NAVAL RESEARCH

REVIEWS

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PROFILES IN SCIENCE

Professor Raymond D. Mindlin

Professor Raymond D. Mindlin has been at Columbia 42 years where he has achieved fame as a teacher and influential scholar in Applied Mechanics, especially as a pioneer in the area of Mechanics of Solids. The Office of Naval Research for many years has supported the work of Mindlin and his students.

His analytical studies always explain and interpret in mathematical terms observed but poorly understood physical phenomena. This approach was used in his important work with problems of elastic contact and of granular media and the problem areas of generalized elastic continua and crystal plates. His continued efforts to bridge the gap between continum and lattice theories aided decisively in explaining certain observed anomalies.

Mindlin's contributions to the dynamics of package cushioning has had much influence on the design of supports and containers for the protection of equipment from mechanical shock and vibration.

The Civil Engineering Laboratory*

The Navy's Civil Engineering Laboratory was established at Solomons, Maryland, in 1948. On January 23rd, 1950, it was relocated at Port Hueneme, California, a seaport town some 60 miles northwest of Los Angeles. Now a detachment of the U.S. Naval Construction Battalion Center, Port Hueneme, it is headed by an Officer-in-Charge, with a civilian Technical Director. Program management responsibility is exercised by the Assistant Commander for Research and Development, Naval Facilities Engineering Command.

CEL is one of a kind in the Navy. Its mission is "to be the principal RDT&E center for shore and seafloor facilities, and the support of Navy and Marine Corps construction forces". It would be difficult to suggest a more apt description of the working philosophy of the Laboratory than by quoting its motto, Admiral Robert Peary's well known declaration, "I will find a way or make one". That statement applies with fresh significance to the needs of today's Navy, and CEL is meeting the challenge by devoting its varied talents to alert and imaginative research, development, test and evaluation in many fields of technology.

The Laboratory provides quick, direct technical advice and support to Naval facilities and field operations. A telephone line is open 24 hours a day for the convenience of personnel with problems requiring a speedy solution. In the case of a flood ravaged Naval Communications Station in the Philippines, two engineers from CEL were on the job the morning of the day after the call for on-site assistance was received.

In the many and varied tasks they undertake, CEL's engineers and scientists are motivated to find practical solutions and to provide usable results. An organized effort is made to disseminate the Laboratory's findings widely throughout the Naval Shore Establishment by a program of technology exchange, and within the limits of security, to both the Government and the public sectors. Several of its products have found their way into the industrial community (Figure 1).

At any given time, work in progress at CEL goes far beyond the "civil" engineering connotation in the Laboratory's name. It includes civil, electrical, structural, mechanical, general, sanitary, ocean, environmental and polar engineering, plus many of the sciences.

*This article was prepared by Raymond K. Darby of the Information and Presentations Division, Civil Engineering Laboratory.

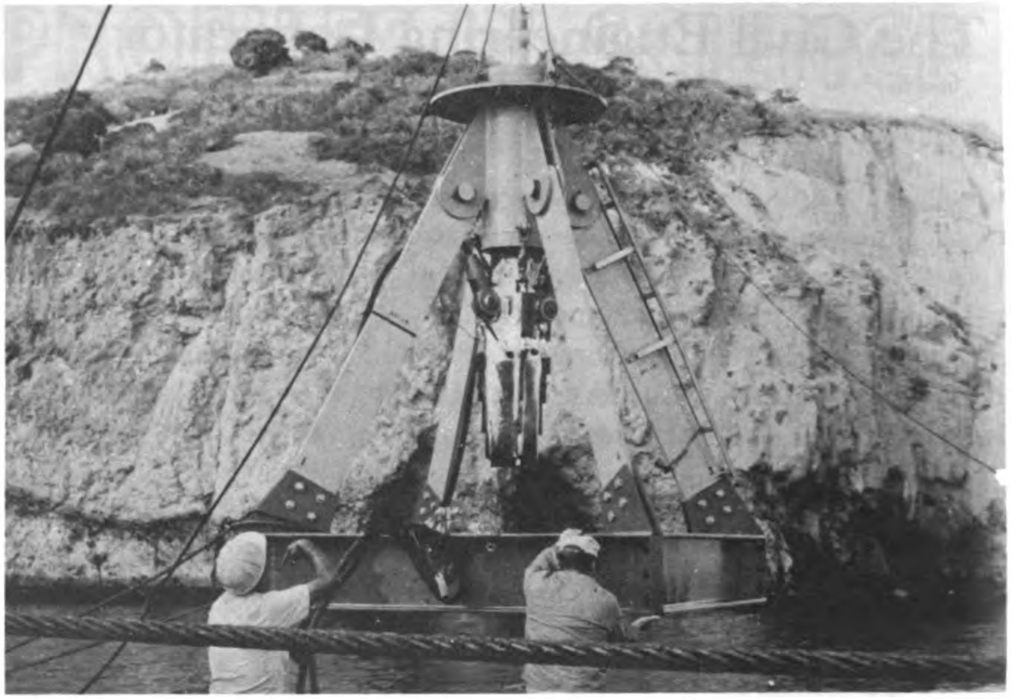

Figure 1 – The CEL launched penetrating salvage anchor system being prepared for a test, using a dummy projectile, to verify the launching system performance

Some major accomplishments of CEL will further illustrate the diversity of this effort.

In the ocean engineering field, the Laboratory has made extensive investigations revolving around the use of concrete in the sea. The construction and emplacement of the 50-ton, unmanned concrete SEACON structure at a 600 foot depth in the Santa Barbara Channel, which incorporated a number of significant additional experiments, considerably advanced the technology of construction for seafloor facilities. SEACON remained on the bottom for a period of 11 months, and was successfully recovered in first rate condition.

The use of plastic materials to fabricate a two-man capsule capable of descending to 600 feet in the ocean and providing 360° visibility was demonstrated in the CEL-designed NEMO. NEMO was assembled from 12 acrylic plastic pentagons in the form of a sphere, with a 6-foot diameter. Like many other hardware items designed for undersea use, the NEMO capsule was tested in CEL's 72 inch ocean pressure vessel . . . the largest of 22 various sized pressure vessels in the Laboratory's Deep Ocean Test Facility . . . before being certified at sea. NEMO is currently in use at Southwest Research Institute in San Antonio, Texas, for undersea observation purposes (Figure 2).

A concept for floating mobile bases to meet forward area surveillance and basing requirements of the Navy in the mid-1980's, was

Figure 2 — CEL's NEMO (Naval Experimental Manned Observatory) can carry two men to a depth of 600 feet. Constructed from 12 acrylic plastic pentagons bonded together to form a sphere, NEMO provides full 360 degree visibility.

developed by CEL. These platforms, which could be as large as 1,000 by 4,000 feet, were seen as consisting of components mass produced ashore, constructed in modules, launched, towed to the site and assembled there. Concrete appears to stand out as an economical and practical construction material. A one-tenth scale model of one section of a base of this kind was fabricated and launched in Port Hueneme harbor (Figure 3).

In other ocean related projects, the Laboratory has developed propellant actuated anchors for deep ocean moorings, pontoon lift systems for salvage work, diver heating systems and diver tools

