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Dynamic Structural Response of Core-Loc

by George F. Turk and Jeffrey A. Melby, U.S. Army Engineer Waterways Experiment Station

The Core-Loc, invented and developed at the Waterways Experiment Station (WES), is a new-generation, optimized breakwater concrete armor unit for protecting shoreline and navigation structures. This versatile unit can be used for a wide range of coastal armoring applications including the repair and rehabilitation of dolos armor layers. Because of the very difficult construction, in-service, and repair conditions associated with high-energy wave environments, a need was identified to characterize the dynamic impact structural response of the Core-Loc. The most common method of accomplishing this goal is the drop test (Figure 1).

Drop tests are used to evaluate the structural performance of a given armor unit when it is exposed to impact loads. During the test, the armor unit is dropped from incrementally increasing heights onto a rigid concrete base until the unit breaks apart. In this case, the drop heights were increased in 25-mm increments until the units totally failed.

Development of Core-Loc Drop Tests

In 1995, WES entered into a Cooperative Research and Development Agreement with the Concrete Technology Corporation (CTC), Tacoma, WA, to develop and conduct the first drop tests on four prototype 9.2-tonne Core-Locs. For comparative purposes, drop tests were also performed on several surplus 10.9-tonne dolosse that CTC had stored in its Tacoma yard.

The Core-Loc units cast at CTC were the first prototypes ever built. Thus, a rational decision had to be made as to standard drop-test configurations. One aim was to compare results with past drop tests of other popular types of concrete armor units. In order to best accomplish this goal, several types of drops were performed. The standard drop test for dolosse is shown in Figure 2. To compare Core-Loc units to dolosse, the hammer drop was chosen (Figure 3). Tetrapods are typically dropped as shown in Figure 4. The Core-Loc drop configuration, dubbed the anvil drop (Figure 5), is similar to the tetrapod drop in that the unit is completely lifted off the base. A third Core-Loc drop configuration, unlike any other armor unit drop test, was needed to emulate the typical manner by which a Core-Loc can fall over due to handling mishaps. This drop is called a tip drop (Figure 6). Each of

