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Research and Development

Techniques for Mixing Dispersants with Spilled Oil

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TECHNIQUES FOR MIXING DISPERSANTS WITH SPILLED OIL

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory -Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report describes performance testing of three standard devices and one experimental device for mixing dispersants with spilled oil. Based on these results, a user can select the method best suited to his operating conditions. The methods, results, and techniques described are of interest to those interested in specifying, using, or testing such equipment. Further information may be obtained through the Resource Extraction & Handling Division, Oil and Hazardous Materials Spills Branch, Edison, New Jersey.

David G. Stephan
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ABSTRACT

The effective use of some oil spill dispersants requires the addition of mixing energy to the dispersant-treated slick. Various methods of energy application have included the use of fire hose streams directed to the water surface, outboard motors mounted on work boats, and the five-bar gate, a pallet-like device towed on the surface behind vessels of opportunity.

The U.S. Environmental Protection Agency sponsored this test program at their Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) to evaluate the above devices as well as a modified version of the five-bar gate. Three test fluid mixtures with different interfacial tensions were distributed onto the water surface, and each mixing device was towed through them at speeds from 1.02 m/s to 2.54 m/s in three wave conditions. Droplet penetration was documented via underwater photography.

Analysis of the results showed that the modified five-bar gate produced the greatest overall penetration (2.4 m) at a tow speed of 2.0 m/s. In general, performance was unaffected by wave action, and variations in interfacial tension produced no observable trend among all devices.

This report was submitted in fulfillment of Contract No. 68-03-0490, Job Order No. 24, by Mason & Hanger-Silas Mason Co., Inc., under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period April 22 to May 6, 1976, and work was completed as of January 1, 1977.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

cm	--centimetre
CPM	--crests per minute
dynes/cm	--dynes per centimetre
ergs/cm^2	--ergs per centimetre squared
HC	--harbor chop wave condition
HLB	--hydrophilic to lipophilic balance ratio
IFT	--interfacial tension
JO 24	--job order 24
J/m^2	--joules per metre squared
kg	--kilograms
KJ/m	--kilojoules
kw	--kilowatt
m	--metres
m/s	--metres per second
mm	--millimetre
mV	--millivolts
N/m	--newton per metre
OHMSETT	--Oil and Hazardous Materials Simulated Environmental Test Tank
ppt	--parts per thousand
sin	--sine
Whit.	--Whitman
K.E.	--Kinetic energy

SYMBOLS

$\angle^{\circ}$	--angular degrees
$^{\circ}$	--degrees
$r_{o/w}$	--interfacial tension of oil/water
%	--percent
$S_{o/w}$	--spreading coefficient for oil on water
r_o	--surface tension of oil
r_w	--surface tension of water

CONVERSIONS

METRIC TO ENGLISH

To convert from	to	Multiply by
Celsius	degree Fahrenheit	$t_C = (t_F-32)/1.8$
joule	erg	1.000 E+07
joule	foot-pound-force	7.374 E-01
kilogram	pound-mass (lbm avoir)	2.205 E+00
metre	foot	3.281 E+00
metre	inch	3.937 E+01
$metre^2$	$foot^2$	1.076 E+01
$metre^2$	$inch^2$	1.549 E+03
$metre^3$	gallon (U.S. liquid)	2.642 E+02
$metre^3$	litre	1.000 E+03
metre/second	foot/minute	1.969 E+02
metre/second	knot	1.944 E+00
$metre^2$/second	centistoke	1.000 E+06
$metre^3$/second	$foot^3$/minute	2.119 E+03
$metre^3$/second	gallon (U.S. liquid)/minute	1.587 E+04
newton	pound-force (lbf avoir)	2.248 E-01
watt	horsepower (550 ft lbf/s)	1.341 E-03

ENGLISH TO METRIC

centistoke	$metre^2$/second	1.000 E-06
degree Fahrenheit	Celsius	$t_C = (t_F-32)/1.8$
erg	joule	1.000 E-07
foot	metre	3.048 E-01
$foot^2$	$metre^2$	9.290 E-02
foot/minute	metre/second	5.080 E-03
$foot^3$/minute	$metre^3$/second	4.719 E-04
foot-pound-force	joule	1.356 E+00
gallon (U.S. liquid)	$metre^3$	3.785 E-03
gallon (U.S. liquid)/ minute	$metre^3$/second	6.309 E-05
horsepower (550 ft lbf/s)	watt	7.457 E+02
inch	metre	2.540 E-02
$inch^2$	$metre^2$	6.452 E-04
knot (international)	metre/second	5.144 E-01
litre	$metre^3$	1.000 E-03
pound-force (lbf avoir)	newton	4.448 E+00
pound-mass (lbm avoir)	kilogram	4.535 E-01

ACKNOWLEDGMENTS

U.S. Environmental Protection Agency project representative, Mr. Leo McCarthy, provided valuable guidance and contributed significantly to the success of this project.

Mr. S.G. Keadle of Mason & Hanger contributed significantly to the design and fabrication of the modified five-bar gate.

SECTION 1

INTRODUCTION

BACKGROUND

Some dispersants require the addition of mixing energy after their application to the oil slick. Much research effort has been applied to the development of dispersant chemicals, methods of application to oil slicks, and the effects of dispersant use on marine life (references 2 through 7). However, relatively little effort has been expended on developing effective devices to stir the oil/dispersant mixture into the water column (8). Devices used thus far include water streams from fire hoses, motorboat propeller wash, and the five-bar gate developed by the Warren Springs Laboratory (8). The performance of these dispersant mixing devices, when applied to floating oil slicks in the OHMSETT test tank (see Appendix A), is qualitatively evaluated in this report.

SCOPE

The purpose of this project was to test and evaluate oil spill/-dispersant mixing equipment. The equipment tested consisted of a motorboat, a fire hose system, a standard five-bar gate, and a specially modified five-bar gate. Test conditions and procedures were designed to simulate typical real world environments and to permit a performance evaluation of the equipment when used on oil. The oil selected for the tests was Sunvis #31, used as delivered (no surfactant added), and two mixtures of oil and surfactant (Igepal CO-430). Properties of these three test mixtures are given in Table 1.

TABLE 1. TEST FLUID PROPERTIES

Test fluid	Viscosity ($x10^{-6}m^2/s$)	Interfacial tension ($x10^{-3}N/m$)	Surface tension ($x10^{-3}N/m$)	Specific Gravity
Sunvis #31	190	18	31	0.868
Sunvis #31 plus ∿ 0.025% Igepal CO-430	220	8	29	0.868
Sunvis #31 plus ∿ 0.05% Igepal CO-430	235	2	29	0.868

Spreading rate near the source of an oil slick is based on the volume and density of the oil. This provides a static head which overcomes other factors such as surface tension and oil viscosity, and causes the oil to spread across the water surface. Spreading rate and thickness of the oil film varies with time and distance from the origin, with surface tension and viscosity forces eventually dominating.

Canevari (2) finds the spreading to be predicted by a spreading coefficient. The coefficient is defined as:

$$S_{o/w} = r_w - r_{o/w} - r_o$$

where $S_{o/w}$ = spreading coefficient for oil on water, ergs/cm

r_w = surface tension of the water phase, dynes/cm

r_o = surface tension of the oil phase, dynes/cm

$r_{o/w}$ = interfacial tension of the oil/water phase, dynes/cm

If $S_{o/w}$ is a positive value, the oil will spread on water; otherwise, it will not.

It can be seen from the equation above that lowering the interfacial tension between oil and water will increase the spreading coefficient. Each surfactant molecule contains both water compatible (hydrophilic) and oil compatible (lipophilic) chemical groups. The molecule positions itself at the oil/water interface with its hydrophilic portion in the water phase and its lipophilic portion in the oil phase. The ratio of hydrophilic to lipophilic sites (HLB) contained in each surfactant molecule determines the type and stability of the resulting dispersion. A surfactant that is principally hydrophilic disperses oil in water; while one that is principally lipophilic disperses water in oil.

SECTION 2

CONCLUSIONS

The following conclusions resulted from this test:

- The OHMSETT modification of the five-bar gate proved to be the most effective device for breaking up a 1-mm thick oil slick into droplets, as measured by the depth of droplet penetration.
- There was no clear relationship between interfacial tension, tow speed or waves, and droplet penetration depth that was applicable to all four test devices.
- Penetration depths measured with the five-bar gate were in good agreement with previous experimental work done in the United Kingdom (1).

To put these conclusions in proper context, it should be recognized that several potentially important variables were held constant--slick thickness, oil specific gravity, and oil viscosity. Testing the effects of these variables is recommended for future work.

In general, as speed increased, performance increased for each device, passed through an optimum, and then decreased. The deepest droplet penetration of the unaltered oil (when no waves were present) was observed at a speed of 1.5 m/s for the fire hoses and at 2.0 m/s for the boat and motor and for the five-bar gate. Towing the modified five-bar gate at 2.0 m/s caused oil droplets to penetrate to the tank bottom (2.4 m); therefore, optimum speed and maximum penetration depth for this device could not be obtained in this test tank.

Droplet penetration was generally not affected by wave action. When regular waves of 0.3-m height and 13.7-m length were present, depth of droplet penetration of unaltered oil was not affected when using fire hoses, increased for the standard five-bar gate, and decreased when using the boat and motor. Lowering the IFT (interfacial tension) to 2×10^{-3} N/m and using the regular waves, greater droplet penetration was observed for the fire hoses and the boat and motor, with no effect seen for the five-bar gate. In the presence of a 0.3-m harbor chop, the depth of oil droplet penetration decreased for the boat and motor, but was unaffected for the other devices.

Lowering of IFT from 18×10^{-3} N/m to 2×10^{-3} N/m also did not produce a general trend in device performance. Fire hoses produced less penetration, but the five-bar gate produced more penetration. More penetration was also observed with the boat and motor at speeds under 1.5 m/s and less penetration was observed at speeds from 1.5 m/s to 2.5 m/s. Because of time considerations, the modified five-bar gate was not tested with this test mixture.

SECTION 3

RECOMMENDATIONS

A program should be undertaken to investigate and develop other means of physical mixing.

Since the oil droplets tend to be more clearly visible against a dark surface than a light surface, a grid with alternating black and white squares should be used for better resolution of the oil droplets.

An underwater motorized drive camera (on a mount moving with the mixing device) should give better results than photographing through the tank window. If this camera is positioned closer to the surface and pointed at a larger grid which is either painted on the tank wall or moving with the test device, a much better resolution of the oil droplets would result.

Future testing of mixing energy application devices should incorporate dispersant application systems as well as additional modifications to the five-bar gate. These may include different configurations of pipe sections extending below the water surface and oriented at different angles with respect to towing direction.

SECTION 4

MATERIALS AND METHODS

OHMSETT DESCRIPTION

The OHMSETT facility (Appendix A), located in Leonardo, New Jersey, at the Naval Weapons Station Earle, was built specifically for the testing of oil and hazardous materials containment and recovery equipment. The tank is 203.3-m long with a water depth of 2.44 m, and waves can be generated up to 0.68-m high and 28.0-m long. The tank is filled with seawater from Raritan Bay (salinity 16 ppt).

SELECTION OF EQUIPMENT FOR TESTS

Each major type of dispersant mixing device was represented during testing.

Equipment used for the fire hose testing consisted of two nozzles with a 1.3-cm aperture pointed downward over the aft end of the bridge (Figure 1). The nozzles were attached to two 15.2-m long, 3.8-cm diameter double jacketed cotton fiber hoses.

