Environ. Eng. Res. Vol. 9, No. 1, pp. 23~30, 2004
Korean Society of Environmental Engineers

PENETRATION OF DISPERSED AND WEATHERED OIL AND ITS ECOLOGICAL IMPLICATION IN MODEL SANDY BEACH

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(received August 2003, accepted February 2004)

Abstract : Internal flow within tidal flat is closely associated with biological activities in this area. Seawater is a kind of transport medium for dissolved matters and particulate matters, which are necessary for survival of benthic organisms in coastal zone. Therefore, determination of the internal flow rate by wave and tidal actions is important for understanding its ecological role. Various anthropogenic pollutants are threatening the coastal ecosystem. One of significant anthropogenic pollution is oil pollution. Huge oil spill by tanker accidents induce seriously damage to ocean and coastal environment. The purpose of this study is to clear the effects of wave and/or tidal action on penetration of weathered oil and dispersed oil and to evaluate the effects of penetrated oil on seawater infiltration into the sandy beach sediments. A sandy beach simulator was used, which composed of model sandy beach, wave maker, tide control device, temperature control system and computer controlling system. The dispersed oil was penetrated into the sediments by wave action, not by tidal fluctuation. On the contrary, the crude oil and weathered oil was penetrated by tidal fluctuation not by wave action. The first tide is the most important for the penetration of both weathered oil and dispersed oil, and oil concentrations were highest within the upper 2 cm. When oil of 1 L/m^2 was penetrated, the infiltration volume of seawater was decreased to approximately 1/2 by crude oil and 1/5 by weathered oil, not affected by dispersed oil. These results indicate that the crude oil and weathered oil have bad effects on benthic organism due to the reduction in the supply of oxygen, nutrient and organic matters in the sandy beach.

Key Words : Model sandy beach, Weathered oil, Dispersed oil, Seawater infiltration

INTRODUCTION

Internal flow within tidal flat is closely associated with biological activities in this area. Seawater is a kind of transport medium for dissolved matters such as dissolved oxygen, nutrients and organic matter and particulate matters such as plankton, bacteria and detritus, which are necessary for survival of benthic organisms in coastal zone.[1-6] Therefore, determination of the internal flow rate by wave and tidal actions is important for understanding its ecological role.

Various anthropogenic pollutants are threatening the coastal ecosystem. One of the significant anthropogenic pollution is oil pollution. Huge oil spill by tanker accidents induces seriously damage to the ocean and coastal environment. When spilled oil stranded and penetrated into coastal sediments, the oil deteriorates benthic ecosystem directly and indirectly making the sediment anaerobic[7] or reducing of grazing pressure of grazer.[8] In addition, penetrated oil may reduce the supply of oxygen and nutrients necessary for benthic organisms by the reduction of seawater infiltration.

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The author has studied the earlier penetration behavior of spilled fuel oil C and its effects on the infiltration of seawater in coastal zone.[9-11] However, the penetration of crude oil, weathered oil and dispersed oil and their effects on the seawater infiltration are not studied, although fuel oil C and other oils have significant difference in physicochemical properties.[11-12]

The purpose of this study is to clarify the penetration behaviors of spilled oils by wave and/or tidal action and to evaluate the effects of penetrated oils on seawater infiltration into the sandy-beach sediments.

MATERIAL AND METHODS

Experimental Set-up

The sandy-beach simulator is composed of a sandy beach (L 5.0 m×W 0.8 m×H 1.0 m), wave maker (breaking wave height: ~50 mm high), tide control device (tidal period: 1-7hr), reservoir (4 m^3), the temperature control system (3-30°C). This facility, shown in Figure 1, is automatically controlled by computer system. The body of simulator is made of FRP and has two observation windows (0.9 m by 0.6 m for each). The simulator was filled with transparent glass beads (diameter=1 mm, particle density=2.5 g/cm^3) as model sediments to visualize the infiltrations of seawater and spilled oils into sandy beach sediments. The sediment profile was inclined by about 1/10. Synthetic seawater was made to have a salinity of 32±2 psu using tap water and commercial salt for aquarium (MARINE- TEC. Co. Sealife).

In this study, breaking wave height (Hb) and wave periods were set at 50 mm and 0.8 sec, respectively, because low energy waves which had Hb of 50-100 mm and wave periods of 0.8-2.0 sec were often observed in enclosed Hiroshima Bay, Japan. There is no wave reflection in the simulator, because wave absorber is set up in the opposite side of wave maker and absorbs generated wave. Tide was controlled with semi- diurnal tidal cycle, and vertical fluctuation velocity of seawater by tide was determined as 0.009 cm/sec based on the mean tidal range of 2 m in the Hiroshima Bay.