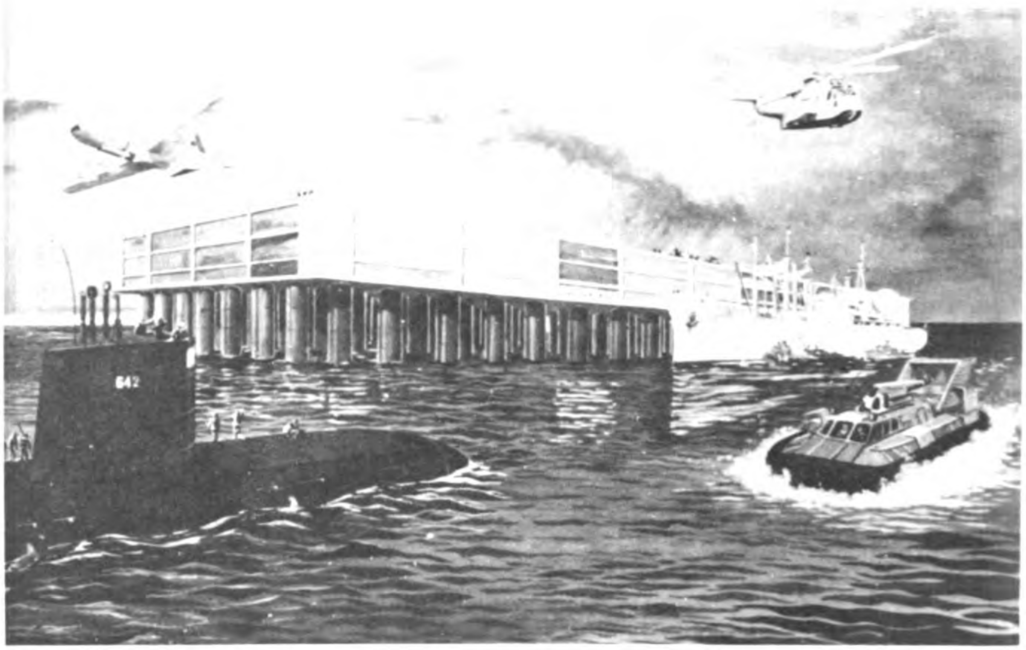

Figure 3 – Artist's concept of a large, mobile floating base made of concrete

(Figure 4). Further adding to the Navy's capabilities in undersea construction work, CEL participated in the test and evaluation of the Buoyancy Transport Vehicle (developed by the Naval Undersea Center), which can perform the functions of a sea-going forklift, and in the development of the Construction Assistance Vehicle, virtually a diver operated undersea pickup truck. For support in its ocean engineering program, the Laboratory owns and operates several surface craft, including a warping tug and an LCM-8 converted for use as a diving boat, and maintains a Diving Locker with 8 qualified personnel.

Materials science is an active area of both research and accomplishment at CEL. Hundreds of recommendations have been made, frequently after considerable study and experimentation, as to the use of different materials and substances in wide-ranging environments, from the deep ocean to the tropics. New protective systems have been formulated for structures exposed to corrosion. The materials exposure program has included the emplacement at varying depths in the ocean of Submersible Test Units containing hundreds of specimens of metals, wood, wire, rope, plastics etc, plus racks of similar specimens in tropical environments ashore. This program has generated a large volume of useful data. A simple kit for the identification of weathered paints was developed in the Laboratory and

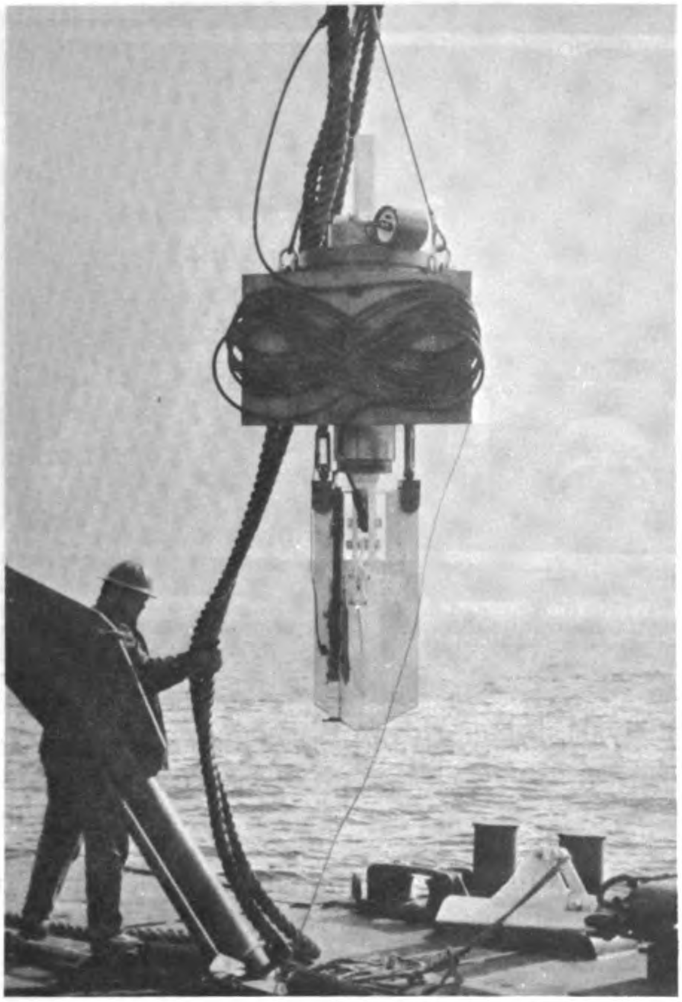

Figure 4 – The CEL propellant-actuated deep water anchor, one of a family of anchors developed for mooring Navy vessels in the deep ocean. Functional in water depths from 50 to 20,000 feet, this anchor has a holding capacity between 20,000 and 60,000 pounds depending on the nature of the seafloor.

is now being produced commercially (Figure 5). A cathodic protection system designed for Navy moorings subject to corrosion damage was also given a trial by a large private industrial firm.

In the amphibious and advanced base field, CEL engineers have made many substantial contributions. They have devised and successfully tested automatic leveling controls for construction equipment that do a more efficient job while reducing the skill and time required of the operators. They have advanced the techniques of ship-to-shore delivery of supplies over remote beachheads. They have developed a helicopter-transportable housing system for forward troops, and a modular system for air, sea or ground delivery of

Figure 5 – The CEL-developed weathered paint identification kit for field personnel with no laboratory training. It is now being manufactured and sold commercially.

fuel, water and firefighting equipment to field units in advanced locations. Resin fiberglass systems for rapid surfacing of roads, helicopter pads, forward storage areas and similar applications have been evaluated, improved, and field tested.

The Laboratory's polar engineering group has evolved new ways to use snow for making vehicular roadways and aircraft runways. Ice technology is constantly being expanded at the South Pole, where a team of Antarctic specialists from CEL is temporarily stationed every austral summer, and in CEL's own polar laboratory at Port Hueneme.

An event of note in the electrical field was the development of a device to detect and monitor fluctuations in the power supply to sensitive apparatus such as communications equipment and computers. This is another CEL product that is now being manufactured and sold commercially. A follow-up device that promises to be of equal or even greater value is an electrical transient direction detector which can identify whether the disturbance is caused by the power source or the load.

Experience has shown that antenna insulators used at Navy Very Low Frequency (VLF) communication stations have a troublesome pattern of failure. CEL is attacking this problem with an in-depth investigation, followed by the development of the technology required to provide dependable antenna insulators and assemblies.

The CEL Environmental Protection Systems Division is involved in the development of hardware and techniques used in the fight against pollution of all kinds. Outstanding among the many different types of projects handled by this Division is its contribution to improved methods of treating oil spills. One CEL product worthy of special note in this area is a universal connector for oil containment booms. The connector has been accepted in the Navy inventory, and manufacturers of oil spill recovery equipment have shown a definite interest in it.

Other environmental activities span the full spectrum of antipollution work. CEL is a participant in and coordinator of the Tri-Service RDT&E Plan for Solid Waste Management, a DOD-wide organization. In 1973, the Laboratory was the recipient of the Secretary of the Navy Environmental Protection Award. Also, during the formative stages of the Naval Environmental Protection Support Service, and into the period when it became fully operational, CEL was Deputy Program Manager for this major Navy activity. The NEPSS is now the Navy's single central environmental information center (Figure 6).

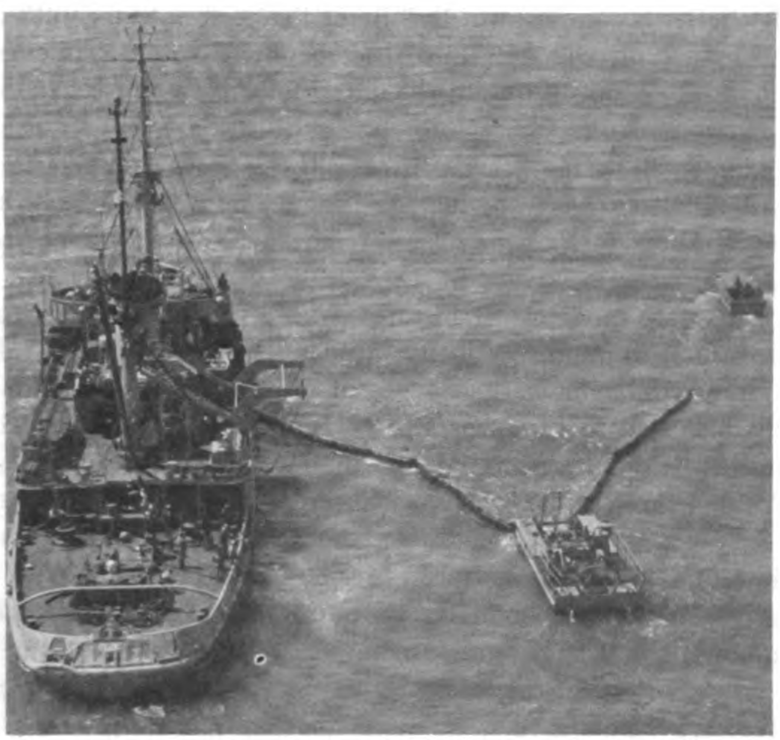

Figure 6 – Environmental protection research at CEL has included the evaluation of oil spill cleanup systems and equipment

Recently, CEL established an Energy Program Office. This Office is responsible for all energy RDT&E for Naval shore facilities. It investigates promising energy concepts and equipment that might aid in the conservation of energy at shore stations, or provide an alternative energy source applicable to Naval requirements, especially at remote sites.