An open motorboat 3.66-meters long with a beam of 1.2 meters was used. The motor was a 55.9-kw (7.5 horsepower) standard outboard motor (Figure 2).

The five-bar gate, fabricated according to specifications supplied by the Warren Springs Laboratory (8), is basically a wooden pallet 1.21-m long and 0.91-m wide. The gate is towed by cables attached to eye bolts underneath the front corners of the device. (Figures 3 and 4).

A modified version of the five-bar gate was fabricated by attaching 15.2-cm sections of 5-cm diameter pipe, cut in half, to the bottom of the device. These pipe sections extended straight down and were oriented so that the interior (concave) facing was toward the forward end of the device. Thirty-five of these sections were attached in four rows. (Figures 5 and 6).

Waves were photographed against a grid painted on the test tank's east wall to measure the height and length. Their period was measured by stopwatch.

Tow speed data was measured by a DC tachometer which was mounted on the motor shaft of the bridge drive.

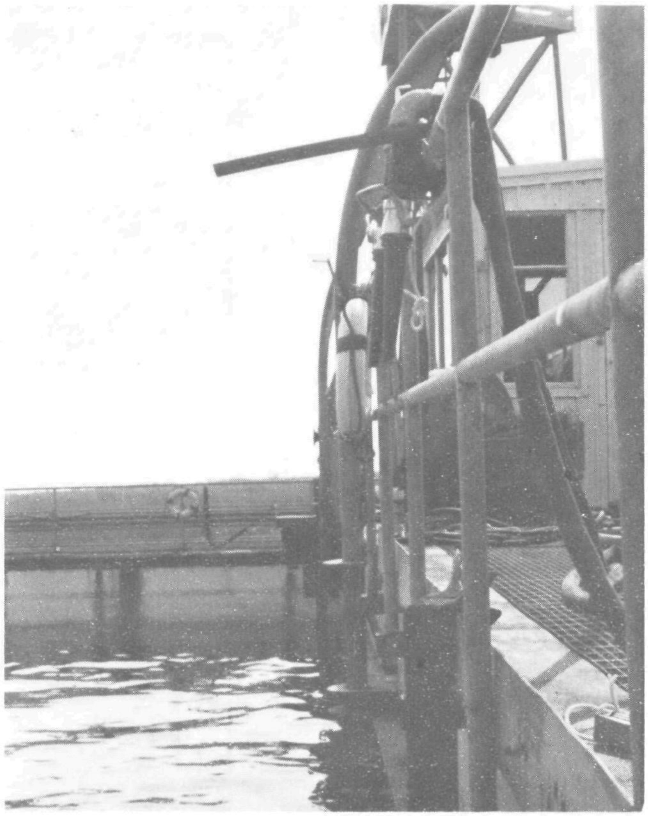

Figure 1. Photograph of fire hose nozzle.

Figure 2. Photograph of motorboat.

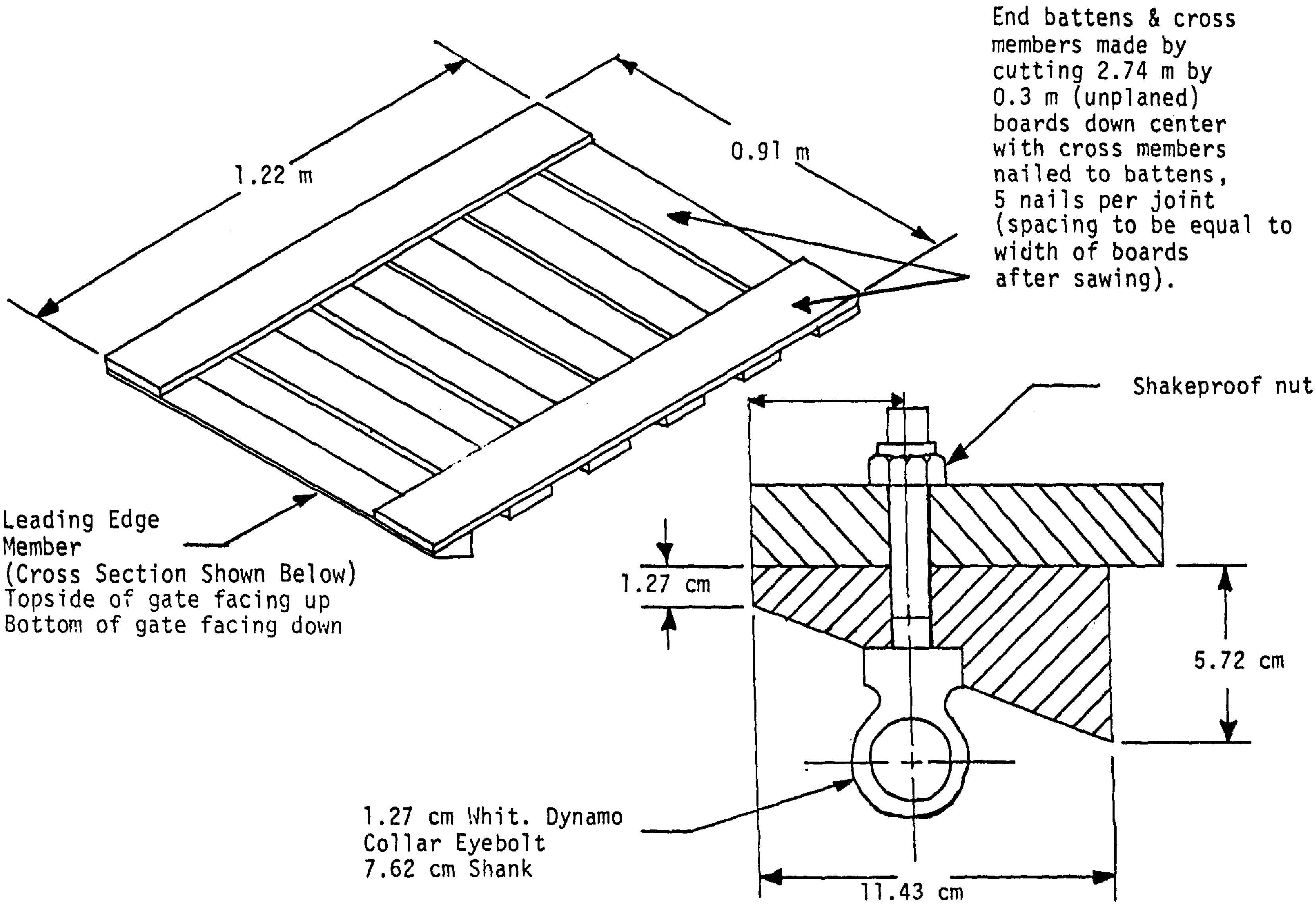

Figure 3. Diagram of five-bar gate.

Figure 4. Photograph of the standard five-bar gate.

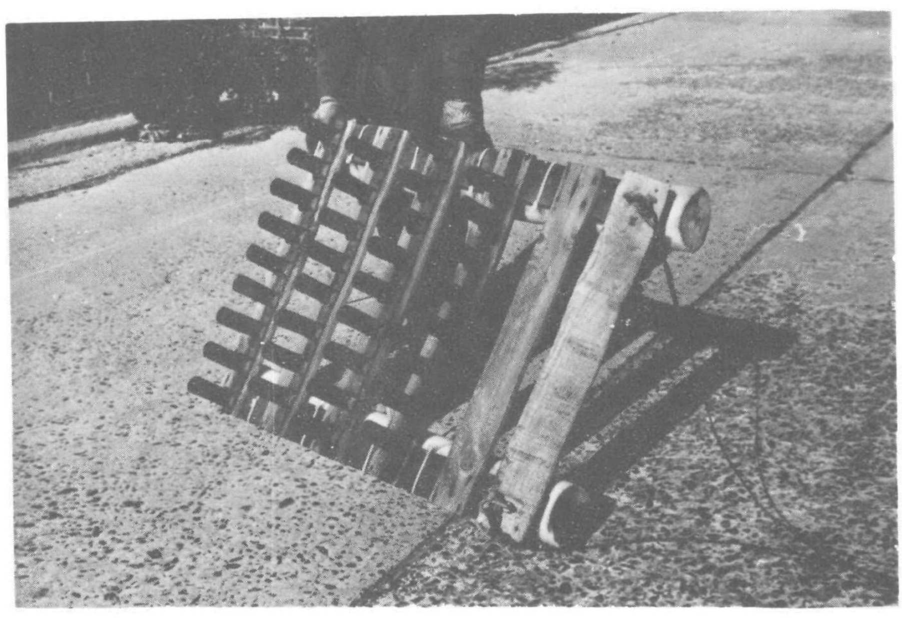

Figure 5. Photograph of the modified five-bar gate.

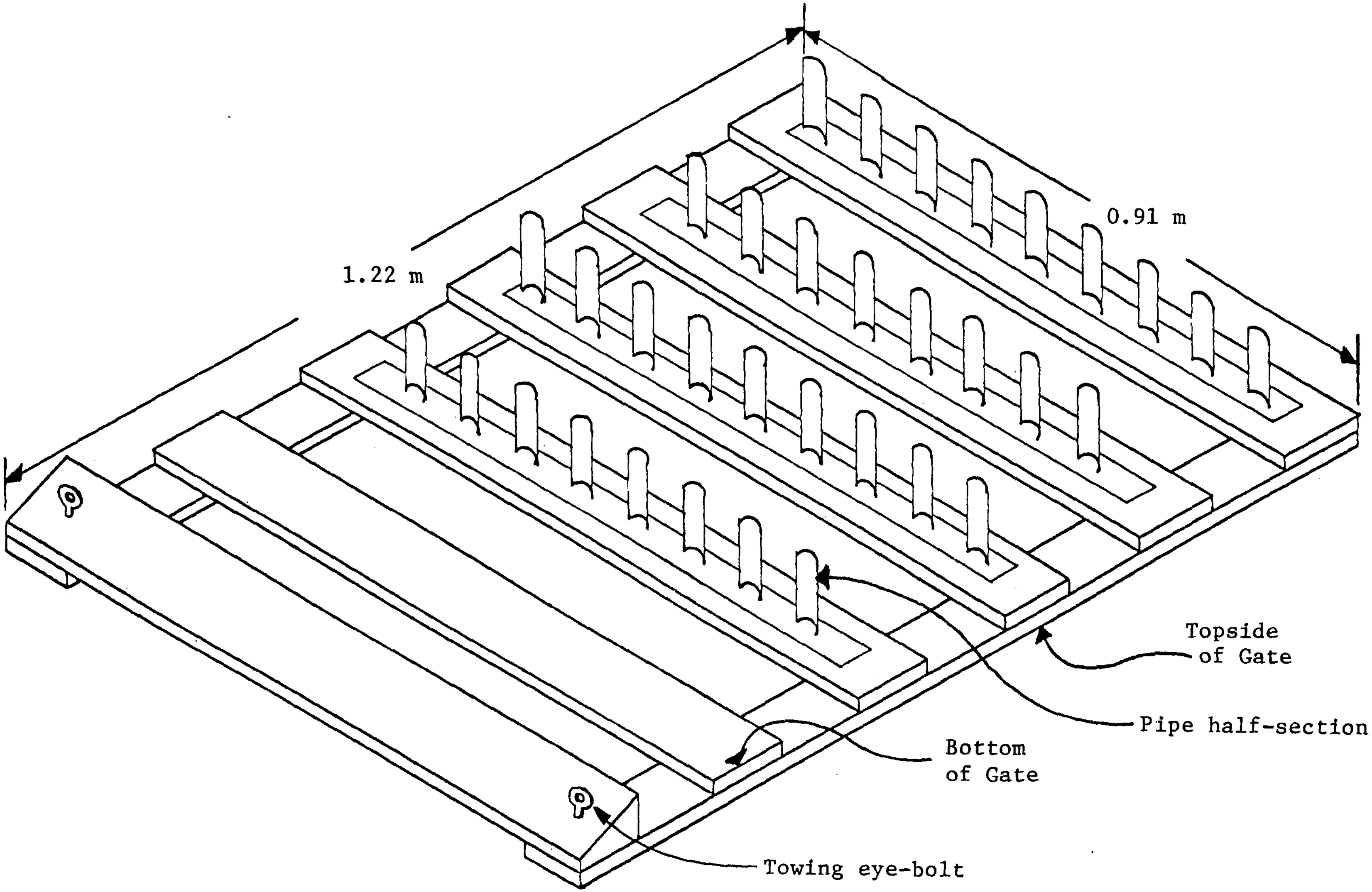

Figure 6. Modified five-bar gate (shown upside down).