Figure 1. First Core-Loc drop test

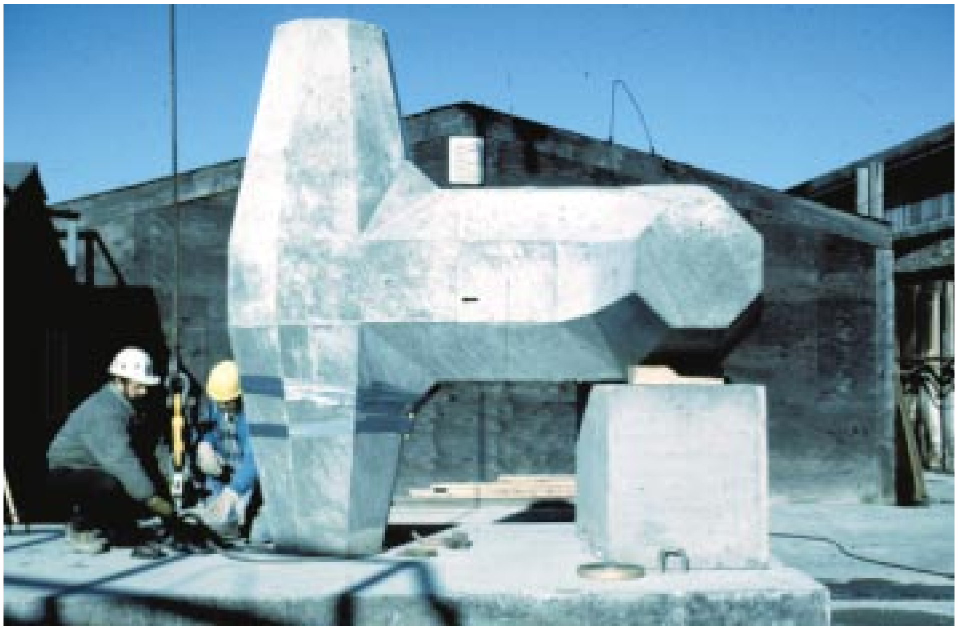


Figure 2. Standard dolos drop test

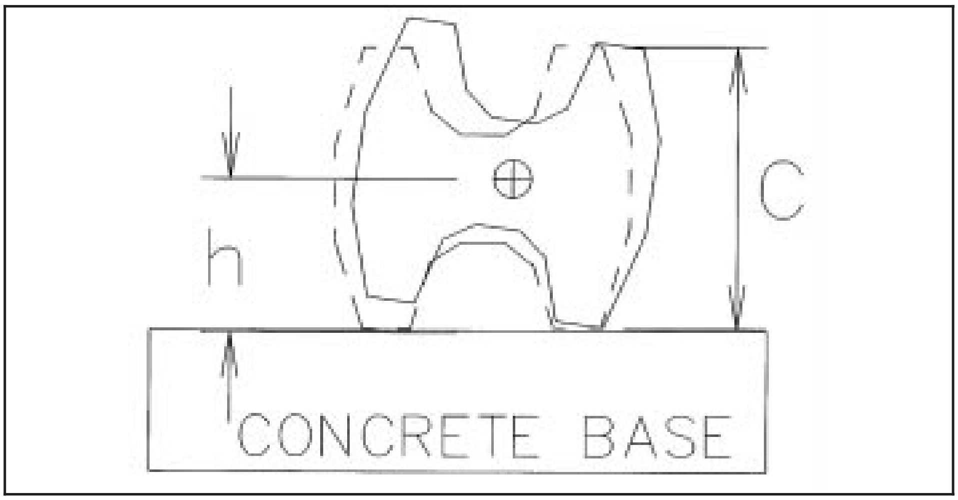


Figure 3. Core-Loc hammer drop test

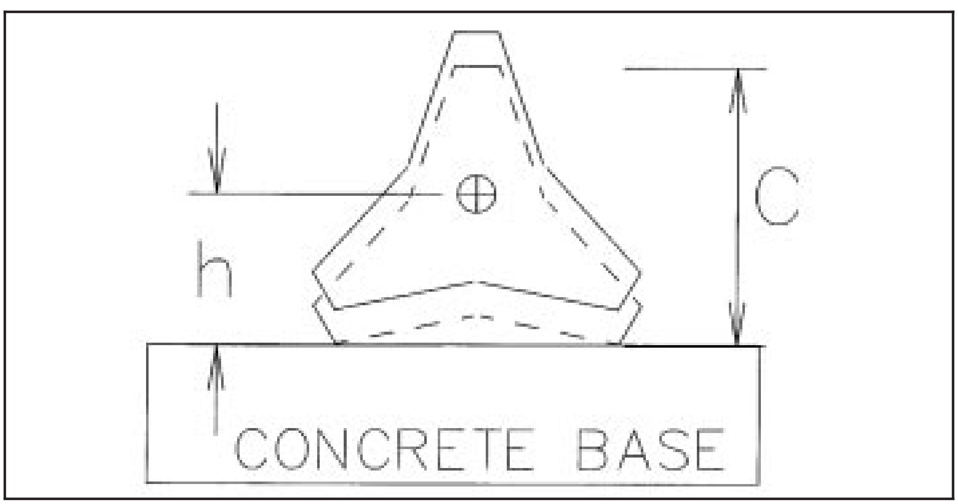


Figure 4. Standard tetrapod drop test

these three configurations was performed during the experiment at CTC.

Preparation

Mold fabrication and concrete casting

The first task of the experiment was to build a steel mold and cast four 9.2-tonne Core-Loc units. A sophisticated four-part steel clamshell form (Figure 7) was constructed to cast the concrete units. This unique mold design simplified the difficult casting and mold-stripping process usually associated with concrete armor units.

The high-strength concrete mixture that was used allowed the molds to be stripped within 24 hr and the drop tests to be performed after 7 days. During each casting, cylinders and beams were made so that the compressive and flexural strength, along with the modulus of elasticity, could be determined. The specimens for a given Core-Loc were evaluated on the day of their drop tests. This way, the strength of the unit could be compared to the strains and associated failure stresses.

The concrete used for the Core-Loc units was required to be at a reasonable strength at the time of testing. In the United States, f_c' = 34 MPa is considered a minimum standard. The average compressive strength of the concrete used for the 9.2-tonne Core-Locs at the time of testing was 43 MPa. The 10.9-tonne dolosse used were 2 years old and had a concrete compressive strength of 81.2 MPa at the time of testing. The average splitting tensile strength was 3.2 MPa for the Core-Loc and 4.2 MPa for the dolos. The mean Young's modulus was 33.4 kPa for the Core-Loc and 35.9 kPa for the dolos.

Instrumentation and data acquisition

Impact structural testing has been conducted for over 2 decades. During this time, frame drop tests have been conducted by Nishigori et al. (1989), Zwamborn and Phelp (1988), and others. For most drop tests in the past, failure was often characterized by some arbitrary crack width; thus, results were dependent on subjective interpretation. Melby and Turk (1994a and b) first collected drop-test data with a sophisticated data acquisition system attached to a 26-kg dolos with sensitive surface-mounted strain gages. This same data acquisition system and strain gaging technique were used on the four 9.2-tonne prototype Core-Loc units.

Five critical high-stress locations were selected from finite element analysis (Melby and Turk 1995a and b). The strain gages were sensitive enough to respond to minute changes in strain with a resolution of ±2 με. These weatherproof gages were extremely sensitive, yet robust enough to survive repeated impacts. The gages were constantly checked for integrity and performed flawlessly throughout the experiment.

Results

While the drop tests for the dolos and Core-Loc are similar, they do not provide a direct comparison. Almost one-third of the 10.9-tonne weight of the dolos was supported on a pedestal, whereas the full 9.2-tonne weight of the Core-Loc was unsupported at impact. Also, the tensile strength of a dolos was 140 percent of that for a Core-Loc, and the compressive strength of a dolos was 188 percent of that for a Core-Loc. Young's modulus was slightly higher for the dolos (107 percent).

In Figures 8-10, maximum principal tensile stress, σ_T, was expressed as a nondimensional stress, $\sigma_T / (E \gamma C)^{1/2}$, where E is Young's modulus, γ is the specific weight of the concrete used, and C is the characteristic length of the armor unit. This was plotted as a function of the centroidal drop height, expressed as the nondimensional parameter $(h/C)^{1/2}$, where h is the drop distance between the centroid of the armor unit and the concrete base. Figure 8 shows the results of the hammer drop tests. When best-fit curves of the data are compared, the stresses generated in the Core-Locs were only 56 percent of those in the dolosse. In the anvil (Figure 9) and tip drop (Figure 10) tests, the tensile stresses