The foregoing is only a sampling of the kind of programs in which the Civil Engineering Laboratory is engaged on a daily basis. With military science and technology advancing so rapidly in all parts of the world, CEL is filling the need of the Navy and the Marine Corps for a research oriented, multi-talented agency capable of producing practical results.

Coanda Effect Oil/Water Separator

A new method of gross separation of free oil from oil/water mixtures is being investigated by CEL. This technique uses the fluid dynamic phenomenon called "wall attachment", or Coanda Effect, which can best be described as follows. When a jet stream of fluid enters into a bounded region, it is deflected towards an adjacent wall, becomes attached to it, and flows along it. The jet bends during its attachment, thus generating a centrifugal force field and forming a separation bubble. If the jet is composed of two fluids that will not mix, such as oil and water, the lighter oil will flow into the separation bubble, while the heavier water tends to flow away from it. The oil accumulated in the separation bubble can then be removed.

An experimental 3-stage Coanda Effect oil/water separator was designed and built. Feasibility tests were conducted, using an oil/water mixture containing 6 percent oil. About 50% of the oil was removed as the mixture passed through each stage.

A second 3-stage model was fabricated, with a modified design using a splitter, or jet divider, to improve velocity profiles. This model was tested with oil/water mixtures containing various types of oil, and also with real oily wastes. Test results indicated that the separator's effectiveness is highly dependent upon the quality of the oil/water mixture and the rate of flow. At the optimum flow rate of 3.5 gpm through the separator, corresponding to a Reynolds number of 7787 at the nozzle, its effectiveness was about 60 percent. For example, when the separator treated a test mixture with 4824 ppm hydraulic oil, it produced two effluents, one of oil containing about 50 percent water, and the other of water containing about 1967 ppm of oil.

Based on the results of these tests, a multi-stage separator to process 20 gpm of mixtures has been designed.

The chief investigator on this project is Dharam Pal, of CEL's Mechanical Systems Division.

Concrete Research at CEL

Harvey H. Haynes*

For many years, the Civil Engineering Laboratory has conducted research involving concrete of all types, with particular emphasis on its use as the major undersea building material of the future. Concrete has several advantages that make it highly adaptable to the ocean environment. First, the durability of high quality concrete is outstanding, permitting long operational life with low maintenance. Second, the low strength-to-weight ratio of concrete as compared to steel is an advantage in the design of large, hollow structures which tend to be excessively buoyant, and ballast can be added more efficiently to attain the desired buoyancy by adjusting the wall thickness, without excessive overdesign. Third, large pressure-resistant concrete structures cost at least 50% less than large structures of other materials because of the relative ease of fabricating hulls of complex curvature, and the low cost of concrete.

It has been established that concrete pressure-resistant structures can function successfully at depths to 3000 feet in the ocean. This depth range encompasses the area where most of the undersea work by Government and industry will be performed for many years to come. Some examples are submarine garages, fuel storage, containment vessels to house nuclear reactors, huge cargo submarines, mineral refinement plants, oil drilling enclosures, and transportation tunnels connecting land masses separated by deep water.

CEL's research goal was to develop design information for the use of concrete as an undersea construction material. First generation design guides have been established for predicting failure pressures for spherical and cylindrical hulls. In addition, the Laboratory has investigated the effects of various structural and material properties on the behavior of the structures.

Experimental investigations were performed on 83 model spherical hulls and 41 model cylindrical hulls subjected to hydrostatic loading. The spheres tested were of two sizes. Fifty were of 16-inch outside diameter with wall thicknesses of 1 to 4 inches, and 33 were of 66-inch outside diameter with a 4.12-inch wall thickness. They were fabricated by bonding two hemispheres together with an epoxy adhesive. The cylinder hulls were of 16-inch outside diameter with 1/2, 1, 2, and 3-inch wall thicknesses. They were cast monolithically

*Mr. Haynes is a research structural engineer in CEL's Ocean Structures Division.

and the ends were capped by bonding various types of end-closures to the cylinder sections with epoxy (Figure 1).

Two basic mixes were used. A microconcrete (mortar) was used for the smaller models and a 3/4-inch maximum size aggregate concrete was used for most of the 66-inch spheres. The concrete consisted of ASTM Type 2 portland cement, a coarse aggregate/cement ratio of 2.28, a sand/cement ratio of 1.85, a water/cement ratio of 0.41, and a water-reducing admixture.

All the specimens were tested in the pressure vessels of CEL's Deep Ocean Test Facility, using either fresh or seawater as the pressure medium (Figure 2).

Spherical Structures

The concrete spheres exhibited either one or two stages of failure under short-term loading, depending on the ratio of wall thickness to outside diameter (t/D_o). Only one stage of failure, implosion, was experienced by spheres having a t/D_o ratio of 0.063 (16 X 1 inch spheres and 66 X 4.12 inch spheres). On the other hand, spheres with a t/D_o ratio of 0.125 (16 X 2 inch spheres) and those with greater t/D_o ratios experienced cracking of the concrete in the plane of the wall followed by implosion.

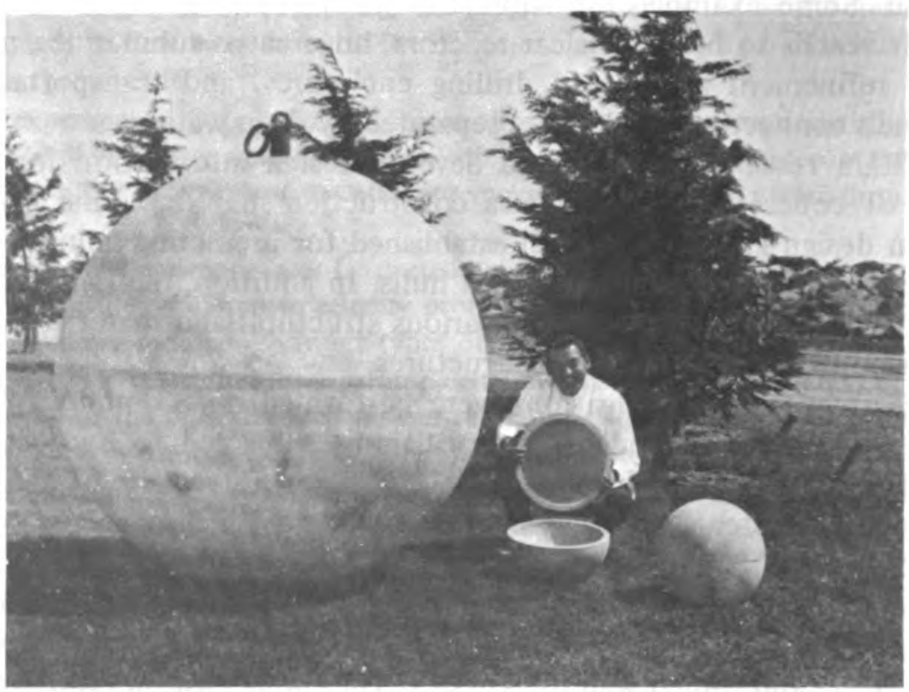

Figure 1 – Concrete spheres of 66-inch and 16-inch outside diameters were tested in the deep-submergence structures program

Figur 2 — A concrete test cylinder, instrumented with strain gages, about to be lowered into the 76-inch pressure vessel at CEL's Deep Ocean Test Facility

An indication of the operational depth range for concrete spheres can be obtained from Figure 3. The reader applies his own safety factor to the spherical structure by selecting an allowable concrete stress as opposed to the ultimate concrete stress. The depth of 3000 feet is within state-of-the-art technology.