PHOTOGRAPHIC DOCUMENTATION

An important aspect of the test was the photographing of oil droplets against a vertical grid through an observation window, in the side of the tank. A 16-mm movie camera, operating at 64 frames per second ("slow motion") was aimed at a 1.22-m x 2.44-m board upon which were painted 30.5-cm squares. One of the squares was further broken down into 2.54-cm squares. Figure 7 shows the location of the grid, as well as other facility modifications required for this project.

TEST FLUIDS

Sunvis #31, a paraffin-based lubricating stock, was used straight, and mixed with either 0.05% or 0.025% Igepal CO-430 surfactant. As can be seen from Table 1 (in Section 1), all three test fluids had essentially identical surface tension and specific gravity. Viscosity varied over a narrow range, but interfacial tension varied by a factor of 10.

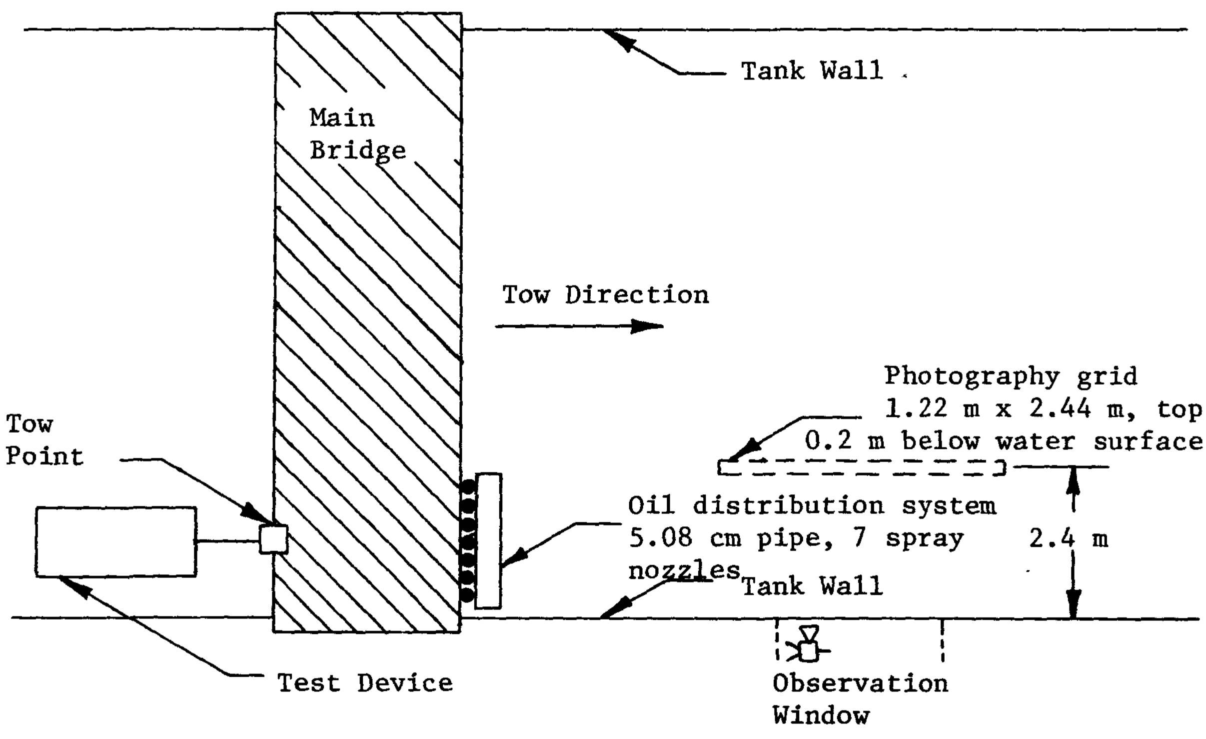

Figure 7. Facility modifications (plan view).

SECTION 5

EXPERIMENTAL PROCEDURES

TEST MATRIX DESIGN

The matrix design was based on variations in interfacial tension, tow speed, and wave condition. The tests were designed to establish penetration depth of the oil droplets after the mixing devices had acted on the slick. Test matrices for each device are listed in Table 2. Test Procedures are given in Appendix B.

All three devices were tested at a slick thickness of 1 mm and slick width of 1 meter. Interfacial tension of the three test fluids was 18×10^{-3} N/m, 8×10^{-3} N/m, or 2×10^{-3} N/m. Tow speed ranged from 1.01 to 2.54 m/s. Waves were adjusted to one of three conditions; calm, 0.3-m high by 13.7-m long regular, and 0.3-m high harbor chop.

The fire hoses were pre-tested to determine the nozzle angle for maximum penetration of the water stream. Depth of penetration for a 45° nozzle angle was observed to be 0.46 m; for 60°, 0.76 m; for 75°, 0.91 m; and for 90°, 1.07 m. Consequently, the water stream from the nozzle was aimed straight down at the tank surface during the main test series.

The towing force on the five-bar gates was measured by a load cell which was connected to the towing cable. This information was used to compute the applied mixing energy (see Appendix C).

TABLE 2. PRIMARY TEST MATRIX

Test no.	% Surfactant	Interfacial tension ($x10^{-3}N/m$)	Speed m/s	Wave
1. A[1] B[2] C[3]	0	18	1.02	Calm
2. A B C	0	18	1.52	Calm
3. A B C	0	18	2.03	Calm
4. A B C	0	18	2.54	Calm
5. A B C	0	18	2.54	0.3 m 4 sec.
6. A B C	0.025	8	1.02	Calm
7. A B C	0.025	8	1.52	Calm
8. A B C	0.025	8	2.03	Calm
9. A B C	0.025	8	2.54	Calm
10. A B C	0.025	8	2.54	0.3 m 4 sec.
11. A B C	0.05	2	1.01	Calm
12. A B C	0.05	2	1.52	Calm
13. A B C	0.05	2	2.03	Calm
14. A B C	0.05	2	2.54	Calm
15. A B C	0.05	2	2.54	Calm
16. D[4]	0	18	2.54	Calm
17. D	0	18	2.54	Calm
18. A B C	0.025	18	2.54	0.3 m HC
19. A B C	0.05	8	1.02	0.3 m HC
20. A B C	0	2	2.03	0.3 m HC

[1]Fire hose.
[2]Motor boat.
[3]Five-bar gate.
[4]Modified five-bar gate.

SECTION 6

RESULTS AND DISCUSSION

In general, droplets did not penetrate the water column very deeply. The exception was the modified five-bar gate which drove the oil droplets to the bottom of the tank. It was noted that the drops exhibited a tendency to rise back to the water surface within fifteen minutes after passage of the test device. Additional effort in improving the existing mixing devices could make much more mixing energy available.

TABLE 3. MAXIMUM DROPLET PENETRATION (cm) FOR DIFFERENT INTERFACIAL TENSIONS IN CALM WATER (AT VARYING TOW SPEEDS)

Device	IFT $x10^{-3}$N/m	Observed Maximum droplet penetration cm	Tow speed of observed max. penetration m/s
Five-bar gate	18	35.5	2
	8	35.5	1
	2	40.6	1
Fire hoses	18	121.9	1.5
	8	25.4	2.5
	2	40.6	1.5
Boat and motor	18	125	2
	8	116	1.5
	2	61	1.5
Modified five-bar gate	18	244	4.1

Results obtained from the unaltered oil in calm water (summarized in Table 3) indicate that fire hoses were best at speeds of 1.8 m/s and below because they produced more force per square meter. Maximum penetration depth was 1.2 m at 1.52 m/s in calm water.

A maximum penetration depth of 125 cm was observed at 2.03 m/s for the boat and motor. Below this speed, less power was available to the propeller to disperse the oil, while above this speed the hull of the boat separated the slick so that very little oil was affected by the propeller wash and wake of the boat.

The five-bar gate's maximum oil droplet penetration of 36 cm was at 2.03 m/s. Oil tended to go under the first bars and then go over the back bars, riding on a cushion of water. Oil dispersed by the gate was in finer droplets than it was when the fire hoses or the boat and motor were used, but the depth of penetration was less.

The modified five-bar gate drove the oil droplets to the tank bottom (244 cm) at a speed of 2 m/s. Table 4 summarizes results in waves.

TABLE 4. MAXIMUM DROPLET PENETRATION FOR DIFFERENT WAVE CONDITIONS AND AN IFT OF 18×10^{-3}N/m at 2.5 m/s

Device	Wave Condition	Penetration Depth cm	Tow speed m/s
Five-bar gate	Calm	20.3	2.5
	0.3 m HC	20.3	2.5
	0.3mx13.7m	38.1	2.5
Fire hoses	Calm	25.4	2.5
	0.3 m HC	25.4	2.5
	0.3mx13.7m	25.4	2.5
Boat and motor	Calm	35.5	2.5
	0.3 m HC	30.0	2.5
	0.3mx13.7m	20.3	2.5

The 0.3-m harbor chop wave did not affect the penetration depth of the fire hoses. However, it caused the drops which did penetrate the water to remain suspended longer. This phenomenon was exhibited for all devices tested in the harbor chop wave. The performance of the boat and motor was decreased for two reasons: the wave action caused the slick to be uneven across the boat's path; and the waves caused the boat hull to pound, splashing the oil to the sides, out of the path of the propeller. The five-bar gate rode this wave well, and droplet penetration was unaffected.

In the 0.3-m high, regular wave, penetration depth for the fire hoses was observed to increase slightly. Again, wave-hull interactions caused the oil to be driven away from the motorboat propeller. When pure oil was used, penetration depth slightly increased in the regular wave for the five-bar gate. However, when the IFT was lowered, penetration depth reduced to that of the calm condition. In addition, lowered IFT resulted in smaller oil drop diameter, and therefore, lower rise velocities. Accordingly, oil droplets remained in the water column longer. The effect of various types of waves on the mixing energy required to effectively disperse oil slicks is becoming more important with the development of dispersant chemicals that either need no mixing or are mixed by the wave energy alone (4,5).

Lowering the oil/water interfacial tension caused the fire hoses to lose effectiveness. The slick was observed to spread away from the current. This was caused by the fire hoses impacting the tank water surface relatively more rapidly with lowered IFT. This meant less oil was present to be affected by the downward force of the hose streams (and hence less penetration occurred).

By contrast, the boat and motor gained in effectiveness as IFT was lowered. This may have been caused by the decrease in the amount of energy needed to overcome the lower IFT and to form an oil drop subsurface near the hull of the boat. These drops would follow the hull back to the propeller, and the propeller would then drive the drops down into the water column. Because the boat's propeller was the major factor in depth of penetration for the boat and motor, any test condition which would cause the oil to be more affected by the propeller would increase the penetration depth.