The water level was fluctuated with the range of 45 cm, 15 cm upward and 30 cm downward from the sediment surface of right-side observation window (Figure 2). Out of tidal range was set as lag time for next rising or falling tide to simulate the tidal fluctuation of field, because the oil penetration is correlated with tidal period.

Seawater Tracer and Test Oil

Potassium permanganate solution (0.02 mol/L) was used as a tracer to track the infiltration of seawater into the sandy beach sediments by wave and tidal actions. Specific gravity of the

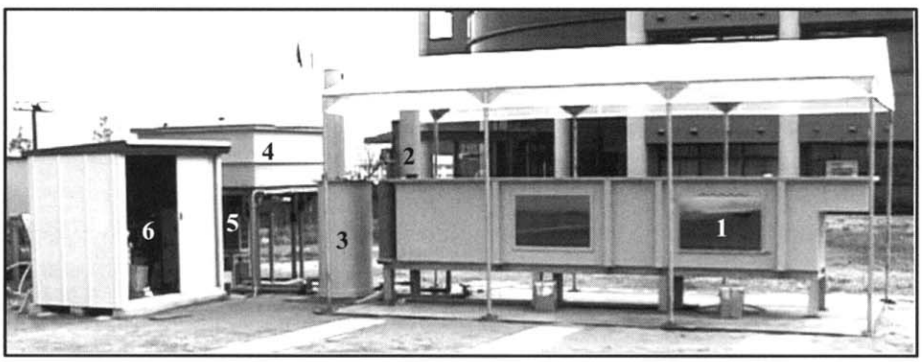


Figure 1. Image of model sandy beach (1: sandy beach, 2: wave maker, 3: tide control device, 4: reservoir, 5: temperature control system and 6: computer control system).

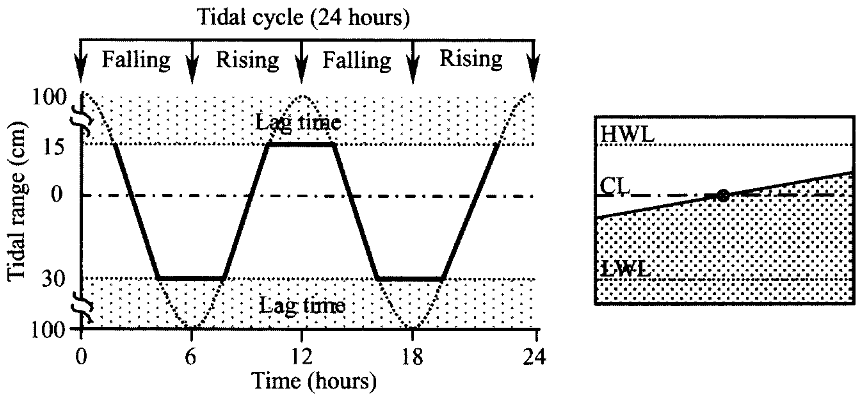


Figure 2. Tidal fluctuation. Dashed line shows tidal range from the sediment surface of observation window on right side (HWL; high water level, CL; center line, LWL; low water level).

potassium permanganate was 1.01. The potassium permanganate of 25 ml was injected onto the saturated sediment surface using pipette.

Upper Zakum crude oil with viscosity of 19 centipoise (cP) at 18°C was used in this study. In order to make weathered oil from the crude oil, the small fraction of the crude oil was evaporated by air stripping method, so that 20% of volatile fraction by weight was reduced. Then the evaporated oil was emulsified with 80% (v/v) seawater by vertically vigorous shaking in a separatory funnel for 30 min equipped in shaker (TAITEC, Co., Recipro Shaker SR-Ⅱw) to obtain stable water-in-oil emulsions (w/o emulsions) formed. These procedures to make the stable emulsified oil were in consideration of the previous oiling studies.[13] The viscosity of the emulsified oil (weathered oil) was 700 cP at 18°C.