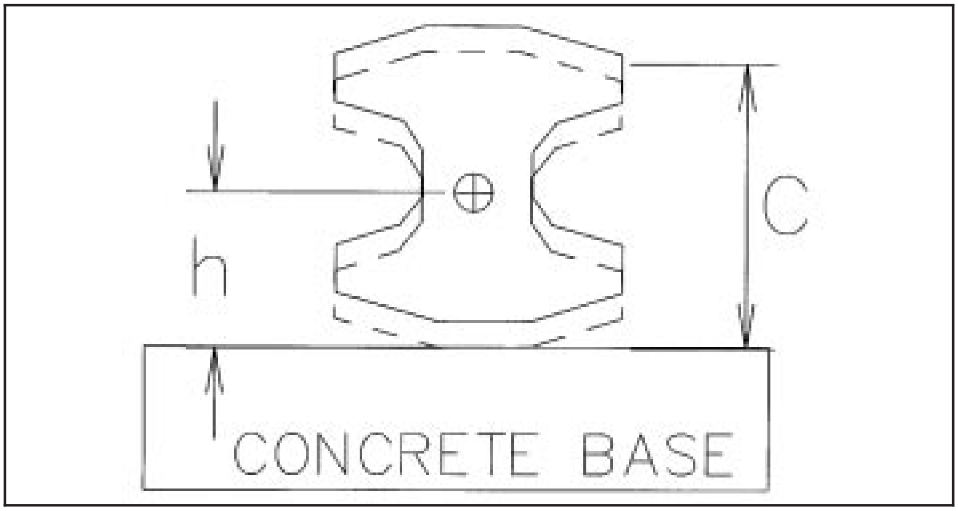


Figure 5. Core-Loc anvil drop test

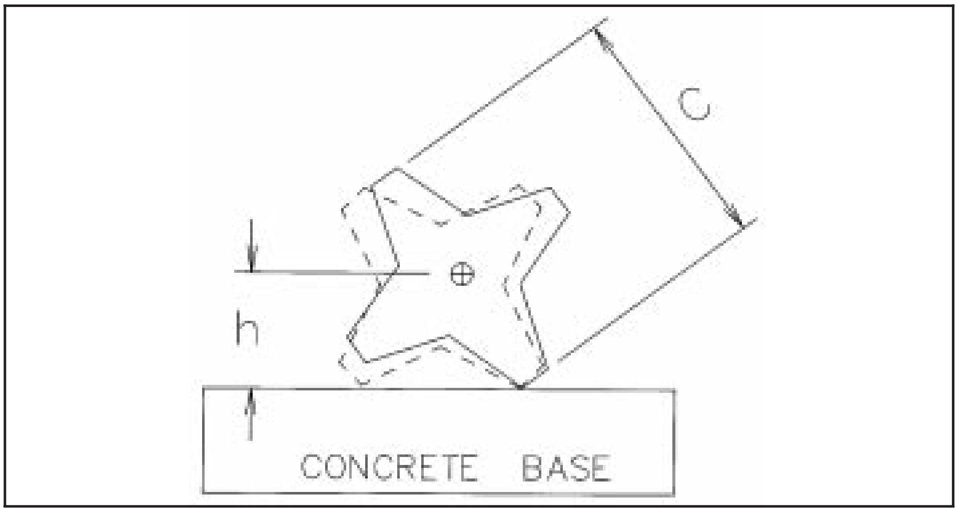


Figure 6. Core-Loc tip drop test

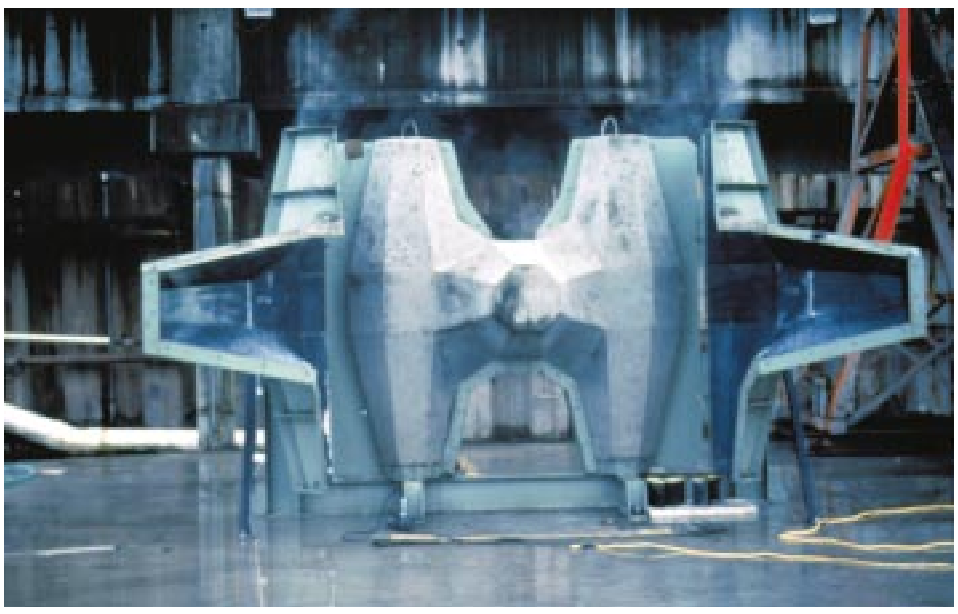


Figure 7. Core-Loc clamshell steel form

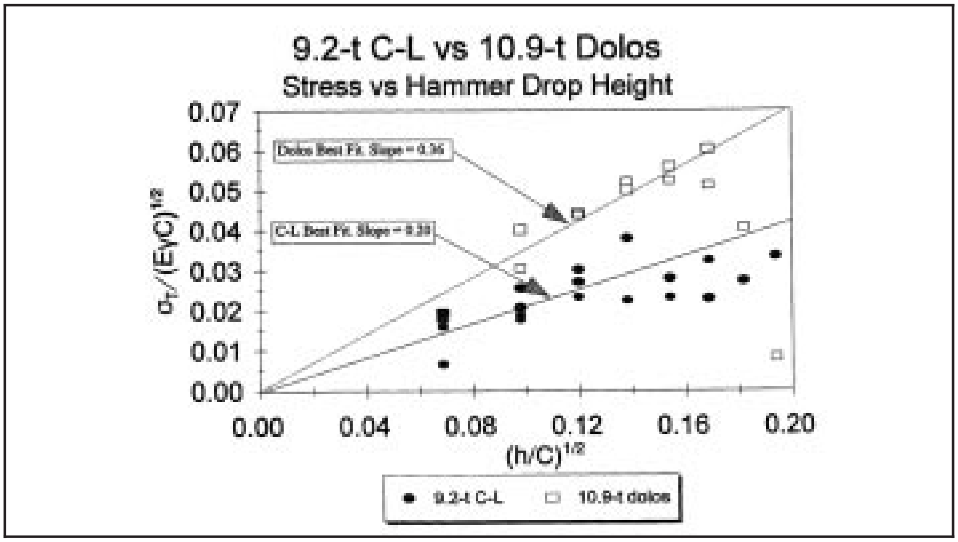


Figure 8. Hammer drop test results — measurements of best-fit curves

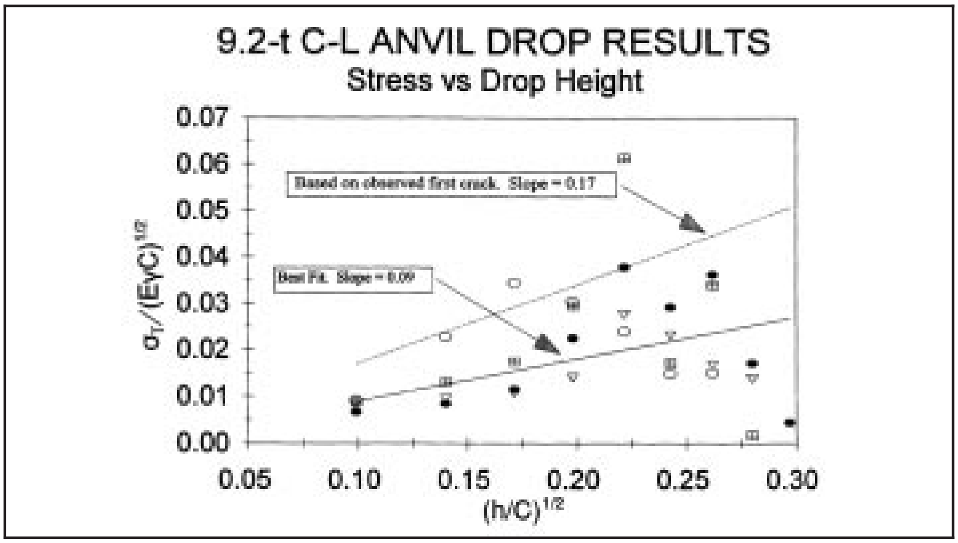


Figure 9. Anvil drop test results — measurements and best-fit curves (❍ = Test 1; ⊞ = Test 2; ▽ = Test 3; and ● = Test 4)

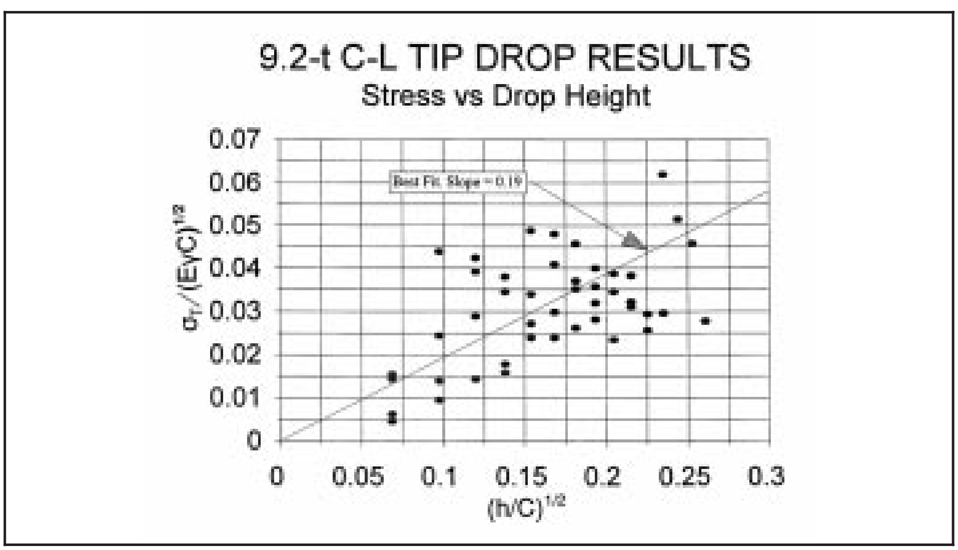


Figure 10. Tip drop test results — measurements of best-fit curves

generated were also significantly lower than those of the dolos drop tests. Repeatedly, the Core-Loc outperformed the dolos both in drop height and number of repeated blows to failure.

Melby and Turk (1994a and b) hypothesized that the dominant failure mode for the Core-Loc would be the breaking off of one of the vertical or horizontal member tips, leaving the majority of the mass of the unit intact for continued breakwater protection. For the anvil drop and the hammer drop (most like the dolos drop test), the failure was as anticipated. The unit tested in the tip drop configuration ultimately broke into two pieces. In this case, a vertical member completely sheared off the unit after a semi-circumferential crack formed on the underside of one of the central horizontal members. This unit was first dropped in 12 incremental heights on both the front and back horizontal members onto 20-mm-thick plywood. The unit showed no cracking to a height of 300 mm, after which the plywood was removed and the drops were repeated on the bare concrete. In all, the unit was subjected to over 40 drops before failure. Of the three dolosse evaluated, all failed within nine drops.