Five-bar gate performance was unaffected by lowering the IFT.

Previous work at OHMSETT, with three test fluids representing a range of specific gravity from 0.710 to 0.975, indicated a definite correlation between larger droplet size and greater penetration depth with the higher specific gravity test fluids (9). Therefore, increasing the specific gravity of the spilled floating oil would make mixing and dispersing easier.

A compilation of all data derived from these tests is available in Appendix C.

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APPENDIX A

OHMSETT TEST FACILITY

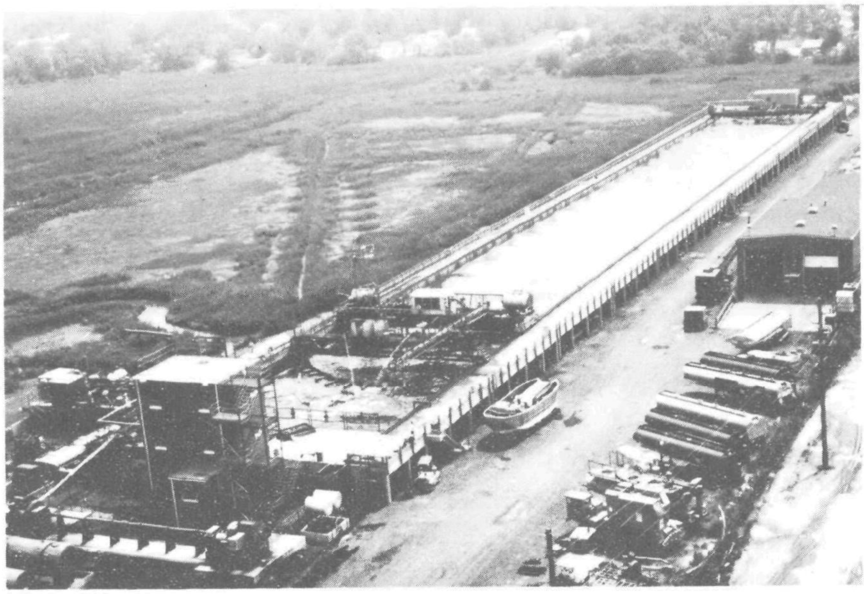


Figure A-1. OHMSETT Test Facility.

GENERAL

The U.S. Environmental Protection Agency is operating an Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) located in Leonardo, New Jersey (Figure A-1). This facility provides an environmentally safe place to conduct testing and development of devices and techniques for the control of oil and hazardous material spills.

The primary feature of the facility is a pile-supported, concrete tank with a water surface 203 metres long by 20 metres wide and with a water depth of 2.4 metres. The tank can be filled with fresh or salt water. The tank is spanned by a bridge capable of exerting a force up to 151 kilonewtons, towing floating equipment at speeds to 3 metres/second for at least 45 seconds. Slower speeds yield longer test runs. The towing bridge is equipped to lay oil or hazardous materials on the surface of the water several metres ahead of the device being tested, so that reproducible thicknesses and widths of the test fluids can be achieved with minimum interference by wind.

The principal systems of the tank include a wave generator and beach, and a filter system. The wave generator and absorber beach have capabilities of producing regular waves to 0.7 metre high and to 28.0 metres long, as well as a series to 1.2 metres high reflecting, complex waves meant to simulate the water surface of a harbor or the sea. The tank water is clarified by recirculation through a 0.13 cubic metre/second diatomaceous earth filter system to permit full use of a sophisticated underwater photography and video imagery system, and to remove the hydrocarbons that enter the tank water as a result of testing. The towing bridge has a built-in skimming barrier which can move oil onto the North end of the tank for cleanup and recycling.

When the tank must be emptied for maintenance purposes, the entire water volume, of 9842 cubic metres is filtered and treated until it meets all applicable State and Federal water quality standards before being discharged. Additional specialized treatment may be used whenever hazardous materials are used for tests. One such device is a trailer-mounted carbon treatment unit for removing organic materials from the water.

Testing at the facility is served from a 650 square metres building adjacent to the tank. This building houses offices, a quality control laboratory (which is very important since test fluids and tank water are both recycled), a small machine shop, and an equipment preparation area.

This government-owned, contractor-operated facility is available for testing purposes on a cost-reimbursable basis. The operating contractor, Mason & Hanger-Silas Mason Co., Inc., provides a permanent staff of fourteen multi-disciplinary personnel. The U.S. Environmental Protection Agency provides expertise in the area of spill control technology, and overall project direction.

For additional information, contact: John S. Farlow, OHMSETT Project Officer, U.S. Environmental Protection Agency, Research and Development, IERL-Ci, Edison, New Jersey 08817, 201-321-6631.

APPENDIX B

TEST PROCEDURES

A step-by-step procedure for the testing program is given below in the following format: Manpower Allocations (Figure B-1), Pre-test Checklist, and Test Sequence.

MANPOWER ALLOCATIONS

1. Test Director - responsible for running the tests according to the prescribed test matrix and test procedure. Manages the test personnel.

2. Photographer - documents the test with 35-mm color slides and 16-mm color motion pictures.

3. Oil distribution operator - maintains the test fluid thickness at 1 mm at the beginning of each test run. Assists with other duties as needed.

4. Bridge and wave generator operator - operates the wave generator and bridge, and collects data for ambient conditions.

PRE-TEST CHECKLIST

To ensure that all test systems and equipment were maintained and ready for the test day, the following checklist was used prior to the first test run:

1. Bridge drive system working.
2. Wave generator system operational.
3. Test device operational.
4. Test instrumentation operational.
5. Test fluid ready.
6. Test fluid distribution system operational.
7. Test support equipment operational.
8. Photographic systems ready.
9. Test personnel prepared and ready.
10. Complete all pre-run data sheets and checklists.

TEST SEQUENCE

Test Procedure - Fire Hoses Penetration Angle Pre-Test

1. Position bridge along tank to facilitate measuring the

depth of penetration of the water streams into the water against the grid.

2. Place fire hose nozzles to give proper angle of water stream to water's surface.

3. Start pump.

4. Open fire hose nozzles.

5. Observe and document penetration of fire hose streams against grid from window in tank wall.

6. Repeat steps 2-5 at next angle of incidence. (Angles used were 45°, 60°, 75°, and 90°).

Fire Hoses Tank Testing

1. Determine correct bridge speed, oil type, and oil flow rate from test plan.
2. Ensure
2. Ensure photographers are ready and initiate waves, if called for.

3. Start fire hose streams.

4. Start bridge moving at correct speed.

5. Start oil distribution.

6. Start photographic documentation to determine maximum penetration of oil droplets caused by fire hose streams.

7. Stop photographic documentation after maximum penetration has been reached.

8. Stop oil distribution.

9. Stop hose streams.

10. Stop bridge and stop waves, if any.

11. Lower skimmer bar, and skim oil in preparation for the next test.

12. Repeat steps 1-11 for each tow speed and wave condition.

Test Procedure - Motor Boat

1. Determine correct bridge speed.

2. Ensure photograpers are ready and initiate waves, if called for.

3. Start bridge moving at correct speed.

4. Match boat speed with bridge speed.

5. Start oil distribution.

6. Start photographic documentation to determine maximum penetration of oil droplets caused by boat wake and propeller wash.

7. Drive boat between grid and camera.

8. Stop photographic documentation after the oil drops reach maximum penetration depth.

9. Stop oil distribution system.

10. Return motor boat to starting position for next test.

11. Stop bridge and waves, if any.

12. Lower skimmer bar and skim oil in preparation for the next test.

13. Figure B-1 shows manpower allocations for the motor boat testing.

Test Procedure - Five-Bar Gate and Modified Five-Bar Gate

1. Determine correct bridge speed, oil type, and oil flow rate from test plan.

2. Ensure photographers are ready and initiate waves, if necessary.

3. Start bridge moving at correct speed.

4. Check gate for proper towing alignment.

5. Start oil distribution.

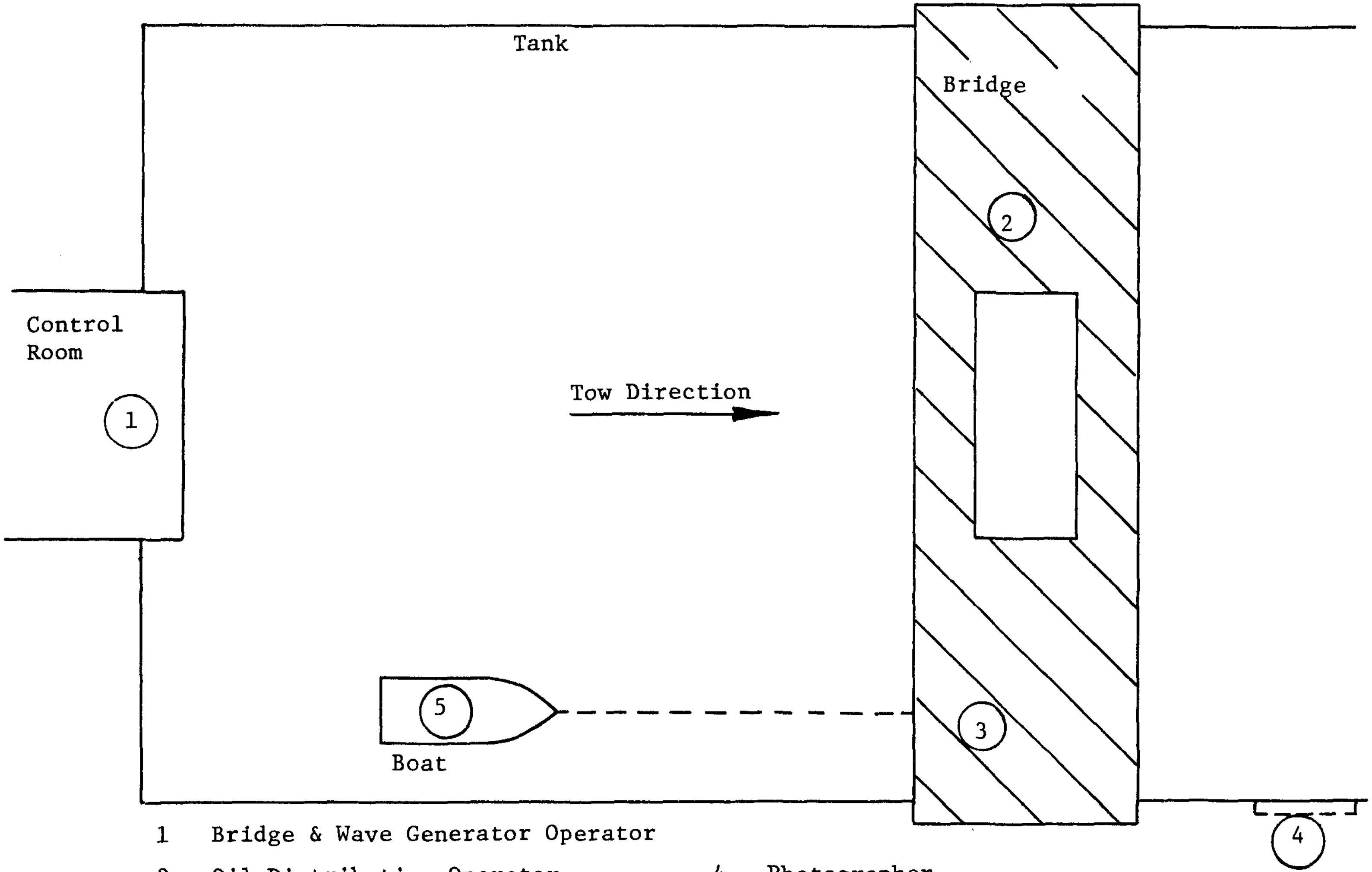
6. Start photographic documentation to determine maximum penetration of oil droplets caused by gate turbulence.