On the other hand, TAIHO Self Mixing S-7 (manufactured by TAIHO Industries Co., LTD.) was selected as a dispersant to make dispersed oil. The dispersant was thoroughly premixed with the evaporated oil in the oil-to-dispersant ratio of 25:1 (w/w), and then horizontally mixed with seawater in a beaker set in shaker (EYELA Co., Uni Thermo Shaker NYS-3000) for 30 min. The ratio of water to oil to dispersant was 25:25:1. The viscosity of the dispersant mixed oil and the dispersed oil with water were 115 and 28 cP at 18°C, respectively. The viscosities of oils were determined by using brook-field viscometer (U-tube Reverse Flow Viscometer, Thomas Kggaku Co., LTD).

Oil (as net evaporated oil) of 1 L/m^2 was applied on the surface of water at high tide in sandy-beach simulator. Added oil volume was considered based on the previous studies on oil spills.[14-18]

Oil Penetration by Wave and/or Tidal Actions

Three experimental approaches were conducted; wave only (for 5 minutes), tide (for 6 hours) and the combination of wave and tide only (for 6 hours). In the case of the "wave only", waves were applied for 5 minutes without any tidal movement. In the case of "tide only", the water level was lowered from HWL to LWL (Figure 2) by tidal fluctuation at tidal velocity of 0.009 cm/sec without any wave. Both wave and tidal fluctuation were applied for a tidal cycle in case of "wave and tide combination".

The infiltration of the oil and seawater was measured by visual observation and image analysis taken by video camera (SONY Co., Digital Handy Camera DCR-VX1000).

Long-term behavior of penetrated oil

To estimate penetration of stranded oil into the sediments, the applied oils were spread over the water surface at HWL, and evenly stranded on the sediment surface by falling of water level. The vertical movement of stranded oil in the sediments was monitored under "wave and tide combination" for 15 tidal cycles.

At the end of experiment, oil-contaminated sediments was sampled with a cylindrical acryl core split lengthwise and taped together (diameter=5 cm, length=30 cm) to determine the vertical distribution of the oil contents. The sediments was sliced with 2 cm interval and mixed completely prior to extraction by dichloromethane. The oil concentration was determined by Thin-layer Chromatography (TLC) in combination with a flame-ionization detector (FID) employing Chromarod Ⅲ (Iatron Laboratories Inc., Tokyo).

Effects of Penetrated Oil on the Seawater Infiltration

To clarify the effects of perpetrated oils on the infiltration of seawater, the potassium permanganate was injected on the upper layer of the oil-penetrated sediments using pipette. Then plunger-type wave maker generated wave. The infiltration of the tracers was surveyed by visual measurement and by a video camera (SONY Co., Digital Handy Camera DCR-VX1000). The infiltration rate of the tracer by wave action into sediments was qualified by analyzing image taken by video camera. The tracers were applied at two tidal cycle intervals.

RESULTS AND DISCUSSIONS

Oil Penetration by Wave and/or Tidal Actions

Figure 3 shows the penetration of seawater and oils by wave and/or tidal actions. Seawater infiltrated into the sediments to 21 cm from the sediment surface by wave action for 5 min. The crude oil and weathered oil did not penetrate into the sediments in spite of the same wave action. On the other hand, periodic wave caused penetration of oil droplets dispersed from the wave breaking run-up point with radial direction similar to infiltration of seawater (see Figure 4-a).[9,19] The infiltration depth of dispersed oil was 12 cm after 300 sec of wave action, but crude oil and weathered oil did not penetrate in 300 sec.

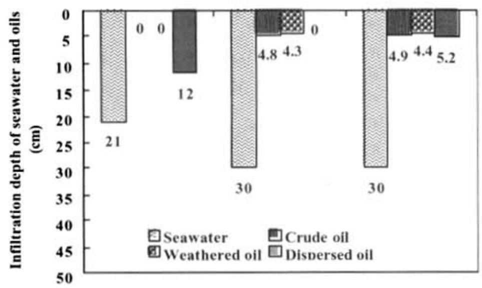
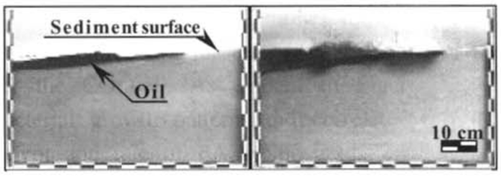
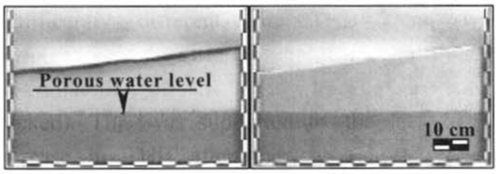


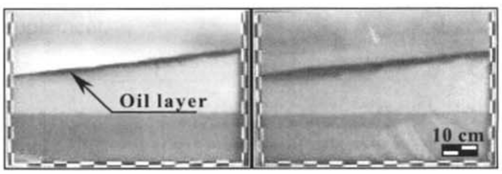
Figure 3. Penetration depths of seawater, crude oil, weathered oil and dispersed oil by wave and/or tidal.