Cylindrical Structures

The implosion behavior of cylindrical structures having various cylinder length to diameter (L/D_o) ratios, wall thickness to diameter (t/D_o) ratios, and end-closure conditions, has been studied. The investigation of the effect of L/D_o ratio showed that the stiffening

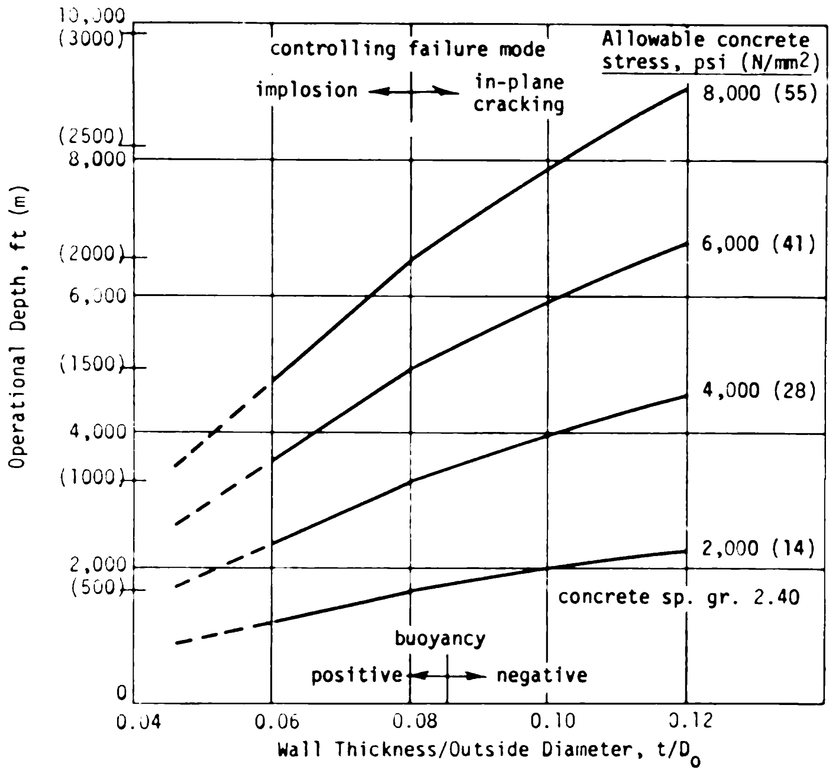

Figure 3 – Design guide to predict operational depth for concrete spherical structures under short-term loading

influence of end-closures caused an increase in implosion pressure. When the L/D_o ratio was 0.5, an increase in implosion pressure of about 20% was observed, compared to specimens with an L/D_o of 2.0 or greater. The study of the effect of various types of end-conditions on cylindrical structures showed that a wide range of end-condition restraints did not cause decreases in implosion pressure compared to standard type end-conditions, which were hemispheres of the same wall thickness as the cylinder. The study of the effect of t/D_o ratio was most significant in defining the implosion behavior of cylindrical structures. The t/D_o ratio ranged from 0.03 where structural instability controlled implosion, to 0.18 where material failure controlled implosion.

Figure 4 shows a design guide for cylindrical structures under short term loading. Again the factors of safety are applied by the designer to select an allowable operational depth. For neutrally buoyant structures, the allowable depth is about 1200 feet.

Structural Parameter Considerations

Penetrators

The effect of penetrators on the short term implosion pressure of 16-inch outside diameter spheres was studied by incorporating in

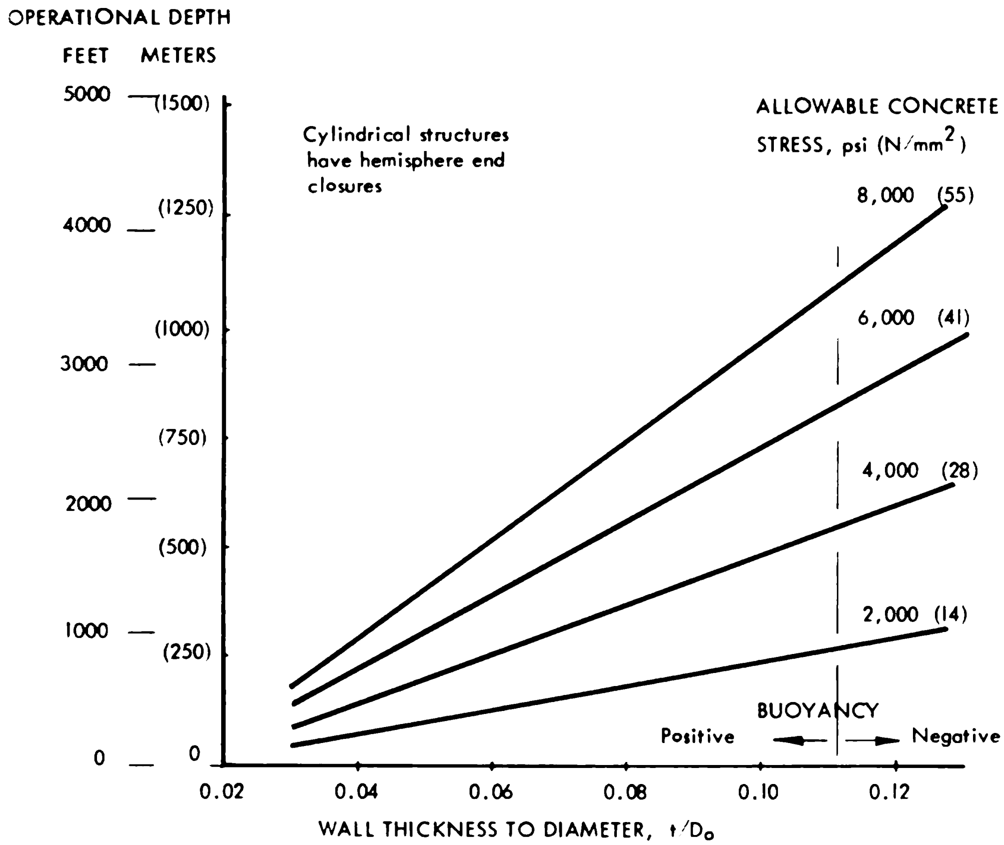

Figure 4 – Design guide to predict operational depth of concrete cylindrical structures under short term loading

the concrete wall solid penetrators of plastic, aluminum and steel that subtended a spherical angle as great as 32 degrees. Some penetrators were also fabricated as operational window assemblies. Test results showed that the plastic penetrators reduced the implosion pressure by 17% as compared to spheres without penetrators. The steel and aluminum penetrators did not cause a reduction in implosion pressure, and the compressive strain in the concrete near these penetrators was increased from 2% to 8%. The tentative conclusion was that properly designed penetrators do not significantly affect the structural behavior of concrete structures.

Out-of-Roundness

Concrete spheres and cylinders do not appear to be overly sensitive to out-of-roundness deviations. As long as maximum out-of-roundness deviations do not exceed local variations in diameter of 10% of the mean wall thickness, and variations in wall thickness of 5% of the mean wall thickness, the design guides for predicting implosion of large scale structures are valid. Present construction practices can easily maintain these out-of-roundness specifications.

Epoxy Joints

Epoxy adhesives were used to join hollow hemispherical sections together in making the spherical specimens and to join end-closures to the cylinders in making the cylindrical specimens. The epoxy joints did not appear to cause implosion failure. However, it is strongly suspected that the joint locations are susceptible to in-plane cracking before cracking occurs in other locations in the structure. The epoxy materials have a very low tangential modulus under high stresses, and therefore would tend to extrude from between the concrete sections. This condition would produce an added tensile strain to already existing radial tensile strain in the concrete.

Mechanical Joints

Mechanical joints located at the equator of relatively small spheres provide access to the interior of the structure. A study was made to determine the effect of mechanical joints of various stiffnesses on the behavior of 16-inch spheres. The best joint design was one which utilized fiberglass and a cross-sectional area that resulted in a joint stiffness approximating that of the concrete replaced by the joint. The implosion pressure of the sphere with a fiberglass joint was 5% lower than that for spheres having a thin epoxy adhesive joint. Plastic joints are not recommended because their stiffness is lower than that of the concrete. Metal joints are considerably stiffer than concrete and they caused reductions in implosion pressures of up to 47%.

Permeability

D'Arcy's law of viscous flow predicts a constant rate of permeability with time. The results obtained from concrete spheres, however, showed that the permeability rate appears to decrease with time. Reasons for this could be continued hydration of cement, other chemical reactions between the seawater and the cement, and possibly microorganisms plugging the voids in the concrete. Only additional tests in the ocean, which are on-going now, will answer the question.