7. Stop photographic documentation after oil drops reach maximum penetration depth.

8. Stop oil distribution system.

9. Stop bridge and stop waves, if any.

10. Lower skimmer bar and skim test oil in preparation for the next test run.



1 Bridge & Wave Generator Operator
2 Oil Distribution Operator
3 Test Director
4 Photographer
5 Boat Operator

Figure B-1. Manpower distribution.

APPENDIX C

TEST RESULTS

DISPERSANT MIXING DEVICES

The following appendix includes raw data compiled from individual test runs. The tables include:

- Test identification
- Device speed
- Mixing energy*
- Oil/water interfacial tension
- Wave characteristics
- Maximum oil drop penetration distance

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*Fire hoses:

$$K.E. = 1/2\ mv^2$$
$$= 1/2\ (\text{flow rate})\ (\text{water density}/g)\ (\text{discharge velocity})$$

$$\frac{K.E.}{\text{area}} = \frac{K.E.}{\text{minute/nozzle}} \quad \frac{\text{number of nozzles}}{\text{sweep width x tow speed}}$$

Five-bar gate:

$$K.E. = 1/2\ mv^2$$
$$= 1/2\ (\text{tow force}/g)\ (\text{tow velocity})^2$$

$$\frac{K.E.}{\text{area}} = \frac{K.E.}{\text{surface area of gate}}$$

TABLE C-1. FIRE HOSE DATA

Test no.	Tow speed m/s	Mixing energy J/m^2	Oil IFT $x10^{-3}N/m$	Wave height m	Wave length m	Wave period s	Droplet Penetration cm
1	1.02	418.7	18	Calm			76.2
2	1.52	278.8	18	"			121.9
3	2.03	209.9	18	Calm			61.0
4	2.54	167.9	18	Calm			25.4
5	2.54	167.9	18	0.3	13.7	4	25.4
6	1.02	418.7	8	Calm			20.3
7	1.52	278.8	8	Calm			20.3
8	2.03	209.9	8	Calm			20.3
9	2.54	167.9	8	Calm			25.4
10	2.54	167.9	8	0.3	13.7	4	30.5
11	1.02	418.7	2	Calm			35.6
12	1.52	278.8	2	Calm			40.6
13	2.03	209.9	2	Calm			30.5
14	2.54	167.9	2	Calm			20.3
15	2.54	167.9	2	0.3	13.7	4	30.5
18	2.54	167.9	18	0.3HC*			20.4
19	2.54	167.9	8	0.3HC			25.4
20	2.54	167.9	2	0.3HC			20.3

*HC - Harbor Chop

TABLE C-2. BOAT AND MOTOR DATA

Test no.	Velocity m/s	Oil IFT $x10^{-3}$N/m	Wave height m	Wave length m	Wave period s	Droplet Penetration cm
1	1.02	18	Calm			38.1
2	1.52	18	Calm			27.9
3	2.03	18	Calm			125.0
4	2.54	18	Calm			35.6
5	2.54	18	0.3	13.7	4	30.0
6	1.02	8	Calm			81.3
7	1.52	8	Calm			116.8
8	2.03	8	Calm			61.0
9	2.54	8	Calm			66.0
10	2.54	8	0.3	13.7	4	33.0
11	1.02	2	Calm			61.0
12	1.52	2	Calm			61.0
13	2.03	2	Calm			50.8
14	2.54	2	Calm			20.3
15	2.54	2	0.3	13.7	4	50.8
18	2.54	18	0.3HC*			20.3
19	2.54	8	0.3HC			35.6
20	2.54	2	0.3HC			50.8

*HC - Harbor Chop

TABLE C-3. FIVE-BAR GATE DATA

Test no.	Tow speed m/s	Mixing energy J/m^2	Oil IFT $x10^{-3}N/m$	Wave height m	Wave length m	Wave period s	Droplet Penetration cm
1	1.02	7.6	18	Calm			20.3
2	1.52	30.1	18	Calm			25.4
3	2.03	95.1	18	Calm			35.6
4	2.54	211.0	18	Calm			20.3
5	2.54	211.0	18	0.3	13.7	4	38.1
6	1.02	7.6	8	Calm			35.6
7	1.52	30.1	8	Calm			20.3
8	2.03	95.1	8	Calm			20.3
9	2.54	211.0	8	Calm			20.3
10	2.54	211.0	8	0.3	13.7	4	20.3
11	1.02	7.6	2	Calm			40.6
12	1.52	30.1	2	Calm			
13	2.03	95.1	2	Calm			30.5
14	2.54	211.0	2	Calm			30.5
15	2.54	211.0	2	0.3	13.7	4	30.5
18	2.54	211.0	18	0.3HC*			20.3
19	2.54	211.0	8	0.3HC			30.5
20	2.54	211.0	2	0.3HC			20.3

*HC - Harbor Chop

TABLE C-4. MODIFIED FIVE-BAR GATE DATA

Test no.	Velocity m/s	Oil IFT $x10^{-3}N/m$	Wave height m	Wave length m	Wave period s	Droplet Penetration cm
16	1.02	18	Calm			> 91.4
17	2.03	18	Calm			>244.0

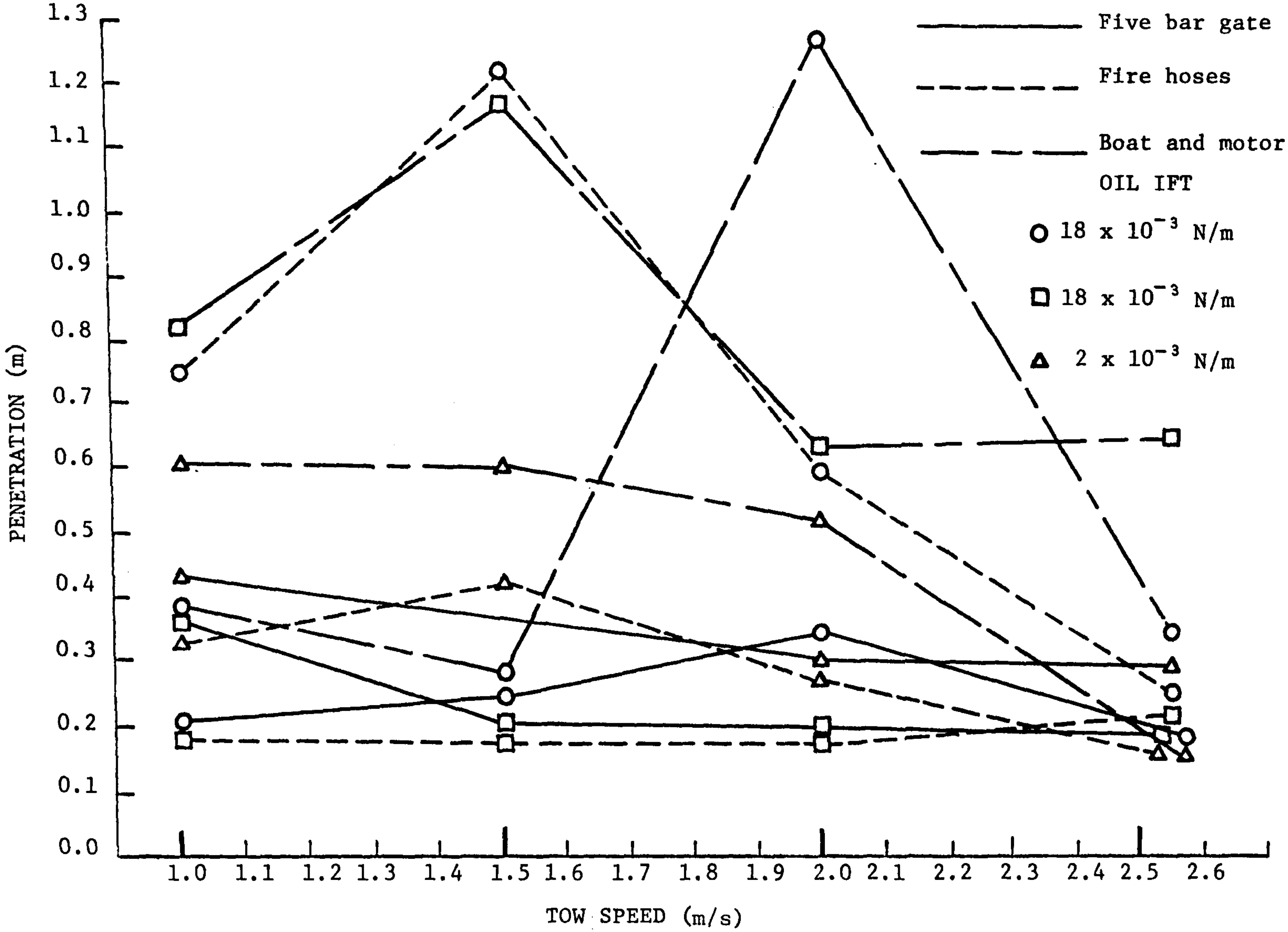

Figure C-1. Drop penetration vs. tow speed, no wave.

