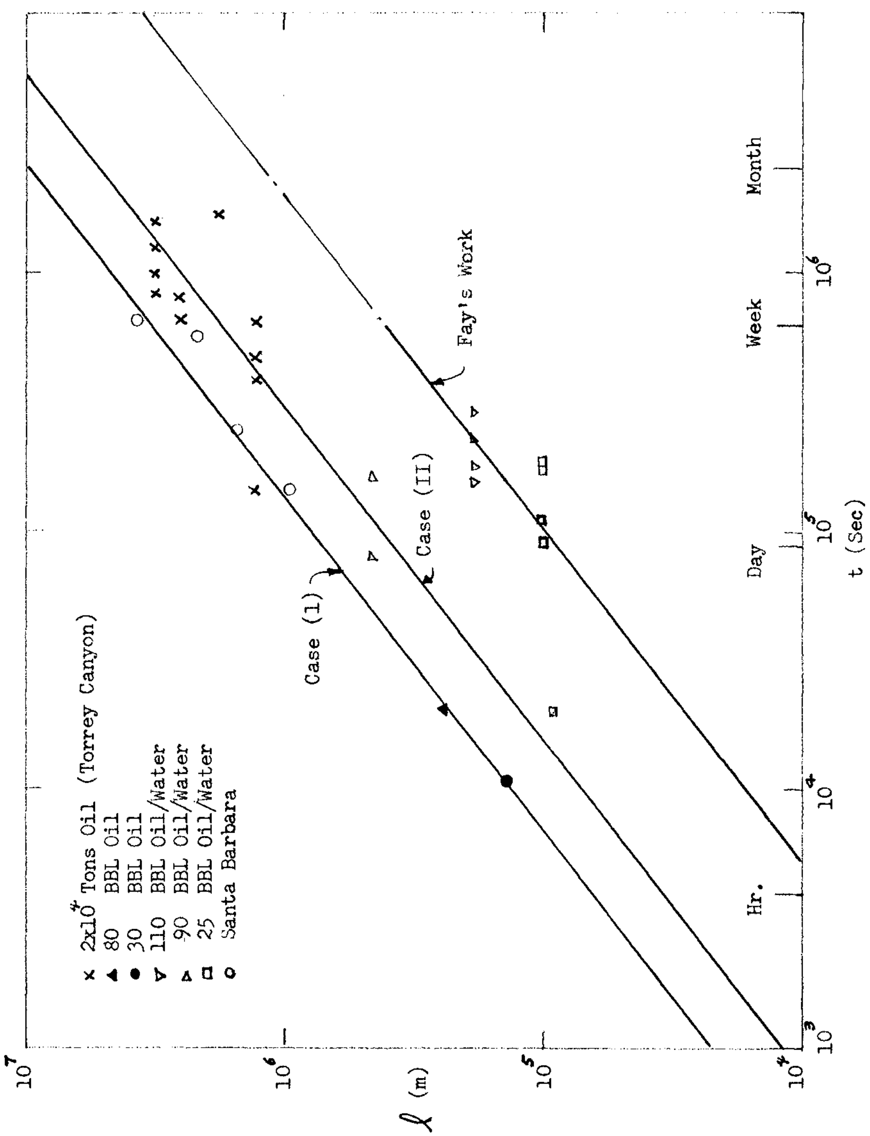

Fig. 2- A Comparison of Measured Oil Slick Size and the Experimentally Obtained Oil Spreading Length in a Sloping Channel