Polymer-Impregnated Concrete

Polymer-impregnated concrete (PIC) is made by impregnating mature concrete with a liquid monomer that is subsequently polymerized in-situ using either thermal or radiation processes. The resultant material contains approximately 6% to 8% by weight of polymer, and develops compressive strengths over 20,000 psi, good durability against chemical attack, and excellent impermeability. The material appears to be ideally suited to underwater pressure-resistant concrete structures.

A test program was conducted using eight 16-inch outside diameter spheres fabricated of PIC materials. The polymer was diallyl phthalate and the average polymer content was 8.4% by weight. The results showed that the spheres exhibited linearly elastic strain behavior and that the strain and implosion pressures were predictable within engineering accuracy using classical elastic theory. Spheres having t/D_o ratios of 0.063 or 0.125 imploded at average pressures of 4810 and 8475 psi respectively. The projected operational depth for buoyant PIC spheres is 4000 feet.

It should be mentioned that the desirable features of impermeability and durability of PIC materials can be obtained with significant cost savings by impregnating the exterior of the wall to a finite depth (e.g., 1 inch or 2.5 cm). Complete impregnation of the wall is only needed if the improved strength properties are required.

On-Going Ocean Tests

Long term ocean tests of eighteen 66-inch outside diameter spheres were initiated in September, 1971. The spheres were placed on the seafloor at depths between 2000 and 5000 feet (Figure 5). They are

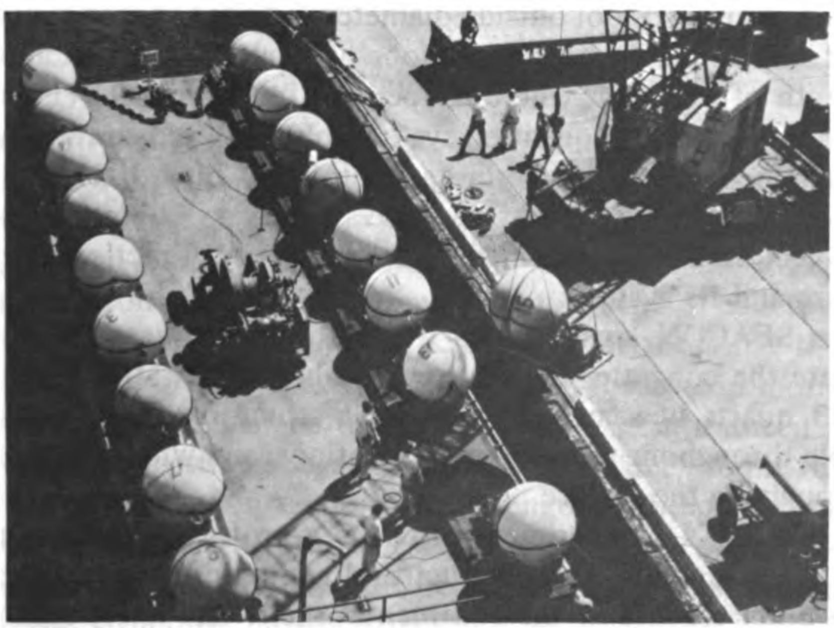

Figure 5 — These eighteen 66-inch outside diameter concrete spheres are currently undergoing long term testing in the ocean at depths between 2000 and 5000 feet

being inspected yearly to see if any of them have imploded and to collect permeability data. Sixteen specimens were of unreinforced concrete. Eight of these were coated with a waterproofing compound, and eight were uncoated. The remaining two spheres were reinforced with steel bars, and half of each sphere was waterproofed.

The spheres were tethered 25 feet off the ocean floor by heavy anchor chains. Permeability data is obtained by counting the links of chain supported by the buoyant sphere. A change in height of one link indicates approximately 4 gallons of water has permeated the sphere. After 3 years on the seafloor, the uncoated spheres have shown an average permeability of about 15 gallons, and the coated spheres, 8 gallons.

Time-dependent implosion of three spheres placed at the deeper depths has occurred. However, other spheres located in the same depth range are still intact. The spheres will be submerged for up to 10 years.

SEACON

SEACON I was the highly successful first major at-sea experiment in the Navy's Deep Ocean Technology Project, Seafloor Construction Experiment (SEACON). It made practical use of much of the technology developed in the experiments previously described, including the structure itself, the hull penetrations, access openings, etc. The focal point of SEACON was a 70,000 pound, unmanned, pressure resistant hollow concrete structure. It was cylindrical in shape, 20 feet long, with a 10-foot outside diameter and a 9 1/2-inch wall thickness. It was emplaced on the seafloor off Santa Barbara, California, at a depth of 600 feet, where it operated for 11 months (Figure 6).

Programmed data acquisition systems plus a closed circuit TV unit provided means for monitoring appropriately placed sensors. Regular reconnaissance with surface vessels and Navy submersibles kept the project engineers informed of the continued functioning of the structure and its systems.

When SEACON I was raised, it was found that seawater did not penetrate the concrete wall. However, a hull penetration leaked and about 3 quarts of seawater entered the structure. All systems were operable throughout the stay on the seafloor, and when the structure was brought to the surface.

The SEACON I experiment provided a prototype demonstration of the Navy's ability to construct and maintain operating facilities on the outer reaches of the continental shelf. The latest techniques and hardware were evaluated in the process of selecting and investigating a suitable site, designing and installing foundations, fabricating

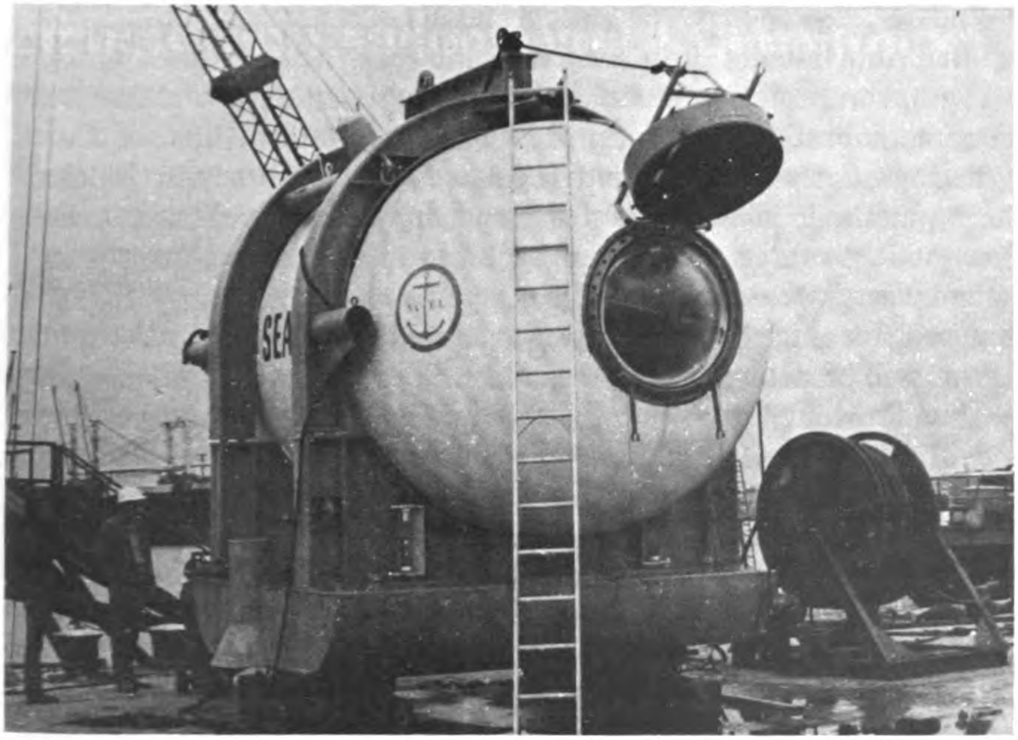

Figure 6 — The 35-ton concrete SEACON I structure, resting on its steel buoyancy/ ballast tank and supported by a steel yoke. SEACON I spent 11 months on the seafloor at a depth of 600 feet.

the pressure-resistant structure of concrete, installing it, providing utilities to it, and maintaining it on the seafloor.

Polymer-Strengthened Concrete

Currently under study at CEL is the development of an organic admixture for making high strength polymer cement concrete (PCC). The principal investigators are Mr. John R. Keeton, research materials engineer, and Dr. Robert L. Alumbaugh, research chemist. For undersea applications, the greater strength of this type of concrete would increase the depth-utility of concrete, and at the same time, produce an impermeable material. The aim is to develop monomer or resin systems that can be used as admixtures (introduced into the concrete along with aggregates, cement, and water), to provide up to a five-fold increase in compressive strength with commensurate increases in associated properties. Although the cost of polymer-strengthened concrete may be three times that of conventional concrete, the structural members will be one-third to one-fifth as large as conventional concrete members, and the increased durability will require less maintenance, making the product cost-effective.