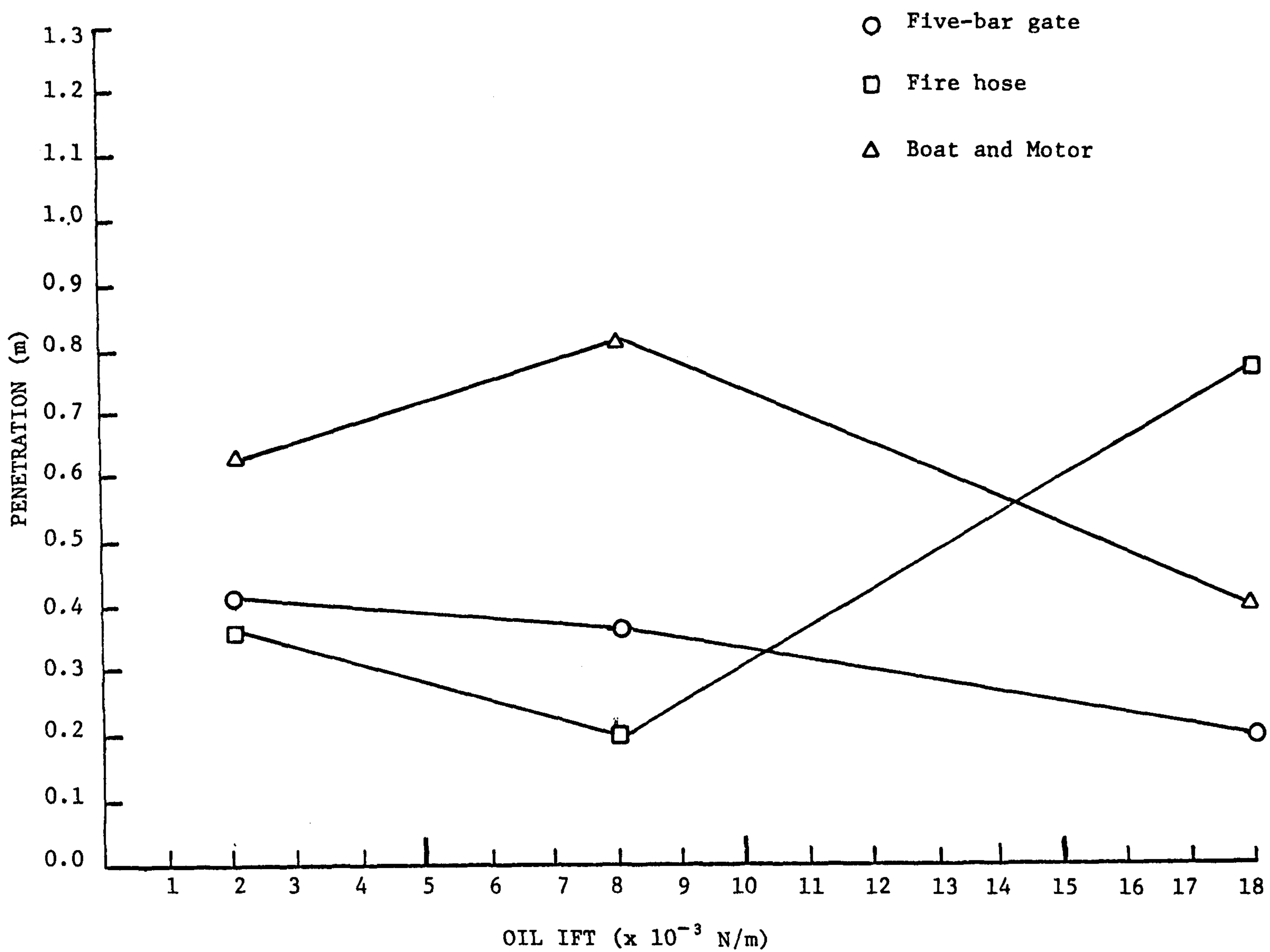

Figure C-2. Drop penetration vs. oil IFT at tow speed of 1.02 m/s, no wave.

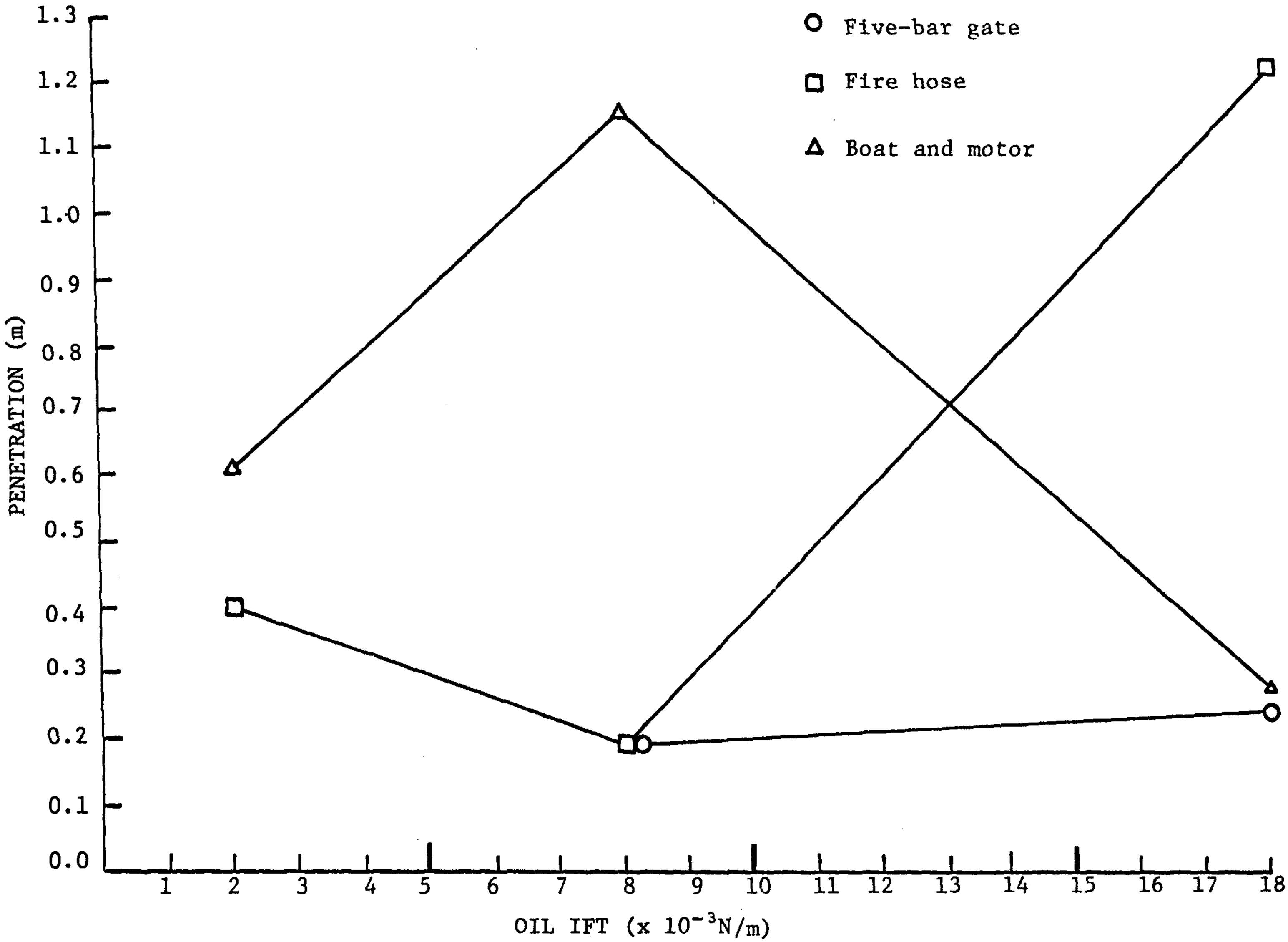

Figure C-3. Drop penetration vs. oil IFT at tow speed of 1.52 m/s, no wave.

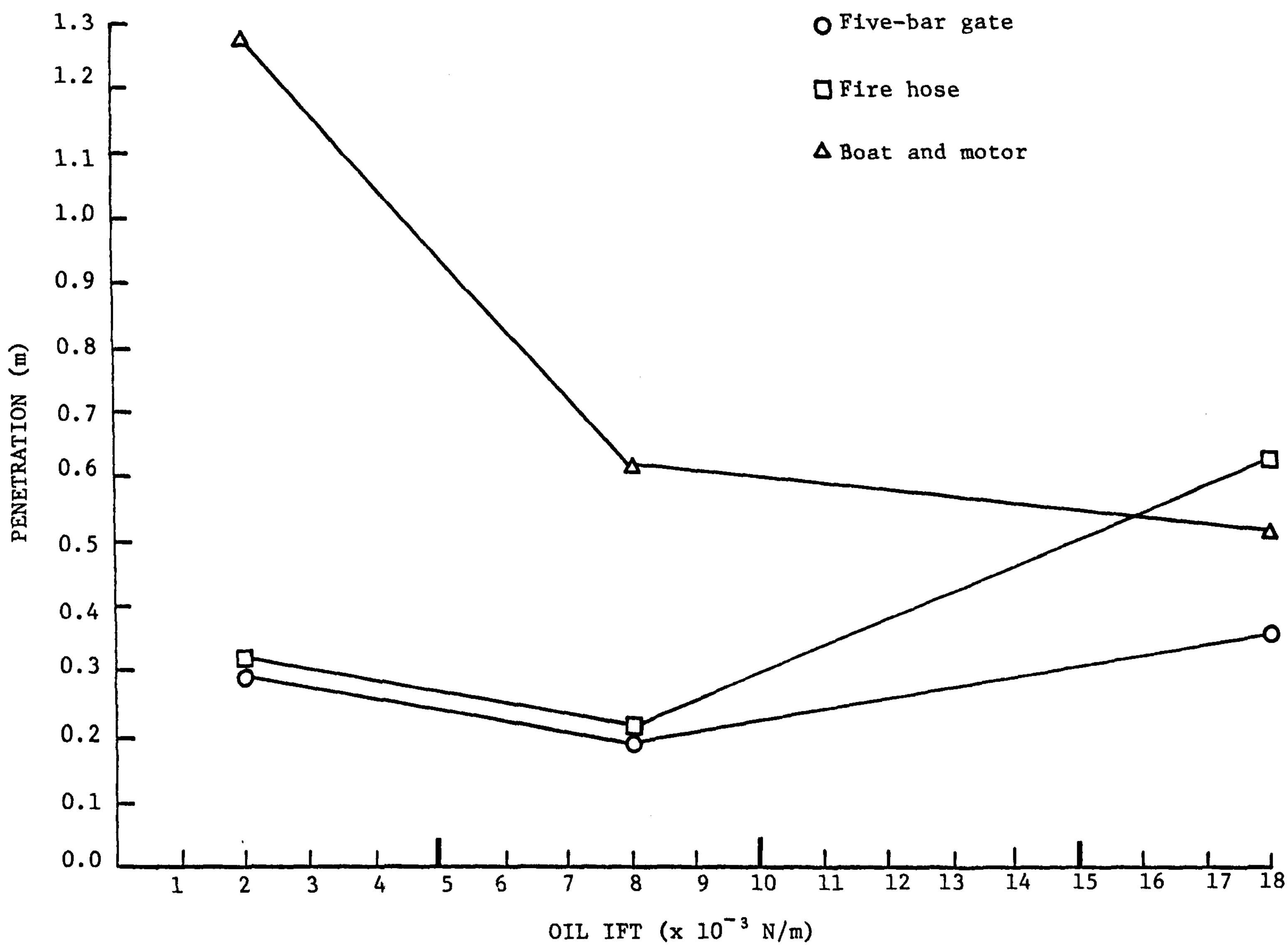

Figure C-4. Drop penetration vs. oil IFT at tow speed of 2.03 m/s, no wave.