Conclusion

All the drop tests conducted at CTC used a very stiff base over a metre in thickness. Dropping units on this type of base creates one of the most severe impacts that can occur. This was a very limited test series that warrants significant expansion. Defining impact strength in itself is very difficult. There is no definite or unique relationship between the static strength of concrete and impact strength, but Neville and Brooks (1987) reported that in general, the higher the compressive strength of the concrete, the lower the energy absorbed per blow before cracking. In comparing drop test results, the 2-week-old Core-Loc consistently showed more impact resistance than the 2-year-old dolosse. Repeatedly, the Core-Loc outperformed the dolos both in drop height and number of repeated blows to failure.

For additional information, contact George Turk at 601-634-2332 or e-mail to turkg@mail.wes.army.mil.

References

Melby, J.A., and Turk, G.F. (1993). "Core-Loc concrete armor units initial stability results," CERC Internal Report, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1994a). "Concrete armor unit performance in light of recent research results," *ASCE/WPCO Sem. on Case Histories of Design, Constr., and Maint. of Rubble Mound Struc.* American Society of Civil Engineers.

__________. (1994b). "Scale and modeling effects in concrete armor units," *Proc. ASCE Coastal Dynamics '94*. Barcelona, Spain.

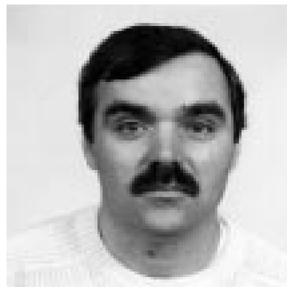
__________. (1995a). "The Core-Loc: optimized concrete armor," *Proc. 24th Int. Conf. On Coast. Engr.* American Society of Civil Engineers, New York.

__________. (1995b). "Core-Loc: optimized concrete armor units," *PIANC Bulletin* 87(5), 5-21.

Neville, A.M., and Brooks, J.J. (1987). *Concrete Technology*. John Wiley, New York.

Nishigori, W., et al. (1989). "Similarity law of impact between model and prototype tetrapods," *ASCE/WPCOE Sem. on Stresses on Concrete Armor Units*. American Society of Civil Engineers, New York.

Zwamborn, J.A., and Phelp, D. (1988). "Structural tests on dolosse," *ASCE/WPCOE Sem. on Stresses on Concrete Armor Units*. American Society of Civil Engineers, New York.



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Jeffrey A. Melby is a research hydraulic engineer in the Wave Research Branch, Wave Dynamics Division, CHL, WES. He holds B.S. and M.S. degrees in civil engineering from Oregon State University and is currently a Ph.D. student at the University of Delaware. Since joining CHL in 1987, he has worked on a variety of coastal structure design projects and is a co-Principal Investigator for the REMR armor unit work unit. Melby is also Principal Investigator for two additional coastal work units.

Sites for Field Demonstrations Needed

The Paint Technology Center at the Construction Engineering Research Laboratory (CERL) is looking for demonstration sites within the Corps for the following technologies:

- Coatings for damp surfaces. We conducted research on coatings for damp surfaces and identified three coatings that performed well in laboratory testing. We applied one of these coatings in the liner of an outlet structure. The walls were damp, and the floor had water running over it. The paint applied well, and its performance is being monitored. We would like to coordinate additional field demonstrations. Desired sites include outlet structures, gate recesses, conduits, and other locations where condensation is a major problem.
- Aluminum epoxy mastics. Our research on aluminum epoxy mastics found them to be an effective alternative to the conventional oil-based coatings for atmospheric steel. We developed a commercial item description (CID) that will be in the next edition of the guide specification for civil works painting. One of the coatings meeting the CID has been applied over various surface preparations on a bridge in a marine environment and is performing very well. We would like to be able to document additional applications and performances.
- High-solids coatings for immersion in abrasive waters. The downstream sides of tainter gates on navigation dams have offered ideal sites for field performance evaluation of high-solids epoxies and epoxy/urethane systems. Applications of a plural component urethane on a trash rack and a polyurea on a lock wall are being monitored. Data on the performance of other commercially available products and additional demonstration sites are desired.
- Metallizing applications. Industry has developed new and faster application equipment as well as new metallizing materials. We are seeking sites where the new developments can be evaluated. Candidate applications desired include high temperature, immersion in fresh and sea water, and applications to retard the attachment of zebra mussels.
- Environmentally acceptable lubricants. We would like to document the Corps' experiences with these products and are also seeking sites where the District would be interested in converting products used in existing equipment to those that are more environmentally acceptable.

If you can provide any information or would like to participate in a demonstration project, please call Al Beitelman at 217-373-7237.

Melting Ice with Space Heaters

by Robert B. Haehnel, F. Donald Haynes, and Charles H. Clark, Cold Regions Research and Engineering Laboratory

Ice accumulations on cables, gears, steel plates, and concrete walls on lock and dam machinery can hamper or even halt project operation. Removal of this ice can be hazardous and time-consuming. In the past, removal has been accomplished mechanically by chipping or thermally by melting with hot water or steam.

More recently, various heating devices have been placed in critical areas to prevent ice formation or to melt existing ice. These devices include heated panels, bubbler systems, radiant heaters, and cartridge heaters. Recently, the performance and applicability of portable space heaters for melting ice were investigated. These heaters have been used successfully at Peoria Lock and Dam on the Illinois Waterway to melt ice accumulations from the bull gear pit. They range in size from 20,000 to 400,000 BTU/ hr (6 to 120 kW/hr) and can be fueled by propane, oil, or kerosene.