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Epoxies, epoxy-acrylates, latexes and polyesters are being incorporated individually into concrete mixtures to produce a high-strength composite product. Consolidation methods include hand tamping, vibration, pressure packing and combinations of these. Both high early strength and regulated set cements will be used. Curing methods include air, steam and dry heat, as well as combinations of these three. In addition to uniformly graded aggregate, gap-graded aggregate will be used to reduce the amount of polymer required for high strength. Bond strength and water absorption factors will be determined in the study.

Thus far, long-term values of splitting tensile strengths at 28 days and 91 days show increases of 1.8 and 2.5 for latex, and 2.2 and 2.9 for epoxy PCC, respectively. Similarly, long-term increases in flexural strengths are 1.6 and 1.5 for latex, and 2.7 and 2.2 for epoxy PCC, respectively. Water absorption tests have shown a 66% decrease in latex PCC and an 82% decrease in epoxy PCC over water absorption of control specimens.

It is believed that the polymer loading required to produce high strength and durability is a function of the aggregate size and gradation as well as the cement content, type and duration of curing, and method of consolidation. Use of gap-grading of the aggregate should reduce the polymer required, other things being equal. Tests will be made to ensure an adequate bond between the polymer cement concrete and reinforcing steel.

Anti-Fouling Concrete

As advancing technology improves the quality of concrete and expands its uses, CEL researchers are looking into the problem of marine fouling when concrete is used in the ocean environment. Mr. James Muraoka, a research biologist, invented and developed a method for incorporating toxic chemicals into concrete to protect it from the 2000 species of plants and animals that have been identified in the fouling community. Mr. Muraoka is now retired, and the work is being carried on by Dr. Harold Vind, a research chemist. Dr. Vind is attempting to improve the strength of anti-fouling concrete.

Muraoka's technique consists of impregnating a porous expanded shale aggregate with mixtures of creosote and other toxic chemicals before combining it with portland cement and water. Creosote oil is the basic chemical ingredient. The toxic chemicals tested include tributyltin oxide, malachite green, quaternary ammonia compound, pentachlorophenol, and copper naphthenate oil.

After the lightweight expanded shale aggregates were saturated with the chemicals and drip dried or washed in mineral spirits, they were found to have absorbed the chemical solution to the extent of about 25 to 30 percent of their dry weight. The toxic chemical mixture constituted 10 to 12 percent of the weight of the anti-fouling concrete made with these aggregates.

Test panels and control panels were submerged in the ocean at various sites and for varying lengths of time. It was found that anti-fouling concrete incorporating a porous expanded shale aggregate impregnated with mixtures of creosote and tributyltin oxide at levels of 100 to 250 ml per liter remains essentially free of marine fouling for at least four years. At the other end of the scale, concrete incorporating aggregate impregnated with a 50-50 mixture of creosote and copper naphthenate is fouled as readily an ordinary concrete containing no toxic chemicals.

The anti-fouling concrete is not quite as strong as concrete containing conventional sand and gravel, but it is sufficiently strong for construction in which a compressive strength of 3500 psi is acceptable.

Coral Concrete

In another area of concrete research, not specifically related to undersea construction, CEL's William R. Lorman, a materials research engineer, has conducted extensive studies in the use of coral as a substitute for standard types of aggregate. In tropical areas, coral is the only natural aggregate available on an atoll for making concrete, and it is usually plentiful.

Lorman's research has covered the different types of coral, of which there are many, and their relative suitability for incorporation into concrete mixtures. Aggregate material obtained as reef, bank-run, or quarry coral varies widely in physical characteristics. Such material is similar to ordinary limestone insofar as hardness is concerned, but values of specific gravity range from as low as 1.6 (some finger coral) to as high as 2.9 (exceptional quarry coral). As a rule, the strongest coralline limestone is the most dense, and the weakest coral is the most porous. In this particular area of limestone, porosity values vary from 1 to 15 percent.

Deterioration of coral concrete is caused by physical and chemical changes, the degrees of which depend upon environment, particularly ambient moisture and temperature. Such changes are associated with the inherent durability of the coralline constituents while it is subject simultaneously to physical loads imposed by the structural design. The coefficient of thermal expansion of coralline limestone varies with the geographical source as well as with geological derivation. The magnitude of thermal movement of coral as concrete (or mortar) aggregate is compatible with that of hydrated portland cement. The coefficient of thermal expansion for concrete and mortar made with portland cement and coral aggregates is considerably less than that for similar concretes and mortars containing siliceous aggregates.

For all practical purposes, the testing of coral aggregates should essentially involve (in addition to gradation analysis) only bulk density, specific gravity, and absorption. The most desirable aggregate is a coralline limestone possessing a structural quality rating greater than 65 percent sound material (fine grained to medium grained calcite). Determination of this rating can only be made by petrographical analysis. However, if the job is in a location remote from laboratory facilities, this would entail only the sending of small samples easily airmailed from the construction site.

Mix design and fabrication of coral concrete involve basic principles that are the same as those applying to conventional concrete. The ideal coral aggregate should consist of about 50 to 60 percent sand, and should be well graded throughout the entire range of size fractions (PLUS No. 100 to MINUS 1 1/2 inches). By using fine and coarse coral aggregates that have been properly crushed and graded, by basing mix computations on reliable values of specific gravity and moisture content (either free moisture or absorption), and by weight proportioning rather than volume proportioning the component materials, coral concrete mixes of fairly high strength and uniformity can be obtained. Figure 7 shows typical compressive strength values that should be expected with concrete incorporating quarry coral aggregate.

Lorman's research background in coral concrete paid off handsomely when he was asked to investigate the feasibility of producing large quantities of coral concrete for a Navy communications facility and airstrip on remote Diego Garcia island, in the Indian Ocean. The only civilian member of a 9-man reconnaissance team, Lorman was able to locate a coral deposit suitable for making aggregate, in the fringing reef of the 11 square mile atoll, and the work proceeded successfully.

Summation

The research described here relates mainly to the use of concrete in the sea. However, CEL's investigators have also contributed to

28-day compressive strength (psi)	2000-3000	3000-4000	4000-5000
Cement content (lb)	470	564	658
Coarse aggregate (lb)	1600	1560	1460
Fine aggregate (lb)	1540	1500	1400
Water, total (lb)	332	320	315
Slump (inches 1/2)	3	3	3
Coarse-fine ratio (by wt)	1.04	1.04	1.04
Aggregate-cement ratio (by wt)	6.7	5.4	4.3
Water-cement ratio (by wt)*	0.71	0.57	0.48

*Based upon net water content, assuming that aggregate is in saturated-surface-dry condition at time of mixing.

Figure 7 — Typical mix proportions (by weight) for one cubic yard of concrete incorporating typical quarry coral aggregate

concrete technology in the areas of expansive cement concretes, large floating mobile bases made of concrete, new developments in cementitious construction materials, airfield pavements, and others. The work is continuing (Figure 8).

Many areas of research for deep-submergence concrete structures have not been investigated, even in an exploratory manner, and will require considerable attention. They include the effects of cyclic loading, impact resistance, reinforcement, and prestressing. Other areas of importance are the development of quality control procedures that will permit fast and accurate measurements of the unit weight and strength properties of concrete, and improving the durability, impermeability, and strength characteristics of concrete.

Pressure resistant concrete structures are not new in concept or application. Many subaqueous transportation tunnels located throughout the world use concrete cylinders as the structural members. The research described herein demonstrates that concrete structures can be used at greater depths than those at which concrete is used today. For example, spherical structures could be used safely at 3000 feet in the ocean, and cylindrical structures at 1200 feet.