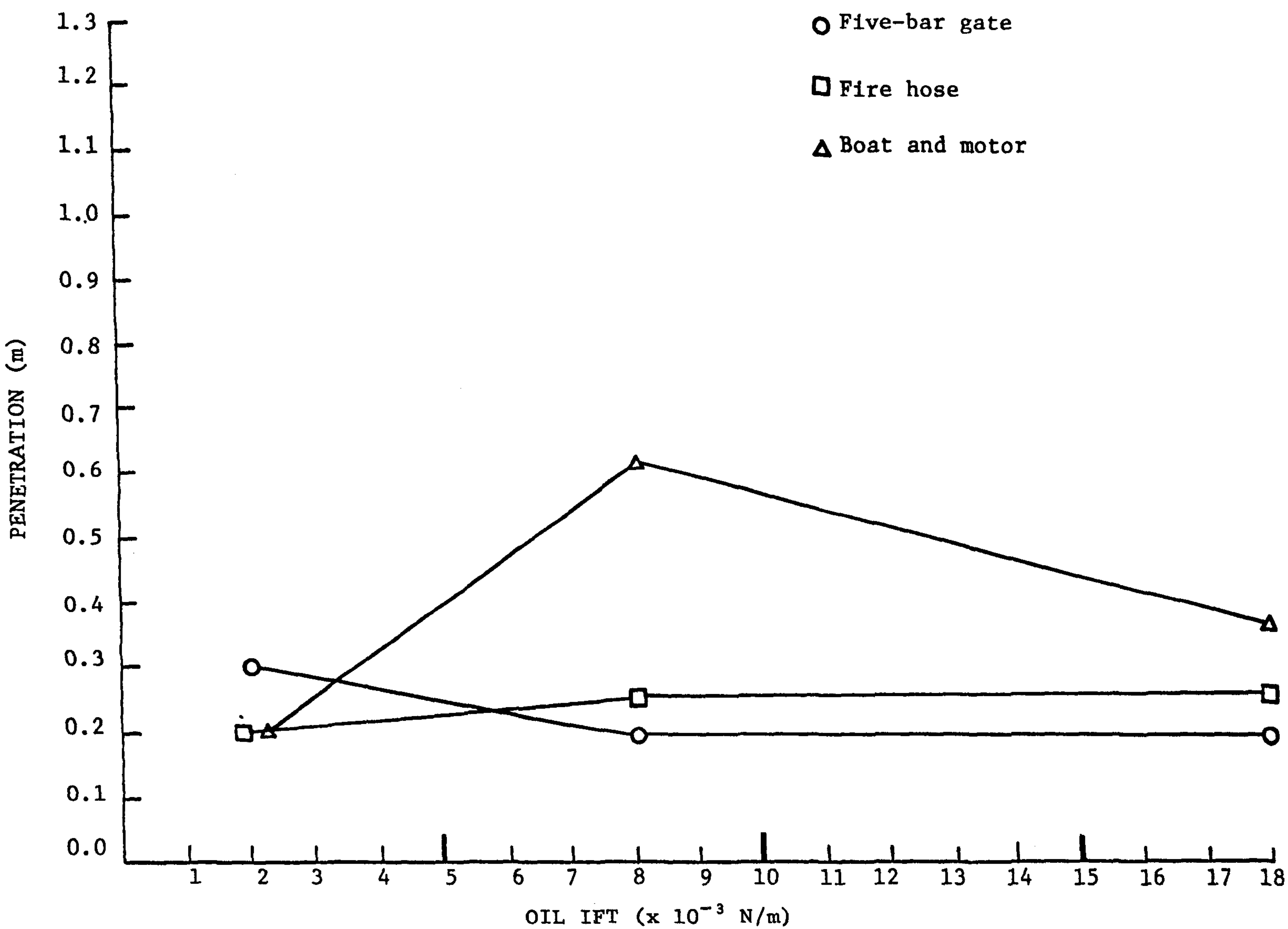

Figure C-5. Drop penetration vs. oil IFT at tow speed of 2.54 m/s, no wave.

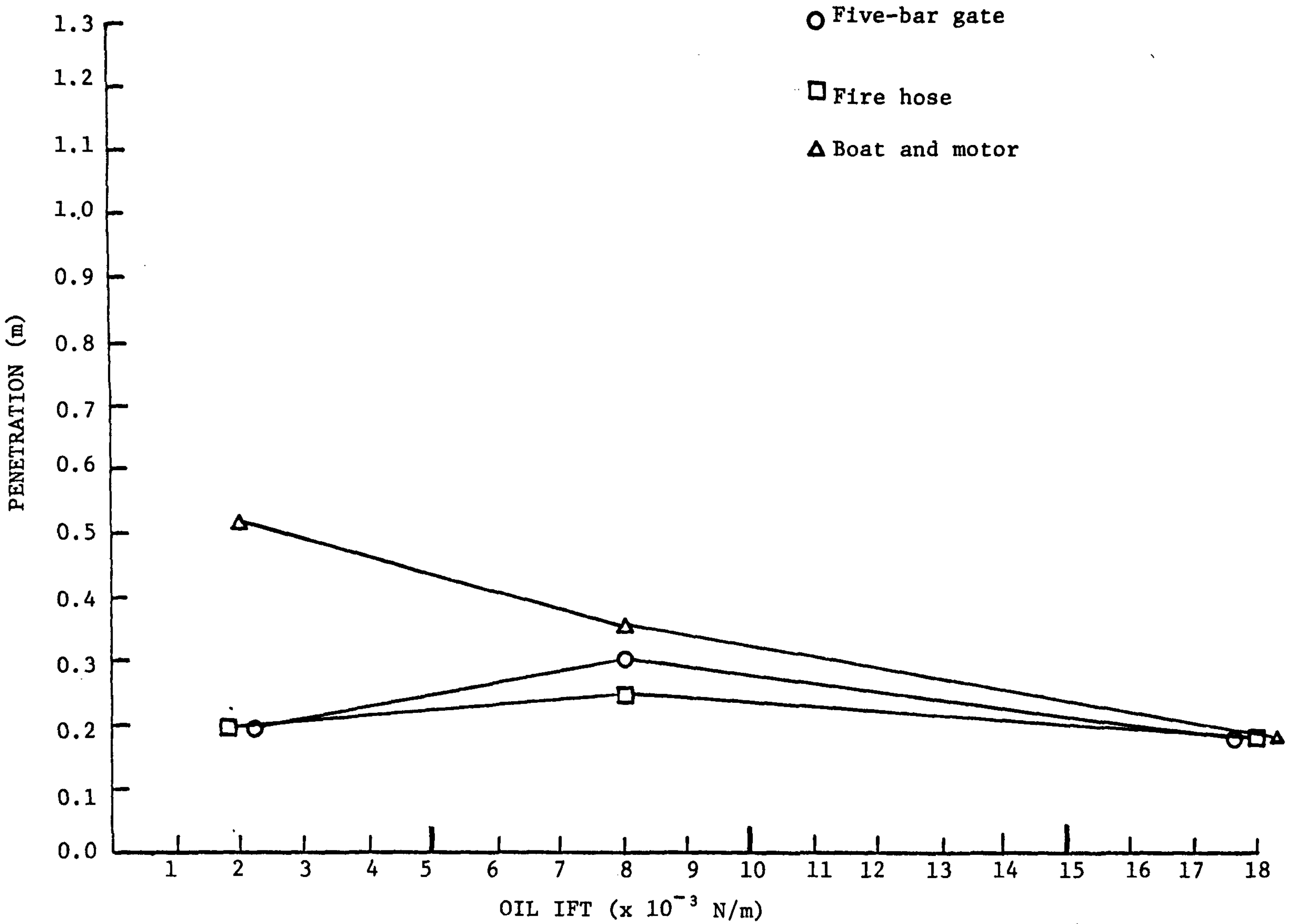

Figure C-6. Drop penetration vs. oil IFT at tow speed of 2.54 m/s, with 0.3 m harbor chop.

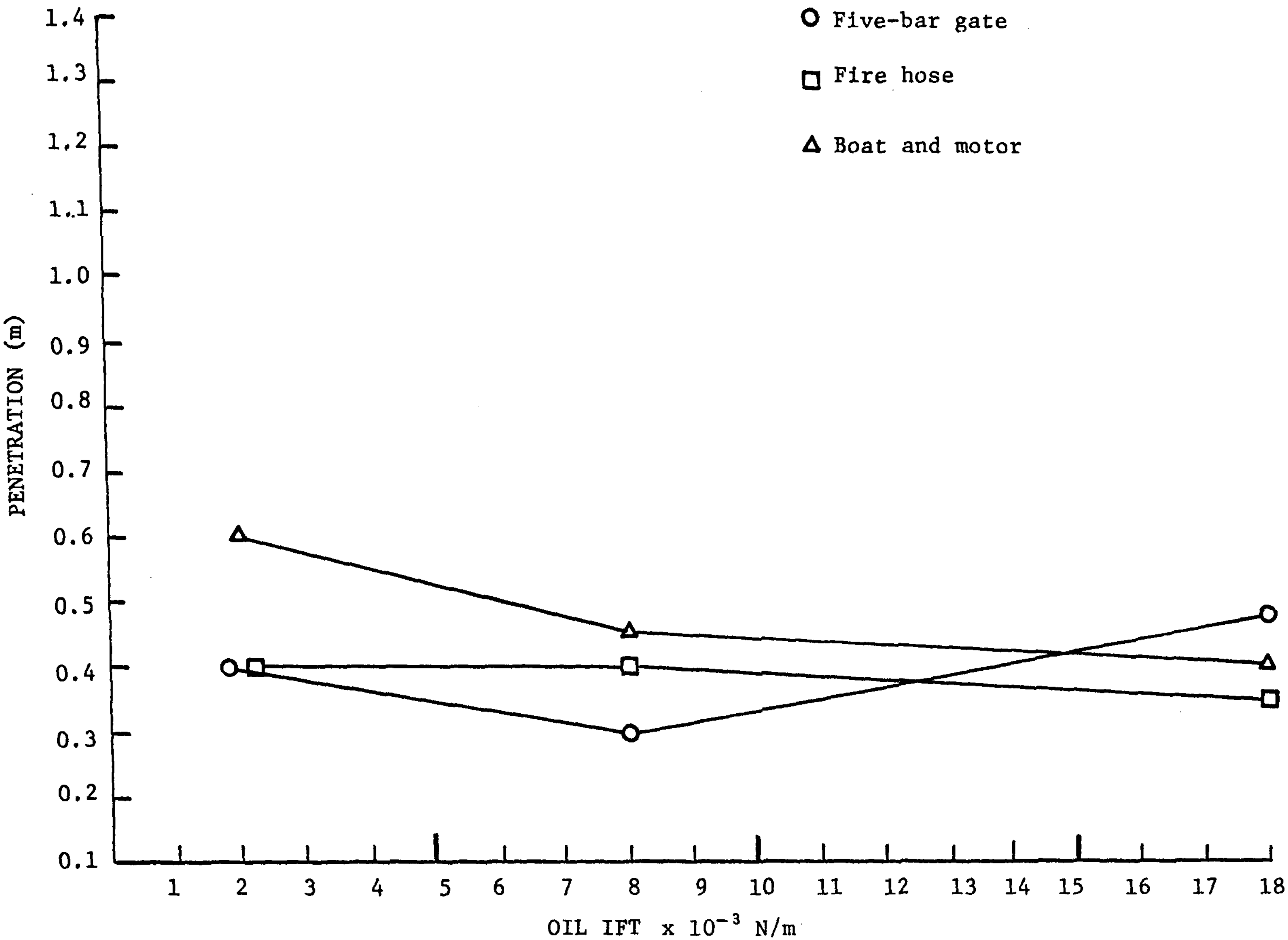

Figure C-7. Drop pentration vs. oil IFT with tow speed of 2.54 m/s, with 0.3 m regular wave.