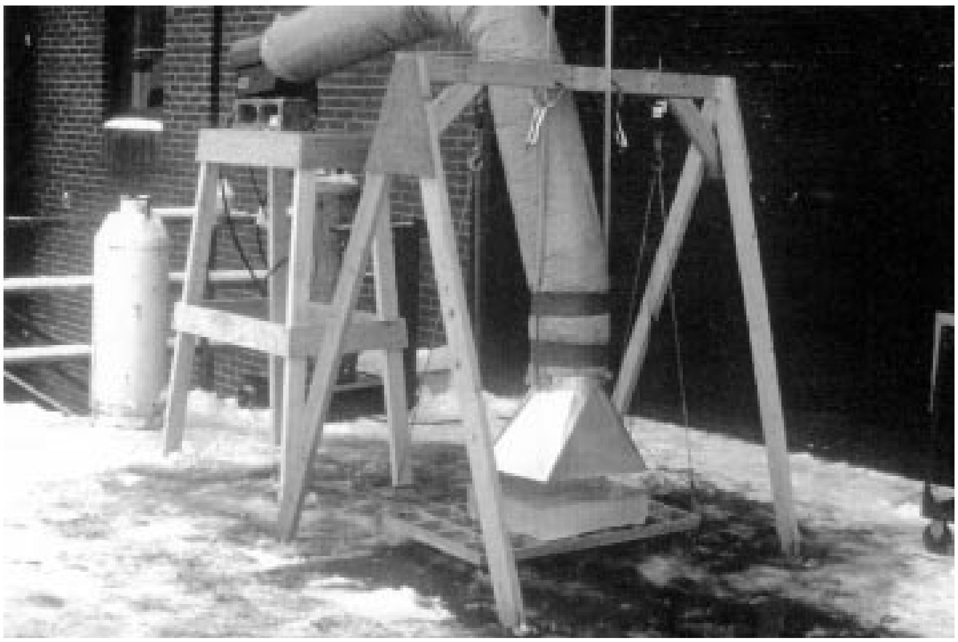

Figure 1. Setup for space heater tests

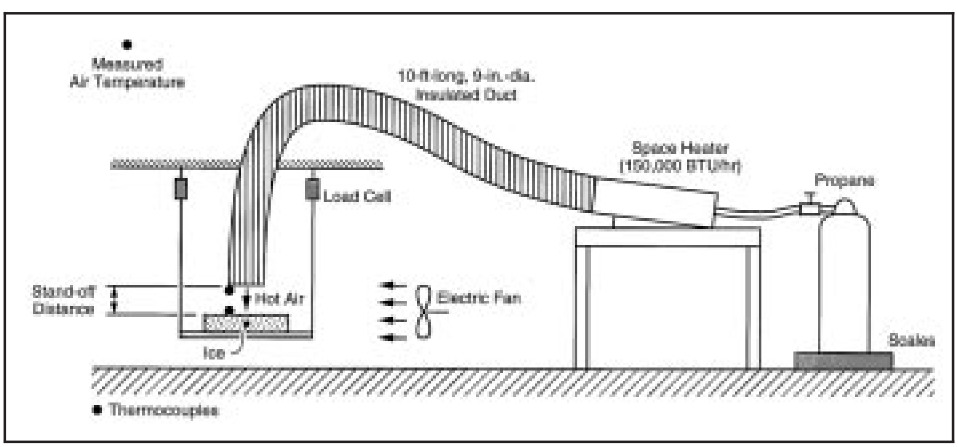

Figure 2. Diagram of test setup

Laboratory Tests

Under the REMR Research Program, the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) has evaluated the performance of space heaters for melting ice. The purpose of these tests was to determine the effects of air temperature, wind speed, and distance between the outlet and ice surface (standoff) with the use of hot air to melt ice. The test setup is shown in Figure 1.

The tests were conducted outdoors, and a fan provided the desired wind speed. The ice blocks were 2 ft (0.61 m) square and about 3 in. (76 mm) thick. Each block was placed on a wood frame that was suspended by two load cells. The hot air was provided by a propane-fired 150,000 BTU/hr (44 kW/hr) Universal TM heater (model no. 150-FAS). For 12 of the test conditions, the blocks were placed flat, and the hot air was delivered from the outlet of the space heater to the horizontal ice surface via an insulated metal duct, as shown in Figure 2. For the remaining four test conditions, the ice was tilted on an incline ranging from 30 to 80 deg from horizontal. For these tests, the duct was removed, and the outlet of the heater impinged directly on the ice block. Ambient air temperature, duct outlet temperature, and ice surface temperature were measured throughout the tests. A typical test lasted 30 min to 1 hr.

The performance parameter calculated for the heater was melting efficiency, e:

$$e = \frac{E_m}{E_f}$$

where E_m is the minimum amount of energy required to melt the ice and E_f is the energy expended melting the ice. Thus, E_f is calculated by multiplying the mass of propane consumed during the test, m_p, times the heating value of propane, h_p.

$$E_f = m_p h_p$$

Similarly,

$$E_m = m_i \left(L_i + c_i \Delta T \right)$$

where m_i is the mass of ice melted, L_i is the latent heat of fusion for ice (333 kJ/kg), c_i is the specific heat for ice (2.04 kJ/kg-K), and ΔT is the difference in temperature between the ice block and the freezing point at the start of the test.

Test Results

The results of the horizontal surface tests are presented in Table 1, and the results for the inclined tests are presented in Table 2. For cases where the number of tests is greater than one, the standard deviation is also calculated.