(a) Weathered oil (left) and dispersed oil (right) by wave action after 90 sec.



(b) Weathered oil (left) and dispersed oil (right) by tide action after 3,800 sec.



(c) Weathered oil (left) and dispersed oil (right) by wave and tidal action after 3,800 sec.

Figure 4. Penetration images of spilled oils by wave and/or wave action.

It is suggested that dispersed oil could be penetrated by wave action, because the small sized-oil droplets in the water column is permitted to penetrate into the interstitial spaces together with seawater.

Seawater also infiltrated into the sediments by tidal fluctuation. The crude oil and weathered oil also penetrated with much slower velocity than seawater. However, the dispersed oil did not penetrate into the sediments despite of same tidal condition (see Figure 4-b). After a falling tide, the infiltration depths of seawater, crude oil and weathered oil were 30 cm, 4.8 cm and 4.3 cm, respectively.

It is suggested that no penetration of dispersed oil by tidal fluctuation is resulted from the less attachment of oil droplets to sediment particles[20], because attached oil (stranded oil) would be penetrated into interstitial spaces of sediments with the falling of porous water level based on the our previous study.[9]

The crude oil, weathered oil and dispersed oil gradually penetrated into the sediments by wave and tidal action (see Figure 4-c). The infiltration depths of seawater, crude oil, and weathered oil and dispersed oil after 6 hr were 30 cm, 4.9 cm, 4.4 cm and 5.2 cm, respectively.

From these results, we would suggest that there are significant differences in penetration behaviors by wave and/or tidal action between the dispersed oil and crude oil and weathered oil. The dispersed oil penetrated into the sediments by wave action, but did not penetrate by tidal fluctuation. On the contrary, the crude oil and weathered oil penetrated by tidal fluctuation not by wave action.

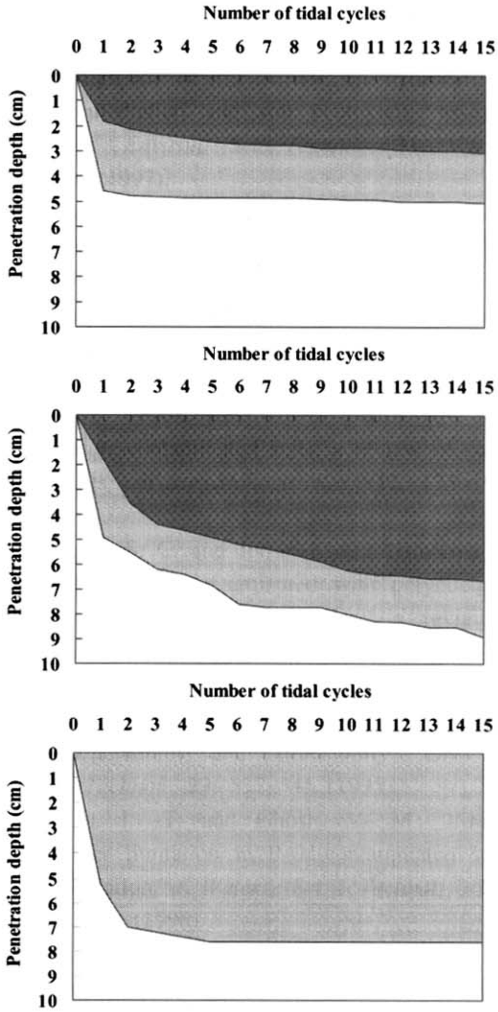


Figure 5. Long-term behaviors of penetrated crude oil (top), weathered oil (middle) and dispersed oil (bottom) over 15th tidal cycles.