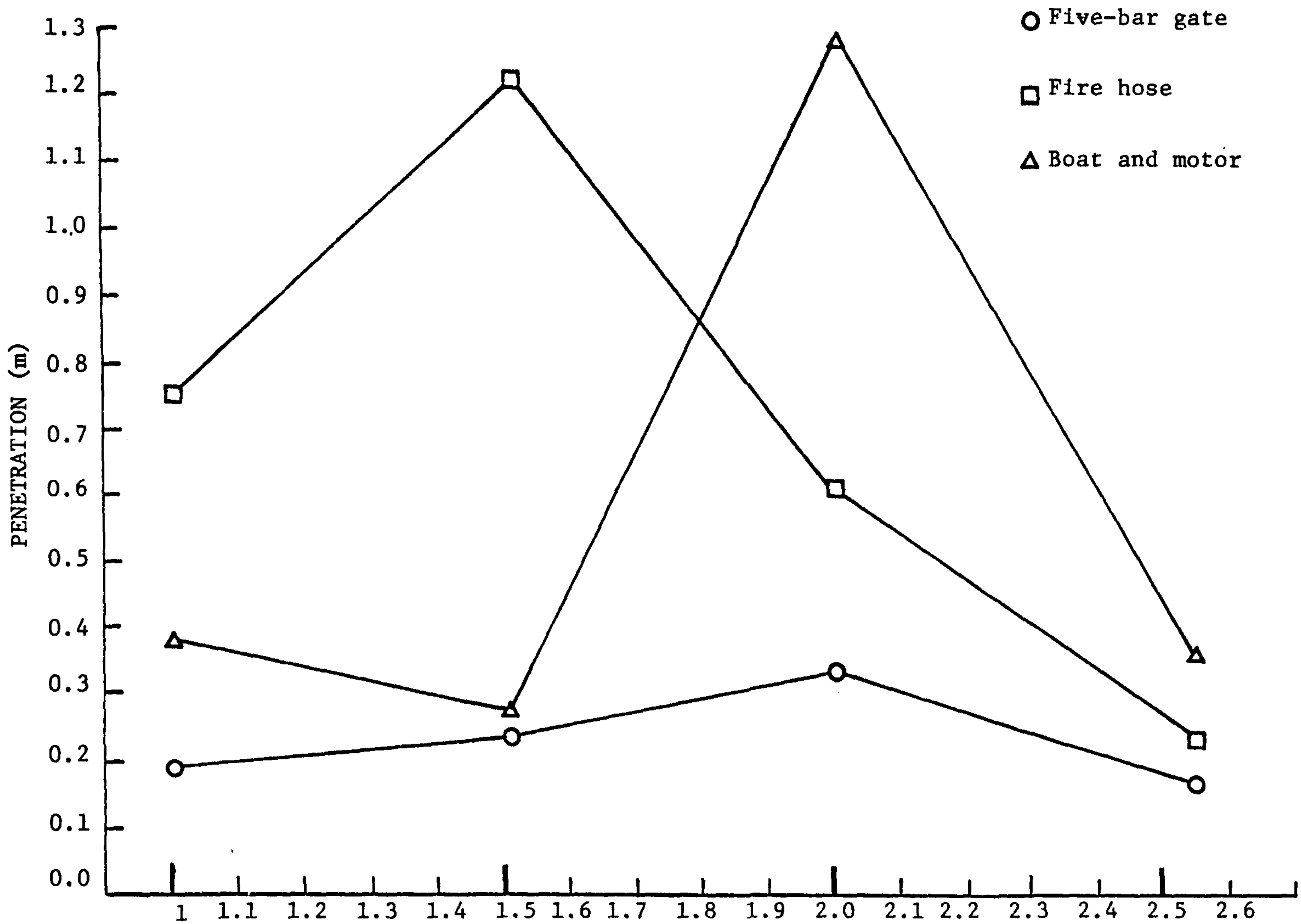

Figure C-8. Drop penetration vs. tow speed (m/s) at IFT = 18 x 10^{-3} N/m, no wave.

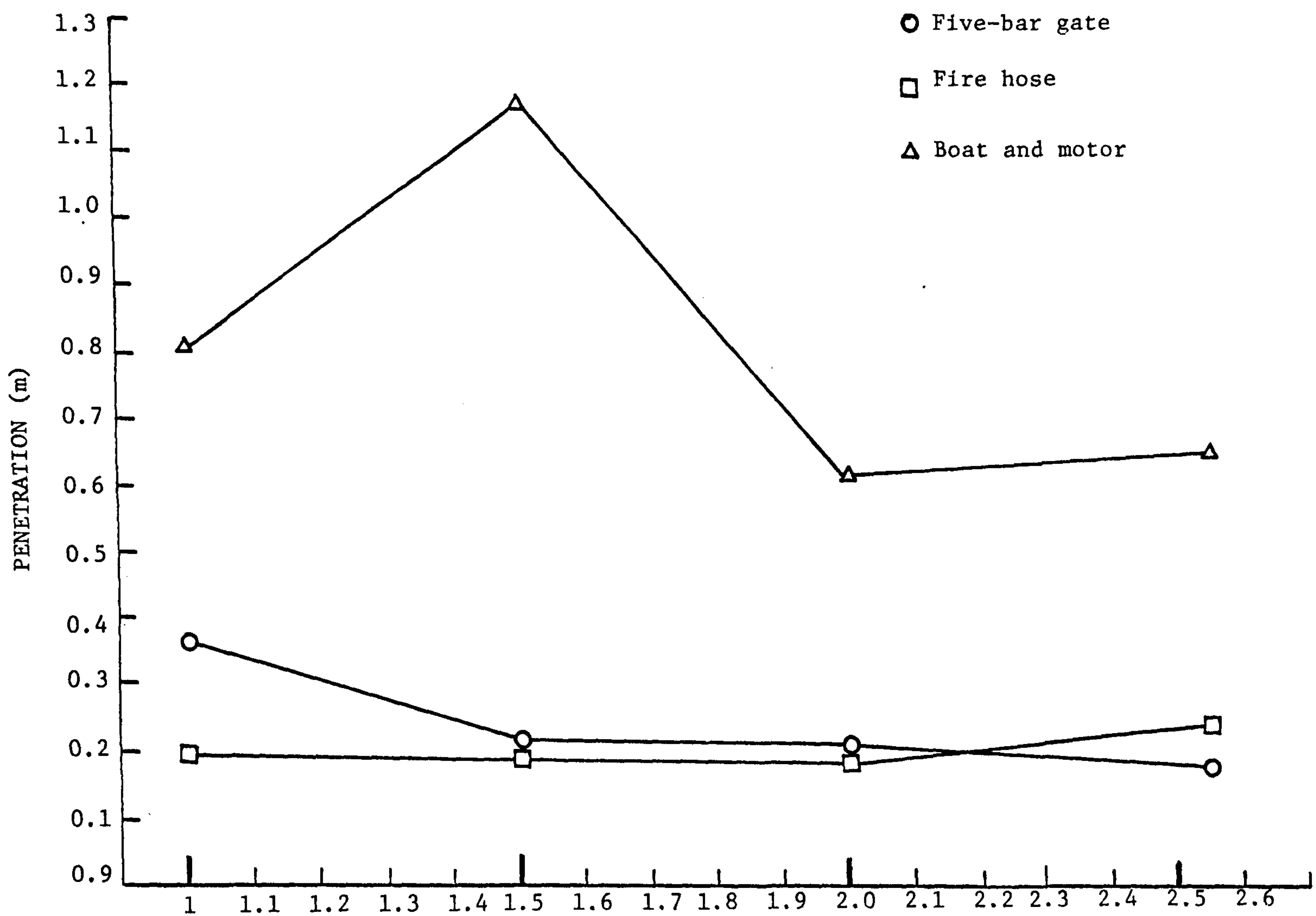

Figure C-9. Drop penetration vs. tow speed (m/s) at IFT = 8×10^{-3} N/m, no wave.

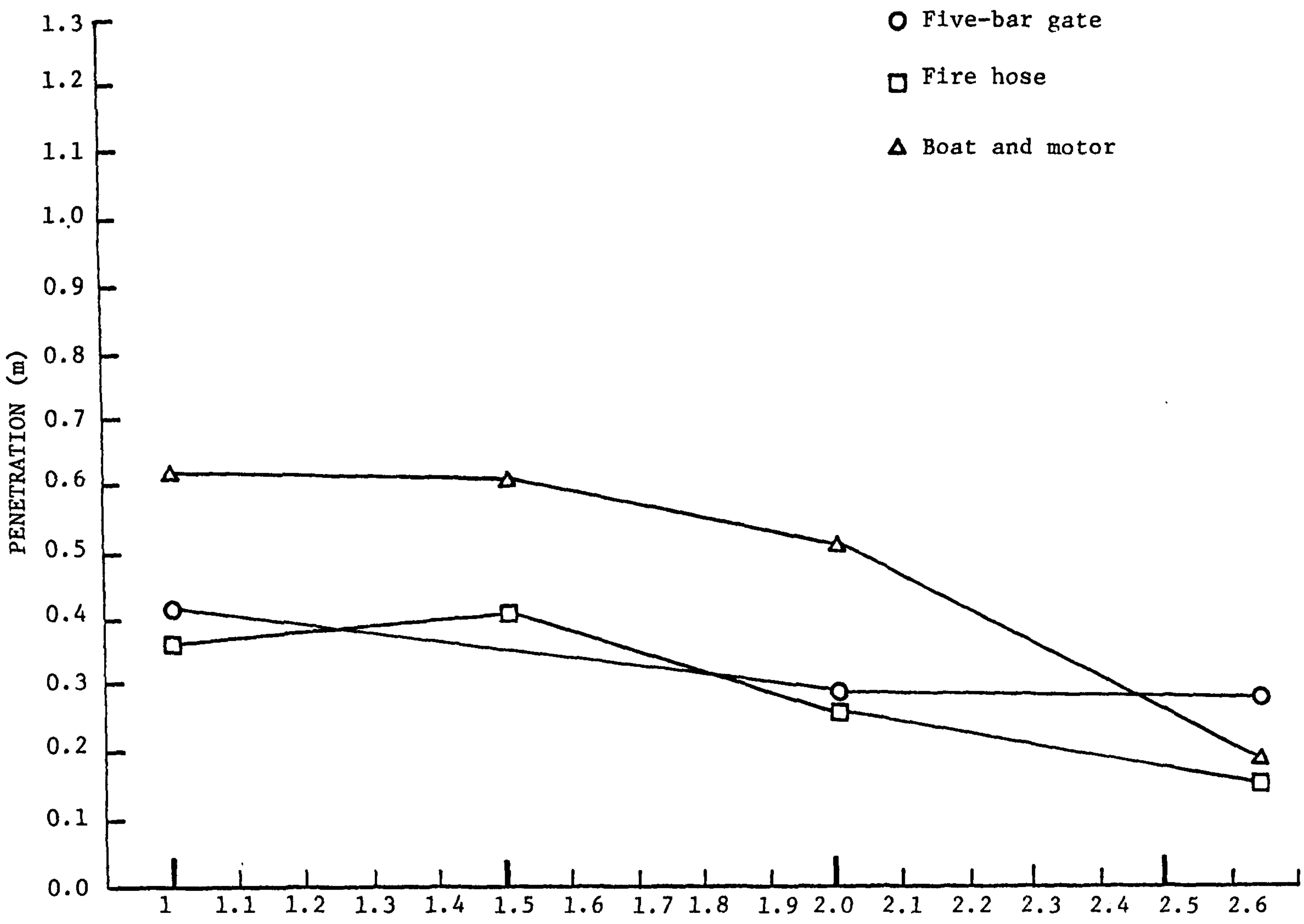

Figure C-10. Drop penetration vs. tow speed (m/s) at IFT = 2 x 10^{-3} N/m, no wave.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-78-128	2.	3. RECIPIENT'S ACCESSION NO.
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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The effective use of some oil spill dispersants requires the addition of mixing energy to the dispersant-treated slick. Various methods of energy application have included the use of fire hose streams directed to the water surface, outboard motors mounted on work boats, and the five-bar gate, a pallet-like device towed on the surface behind vessels of opportunity.

The U.S. Environmental Protection Agency sponsored this test program at their Oil & Hazardous Materials Simulated Environmental Test Tank (OHMSETT) to evaluate the above devices as well as a modified version of the five-bar gate. Three test fluid mixtures with different interfacial tensions were distributed onto the water surface, and each mixing device was towed through them at speeds from 1.02 m/s to 2.54 m/s in three wave conditions. Droplet penetration was documented via underwater photography.

Analysis of the results showed that the modified five-bar gate produced the greatest overall penetration (2.4 m) at a tow speed of 2/0 m/s. In general, performance was unaffected by wave action, and variations in interfacial tension produced no observable trend among all devices.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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