Engineering estimates of the cost of structures in this depth range show that concrete structures in general can cost as much as 50%

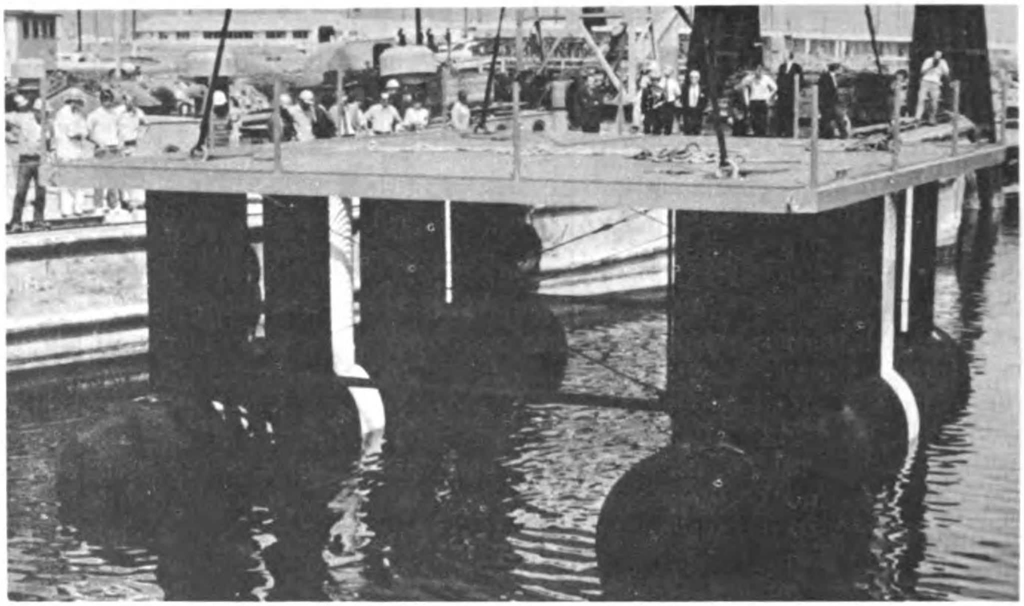

Figure 8 – A one-tenth scale model of one section of a large, floating mobile ocean base, made of concrete, is lowered into Port Hueneme harbor

less than similar steel structures. It is possible that the cost advantage realized by the use of concrete for deep-submergence construction will prompt many military and commerical applications. Presently, a strong military application is for storage of POL (petroleum, oil and lubricants) in seafloor concrete structures.

Underwater Adhesive

There are many uses for adhesive systems that can be mixed and applied underwater, and will cure rapidly to provide good bonding strength. The primary requirement for such an adhesive is for attaching explosives for underwater demolition by UDT and Marine Corps troops. Other possible uses for the product include:

(1) Joining of structural components in underwater construction.

(2) Attachment of a structure to a foundation located underwater.

(3) Attachment of instrumentation or modifications to underwater structures.

(4) Repair of damaged underwater structures.

(5) Patching of damaged underwater cables.

(6) Encapsulation of connections or other critical areas subject to deterioration under water.

(7) Salvage or other recovery of equipment from the ocean floor.

(Continued on Page 34)

High Quality Electric Power

Evo Giorgi*

The continual modernization and upgrading of electronic equipment used in the Naval shore establishment, and the introduction of complex and sophisticated circuitry, have given rise to a number of technical problems. The problem of prime interest is the providing of the very high quality, reliable electrical power required by modern equipment for its successful functioning. The need for an uninterruptible supply of AC power, with as pure a waveform as possible and a minimum of voltage or frequency fluctuation, is particularly acute at communications facilities and computer complexes. Where sensitive, synchronous types of communication equipment of the cryptographic variety are used, power system transients are intolerable. Loss of synchronism due to a transient of interruption in the power supply can cause errors in transmission and a delay of several hours in service due to the need for reestablishing contact and restoring circuits.

Where computers are installed, a power line transient can inject a spurious signal into the programing of the machine or destroy the semiconductors employed in modern circuitry. In fact, wherever semiconductors are used in modern equipment, a price must be paid for their great advantages. This price is the risk of damaged or inoperative equipment due to their sensitivity to disturbances in the power supply.

Because of an increasing number of reports from Naval shore facilities dealing with operational disruptions and failures in newly installed computers, communications equipment and other tactical electronic systems, an Electrical and Electronics Systems Division was established at the Civil Engineering Laboratory (CEL). The overall objective of the Division is to solve the many interrelated problems associated with the supply of electrical power to vital Naval installations.

It is no easy matter to remove all forms of transients from a power line, which normally serves loads other than the sensitive equipment. Therefore it is necessary to identify those forms of line disturbances which definitely cause either an interruption in service or damage to the equipment. Obviously, an outage in the power supply line will cause an interruption in the operation of the equipment. It follows

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that an important field of investigation is the development of some secondary source of power which can almost instantly assume the load if the primary source fails. Accordingly, part of the effort of the CEL Division was to make a thorough examination of all currently known forms of uninterruptible power systems and high-speed switching systems, followed by the research and development work necessary to recommend the most efficient and reliable equipment of this type.

The types of transient disturbances most harmful to critical equipment can be identified if transients on the input side of the equipment can be accurately recorded on a real time basis, and compared with similar records of equipment failures. Those forms of transient which repeatedly associate themselves with equipment failures can then be eliminated.

Research Program

A first step in the solution of this problem was to develop power line transient monitoring and recording equipment, capable of extremely rapid response and accurate reproduction of the waveform disturbances on a continuous basis over fairly long periods of operation. The second step was to develop equipment which will simulate line transients, surges, voltage and frequency excursions, and use this equipment to ascertain which forms of synthesized disturbance actually cause equipment manfunctions and failures. This research effort resulted in the development of the following devices:

Power Transient Data Acquisition Monitor

The power transient data acquisition monitor shown in Figure 1 is capable of recording randomly-occurring power disturbances and transients in an electrical power system automatically and without attendance. Up to 12 power waveforms at different points in the monitored power system can be recorded concurrently.

The monitor is built for transportability. It is housed in 4 standard equipment consoles, each 24 inches wide, 24 inches deep, and 46 inches high, and weighing from 250 to 500 pounds. The consoles are mounted on 5-inch diameter casters and are easily moved by a single person in the immediate monitoring area. Lifting eyes are provided for ease of pickup by crane, and each console has a custom designed fiberglass shipping container which provides protection during shipment between field sites.

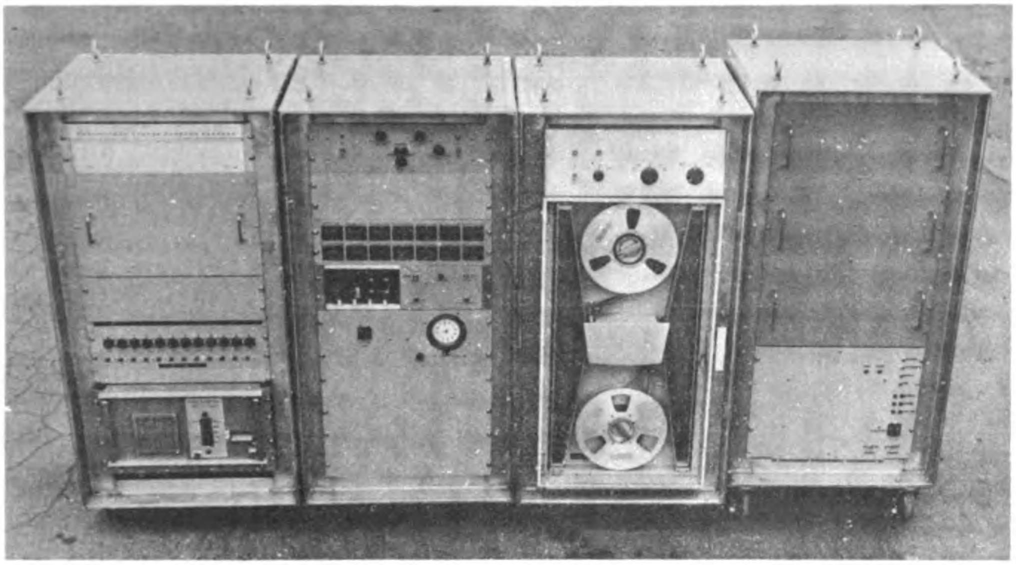

Figure 1 — Power transient data acquisition monitor

The monitor contains a magnetic drum/magnetic tape recording system. The monitored waveforms are continuously recorded and erased from a rotating magnetic drum. When a transient is sensed by any one of the sensors, a signal is provided to initiate the quick start magnetic tape, whereupon data on all channels used on the magnetic drum is transcribed onto the tape. This technique enables the recording of all the waveforms, pretransient, transient and post-transient, associated with power disturbances. It also shortens data processing time because the stored information is limited to power disturbance data only.