The results of these tests showed that, over the temperature ranges tested, ambient air temperature has little effect on the melting efficiency of the space heater (Figure 3). This finding is not surprising because the outlet temperature was typically 400°F (200ºC) while the air temperature was between 14º and 41ºF (-10º and 5ºC). The amount of heat transfer is driven mainly by the temperature differential between the melting temperature of ice and fluid (in this case the exhaust gases); therefore, fluctuations in ΔT of 9° to 18°F (-13° to -8°C) at the most were only about 2 percent of the temperature difference between the heater outlet temperature and the melting temperature of ice. Thus, the temperature of the exhaust gases dominates the heat transfer, and the air temperature primarily affects only the sensible heat stored in the ice block, which is typically very small in comparison to the latent heat of ice. For example, with an air temperature (hence initial block temperature) of 14°F (-10°C), the sensible heat is only about 20 J/g, or about 5 percent of the latent heat of fusion for ice. Even if the ice temperature were to drop to -10°F (-23°C) (an air temperature frequently seen at many Corps projects in the northern part of the United States), the sensible heat represents less than 15 percent of the latent heat of fusion for ice. Thus, the heat required to melt the ice dominates for all air temperatures of interest in this problem.

We also found that under no-wind conditions, the standoff distance has virtually no effect on the melting efficiency (for distances ranging from 2 to 12 in. (51 to 205 mm)), which remains nearly constant at 4 to 5 percent. However, standoff distance does play an important role in the presence of even moderate winds. Figure 4 shows the melting efficiency for standoff distances of 3 and 6 in. (76 and 152 mm) with no wind and with a 7-mph (11-km) wind, respectively. In the no-wind case, the two standoff distances perform almost identically. In the presence of a 7-mph wind with a standoff of 3 in., there is a moderate decline in efficiency of about 25 percent. Yet if the standoff distance is doubled from 3 to 6 in., the efficiency declines by 75 percent.

Indeed, eliminating the effects of wind plays a major role in the efficient melting of ice with space heaters. Figure 5 compares the drop in efficiency with wind speed for air

Table 1. Summary of Results for Horizontal Ice Sheet Tests

Wind Speed, mph[1]			Standoff Distance, in.[2]					Air Temperature, °F[3]							Ave. Efficiency	Standard Deviation	No. of Tests
0	4.6	6.8	2	3	4	6	12	41	32	30	28	27	25	14			
X			X											X	0.0384	0.00866	2
X				X										X	0.0439		1
X				X								X			0.0415	0.00678	5
X					X								X		0.0504		1
X					X					X					0.0470		1
X						X								X	0.0355	0.00591	3
X						X					X				0.0469		1
X						X		X							0.0401		1
X							X		X						0.0431	0.00620	3
	X					X								X	0.0049	0.00225	3
		X				X				X					0.0117	0.00176	2
		X		X							X				0.0317		1

[1] To convert U.S. Statute miles into kilometres, multiply by 1.609345.
[2] To convert inches into millimetres, multiply by 25.4.
[3] To obtain Celsius temperature readings from Fahrenheit readings, use the following formula: C = (5/9) (F–32).

Table 2. Summary of Results for Inclined Ice Sheet Tests*

Tilt Angle, deg	Efficiency, %	No. of Tests
83	0.0508	1
73	0.0492	1
66	0.0584	1
34	0.0483	1

*Stand-off distance was 12 in. (305 mm) for all these tests.