Long-term Behavior of Penetrated Oil

Figure 5 shows the vertical penetration of stranded oils over 15 tidal cycles. The layers of the crude oil and weathered oil penetrating could be separated into black and brown layers. Dispersed oil, however, penetrated with only brown layer. The strongest penetration occurred at first tidal cycle among three oils. The penetration depth of black and brown layers slightly deepened after first tidal cycle to 15th tidal cycle. The black layer of weathered oil was gradually deepened with tidal cycle from 1.8 cm at first tidal cycle to 6.6 cm at 15th tidal cycle, and those of brown layer were 4.9 cm and 8.9 cm at the same tidal cycle. However, the depth of dispersed oil was almost not changed from 7 cm at 2nd tidal cycle to 7.6 cm at 15th tidal cycle.

It is clear that the first tide is the most important for the penetration of among three oils.

Vertical Distribution of Penetrated Oil Concentration

Figure 6 shows the vertical distribution of oil concentration in the sediments after 15th tidal cycle from oil stranding. The concentrations of vertically distributed oils were highest at the top 2 cm sediment layer. Among the three oils, the concentration of crude oil was highest at the top 2 cm sediment-layer. On the contrary, the concentration of the dispersed oil was lowest resulted from less attachment to sediment particles.

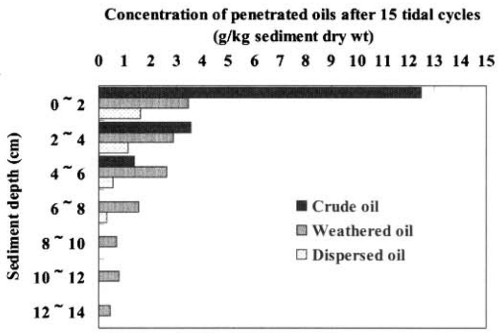


Figure 6. Vertical distribution of penetrated oil concentration after 15th tidal cycle determined by TLC-FID.

Effects of Penetrated Oil on the Seawater Infiltration

Figure 7 shows the effects of crude oil, weathered oil and dispersed oil on the seawater infiltration. Under the unoiled condition, the infiltration rate of seawater (expressed by volume) was 72.54 cm^3/sec. However, at the second tidal cycle after the crude oil stranding, the rate was abruptly decreased to 46.02 cm^3/sec, and at the 4th tidal cycle the rate was decreased to 39.00 cm^3/sec, and then it was steadied from 4th tidal cycle to end.

The rate was decreased to 57.33 cm^3/sec at the second tidal cycle from the penetration of weathered oil, and steadied to 10th tidal cycle. On the other hand, chemically dispersed oil did not almost prevent the infiltration of seawater.

From this result, it is clear that the infiltration volume of seawater was decreased to approximately 1/2 by crude oil and 1/5 by weathered

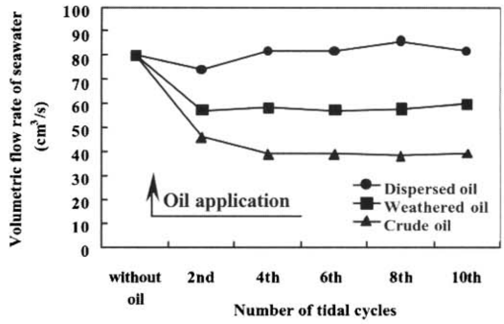


Figure 7. Seawater infiltration through the oil penetrated sediments.

oil, not affected by dispersed oil in sandy beach environment.

CONCLUSIONS

The purpose of this study is to clear the effects of wave and/or tidal action on penetration of weathered oil and dispersed oil and to evaluate the effects of penetrated oil on seawater infiltration into the sandy beach sediments. A sandy beach simulator was used, which composed of model sandy beach, wave maker, tide control device, temperature control system and computer controlling system.

Specific conclusions derived from this study are as follows. The dispersed oil penetrated into the sediments by wave action, but did not penetrate by tidal fluctuation. On the contrary, the crude oil and weathered oil penetrated by tidal fluctuation not by wave action. The first tide is the most important for the penetration of both weathered oil and dispersed oil, and oil concentrations were highest within the upper 2 cm. When oil of 1 L/m^2 was penetrated, the infiltration volume of seawater was decreased to approximately 1/2 by crude oil and 1/5 by weathered oil, and not affected by dispersed oil.

These results indicate that the crude oil and weathered oil have bad effects on benthic organism due to the reduction in the supply of oxygen, nutrient and organic matters in the sandy beach.

ACKNOWLEDGEMENT

This work was supported by the Japan Society for the Promotion of Science (JSPS). This project is a "Research for the Future Program for Evaluation and Restoration of the Effects of Oil Pollution on Coastal Ecosystem".

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