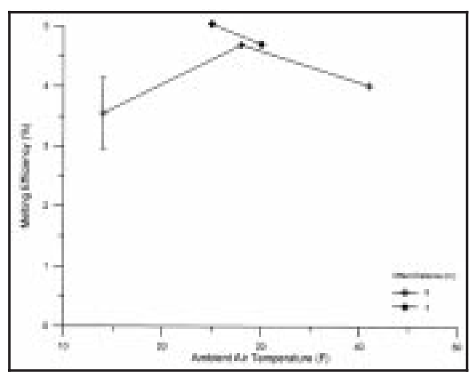

Figure 3. Effect of temperature on melting ice with use of hot air

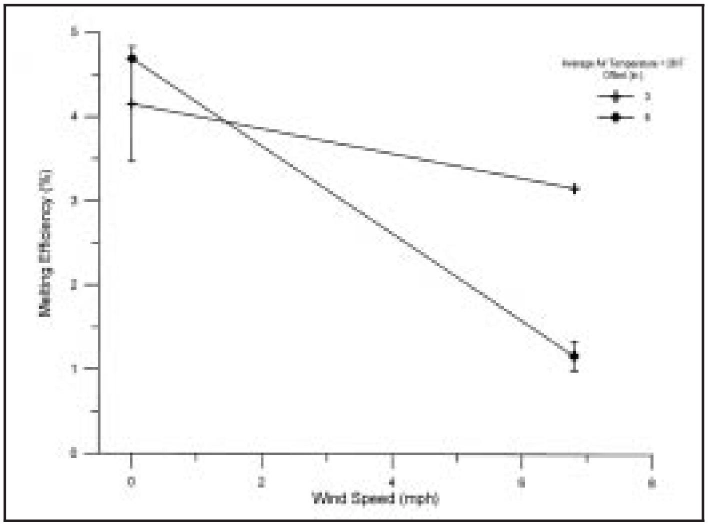

Figure 4. Effect of standoff distance on melting ice with hot air

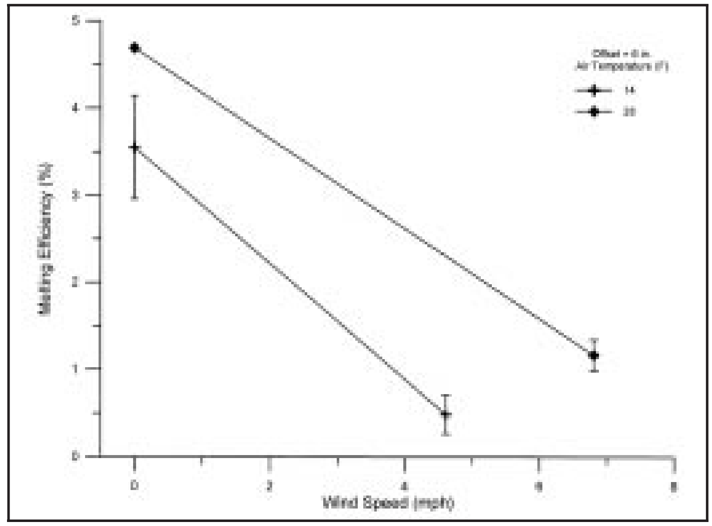

Figure 5. Effect of wind on melting ice with hot air

temperatures of 28° and 14°F (-2° and -10°C). In both cases, we can see the wind cuts efficiency significantly. Interestingly, the slopes of both lines are almost the same, and the average slope for the two lines is -0.006/mph (-0.01 km/hr) over the wind speeds considered in this study. This is about a 12-percent loss in melting efficiency for an increase of 1 mph (1.6 km/hr) in wind speed.

In the inclined ice tests, we found that the angle of impingement had no effect on the melting efficiency. In fact, the only real difference we witnessed was an approximate 15- to 20-percent increase in overall efficiency compared to the horizontal tests. We attribute this change to removing the duct, thereby recovering the losses associated with ducting the hot exhaust gases (i.e., radiation losses from the duct).

In general, we find that melting ice with hot air is a very inefficient process, with not much more than 5 percent of the energy stored in the fuel going to melting the ice. Tests conducted at CRREL using the exhaust gases of a gas turbine engine for melting ice yielded similar results with maximum efficiencies never exceeding 8 percent. Since modern combustion chambers are highly efficient, yielding fuel conversion efficiencies on the order of 85 percent or more, we attribute no more than 15 percent of the loss of energy to incomplete combustion. This means nearly 80 percent of the fuel energy is lost through heat transfer effects such as heat losses through the heater housing and duct work. In addition, incomplete heat transfer between the hot air and ice surface reduces melting efficiency. These tests were conducted in an open-air environment. There was nothing to prevent the hot air from leaving the proximity of the ice surface after it exited the outlet, so most of the heat was carried away in the hot air with very little heat being transferred to the ice surface. These losses can likely be reduced by enclosing the heated space with plastic (Figure 6), which would eliminate wind losses as well as raise the ambient air temperature.

Field Applications

Portable space heaters are readily available at most Corps projects. This work shows that they can be used to melt ice, though under the best of circumstances they have melting efficiencies of only about 5 percent. Wind and losses due to free convection severely reduce the efficiency of melting ice with hot air. A simple means

Figure 6. Space heater used to heat a plastic enclosure, Gavins Point project, Yankton, SD

of reducing these effects is to enclose the area to be deiced within a shelter. If it is intended to be a temporary structure, plastic over a wood frame would suffice. Because of the low ice-melting efficiency of space heaters, this method of deicing or ice prevention should be seen only as a stop gap measure, and more efficient deicing methods, such as heater panels or bubblers, should be used as permanent solutions to perennial icing problems.

For additional information, contact Robert Haehnel at (603) 646-4325.

Additional information about the use of heated panels, bubbler systems, radiant or cartridge heaters, water jets, and polyethelene sheeting for ice control on locks and dams can be obtained from The REMR Bulletin, Vol. 11, No. 1; Vol. 10, No. 4; and Vol. 12, Nos. 2 and 3. The last two issues are available on the REMR Web Site at http://www.wes.army.mil/REMR/bulletin.html (please note that this URL is case sensitive). Copies of the other issues can be obtained by contacting Lee Byrne at (601) 634-2857 or byrnel@mail.wes.army.mil.

Robert Haehnel is a research mechanical engineer at the Cold Regions Research and Engineering Laboratory (CRREL) and works in the Ice Engineering Research Branch. He holds a B.S. degree in engineering from Brigham Young University. Haehnel has been involved in the REMR Research Program for 4 years and has been with CRREL for 7 years. He is a member of the American Society for Mechanical Engineers.

Charles Clark is an electronics technician in the Ice Engineering Research Branch at CRREL. He holds an AAS degree in electronic engineering technology. He has been an electronics technician for 30 years and has worked at CRREL for the past 14 years. Clark has been a member of the Institute of Electrical and Electronics Engineers (IEEE) since 1963.

Donald Haynes was a mechanical engineer in the Ice Engineering Research Branch, CRREL, Hanover, NH, until his retirement in 1996. He has a B.S. degree in mechanical engineering from the University of Arizona and an M.S. degree in mechanical engineering from Michigan Technological University. Haynes has over 20 years of experience in applied research on icing problems and served as the Principal Investigator for the REMR research work unit on icing problems until his retirement. He is a registered Professional Engineer in the State of New Hampshire.

Notice

This will be the last printed version of *The REMR Bulletin*. Due to reduced funding for the REMR Research Program, it is necessary to take several cost-saving measures to ensure that all ongoing research studies can be brought to closure. Future issues of *The REMR Bulletin* will only be available electronically on the Internet at http://www.wes.army.mil/REMR/remr.html (please note this URL is case sensitive). Through use of the World Wide Web, the bulletin will continue to provide timely information about program activities and publications during the remainder of this fiscal year.

As the REMR Research Program approaches its end in September 1998, it will continue its commitment to the timely transmittal of REMR-developed technology to the Corps, industry, and academia. Although supplements to *The REMR Notebook* will no longer be printed, a final edition of the notebook will be produced electronically on CD-ROM. This electronic form of the notebook will include all previously published technical notes as well as new ones. As ongoing work units are finalized, they will be reported in bulletin articles, in technical notes incorporated into the notebook, and in printed technical reports. Availability of these items will be posted on-line in the bulletin.

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