The four consoles are designated memory, record, control, and power. The memory console contains power transient sensors, input attenuators, a magnetic drum, associated drum electronics with record and playback heads and an IRIG B time code clock. Nine transient sensors provide signals, via logic circuitry, to initiate the quick-start magnetic tape, and gate the drum playback circuits for recording data and time of occurrence onto the magnetic tape.

Input attenuators are provided to reduce the monitored voltage to a value usable by the voltage-controlled oscillators (VCO's). The VCO center frequency is 100 KHz. The output of the VCO is frequency modulated by the input signal, is amplified, and drives a recording head. The gap between the heads and the drum is set to 0.001 inch. The 6-inch diameter magnetic drum rotates at 1200 RPM. The playback head is positioned so that the point on the drum surface where the recording is made passes under the playback head near the completion of a single drum revolution. The signal from the playback head is applied to a playback amplifier. This amplifier output is gated to the magnetic tape recording system whenever the transient sensors initiate a record cycle. The IRIG B time code clock furnishes coded data on day, hour, minute and second. This data is continuously recorded on one channel of the drum for transcribing onto the magnetic tape.

The record console houses a quick-start magnetic tape deck which reaches a speed of 60 inches per second in about two milliseconds. Each recording runs for about two seconds, and consists of 42 milliseconds of predisturbance and approximately two seconds of disturbance and post-disturbance data. A standard 3600-foot roll of magnetic tape records approximately 360 occurrences of power disturbance waveforms. Using a standard playback unit, the recorded data can be viewed on an oscilloscope, or a permanent record can be made with a light beam oscillograph.

The power console houses a 2.5 KVA static interruptible power supply. A 125 volt DC battery bank with a 25 ampere capacity is required. The sustaining duration of monitor operation during a prime power failure depends on the battery capacity.

Power Transient Synthesizer

The power transient synthesizer, shown in Figure 2, was developed by CEL as a source of power with controlled output parameters for susceptibility testing and calibration of equipment. It simulates fluctuations and disturbances which occur in utility Alternating Current (AC) power supply systems and in poorly regulated Direct Current (DC) power sources. The synthesizer is fundamentally a solid state power supply providing (1) AC power at 15 KVA, 120/208 volts, 3 phase, or 7.5 KVA, 120 volts, single phase, at base frequencies of 50 or 60 hertz, and (2) DC power at 1 KW, 0-264 volts. It supplies power with overvoltages, undervoltages, momentary power outages, pulse voltages superimposed on the fundamental sinewave or DC output, frequency deviations about the fundamental frequency (50 or 60 hertz), and high frequencies (400 to 10000 hertz) in magnitudes up to 75 volts root mean square (rms) superimposed on any selected phase of AC power or the DC power output. Phase control circuitry is also provided to permit asynchronous operation of the synthesizer for testing electrical equipment, such as solid state switches, at selected phase differences with respect to the normal AC power source.

The synthesizer is housed in four cabinets, each 24 inches wide, 36 inches deep, and 72 inches high. Each cabinet is equipped with

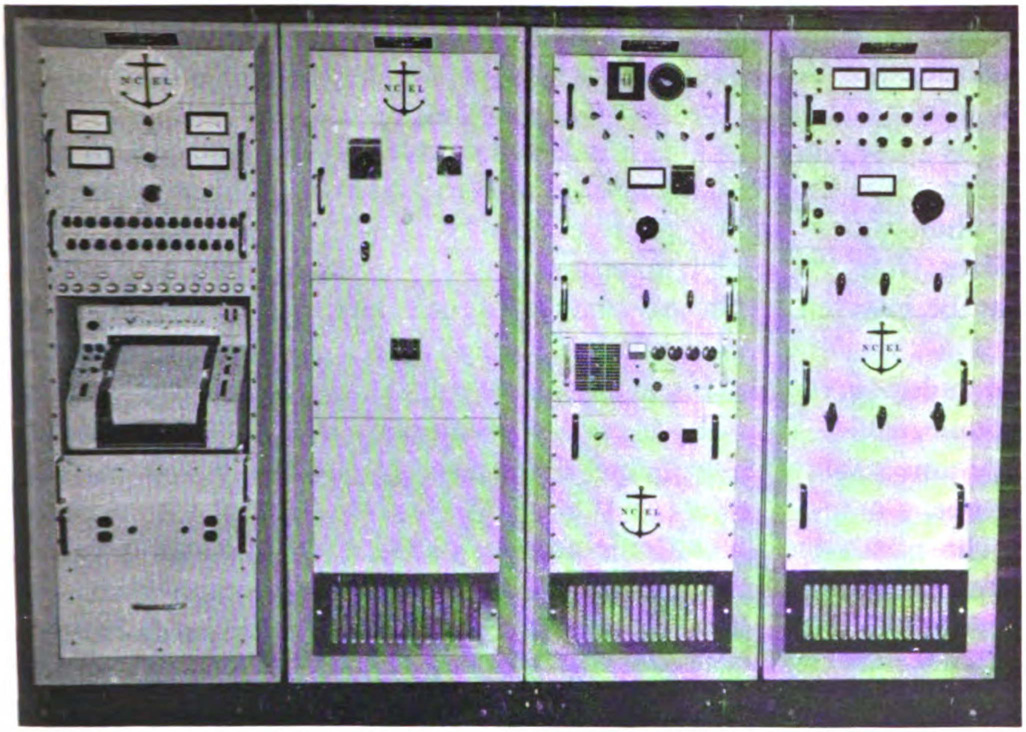

Figure 2 — Power transient synthesizer

heavy duty casters and is ruggedized to permit fork-lift loading onto transport vehicles for long distance shipment. The synthesizer consists of four major units: the inverter unit, excursion unit, pulser unit, and monitor unit.

The inverter unit is a solid state frequency conversion module which receives external 120/208 volt, 60 hertz, 3-phase power and converts it to any of several AC power output waveforms at either 50 or 60 hertz. Output waveforms available are single phase sinewave, 3-phase sinewave, and 3-phase square wave. The frequency can be programed for a range of variations about the base frequency.

The excursion unit has three modules. These are an AC voltage excursion module, a frequency excursion and phase control module, and a high frequency power source module. Programed voltage excursions or outages on the AC or DC power output are provided by the voltage excursion module. Frequency excursions of the AC power output are provided by a programable, voltage-controlled oscillator in the frequency excursion module which is phase-locked through a synchro control transformer and related circuitry with an external power source. This provides for the continuously variable, 0 to 360 degrees, asynchronous operation of the inverter unit. The high frequency power source module generates high frequencies in the range of 400 to 10000 hertz with amplitudes of up to 75 volts rms, and superimposes this high frequency power on any selected phase of the AC power output or on the DC power output.

The pulse unit contains a pulse generator module capable of generating positive or negative pulses of 0 to 4000 volts and superimposing these pulses on any phase of the AC or DC power output. Pulse widths from 2 to 1000 microseconds are selectable and the pulses may be injected on the AC sinewave at selected phase angles from 0° to 315° in 45 degree increments. In addition to the pulse generator, the pulser unit contains a 0 to 264 volts, 1KW DC power supply module, and a DC voltage excursion module. This module provides programed voltage excursions or outages of the DC power supply output.

The monitor unit contains a meter panel, a patch panel, a galvanometer attenuator panel, and a light beam oscillograph chart recorder. The meter panel has instrumentation for monitoring output power parameters for the AC and DC power output. All AC or DC measured or recorded power parameters are terminated at the patch panel so that the selected parameters may be patched into the chart recorder through the galvonometer attenuator panel. The chart recorder is a 24-channel oscillograph with a wide range of selectable chart speeds. In addition, the recorder is equipped with trace identification and selectable time line accessories.

Pulse Generator

The pulse generator developed by CEL is shown in Figure 3. It weighs approximately 600 pounds and is housed in an 80 X 36 X 24-inch cabinet mounted on casters for easy movement in the test area. A high voltage coaxial cable terminating in two flexible leads is used for the output. Neither lead is grounded. This "floating" output permits reversing the leads to grounded test items without short circuit problems. Reversing the leads provides reversed polarity pulse voltage to the test item. The pulse generator can be energized from a 120, 208, or 440 volt, single phase, 60 hertz power source. Various selector switches and control knobs are used to select the pulse magnitude and duration, pulse rise time, pulse repetition rate, polarity, and phase angle of pulse voltage application. The generator supplies up to 10KV of 2, 10, and 100 microsecond pulse duration with the rise time adjustable to less than one microsecond. Pulse wave shaping to apply a variety of waveforms to loads can also be accomplished with external circuitry. The pulse can be initiated manually or delivered automatically at a repetition rate of one or two pulses per second.

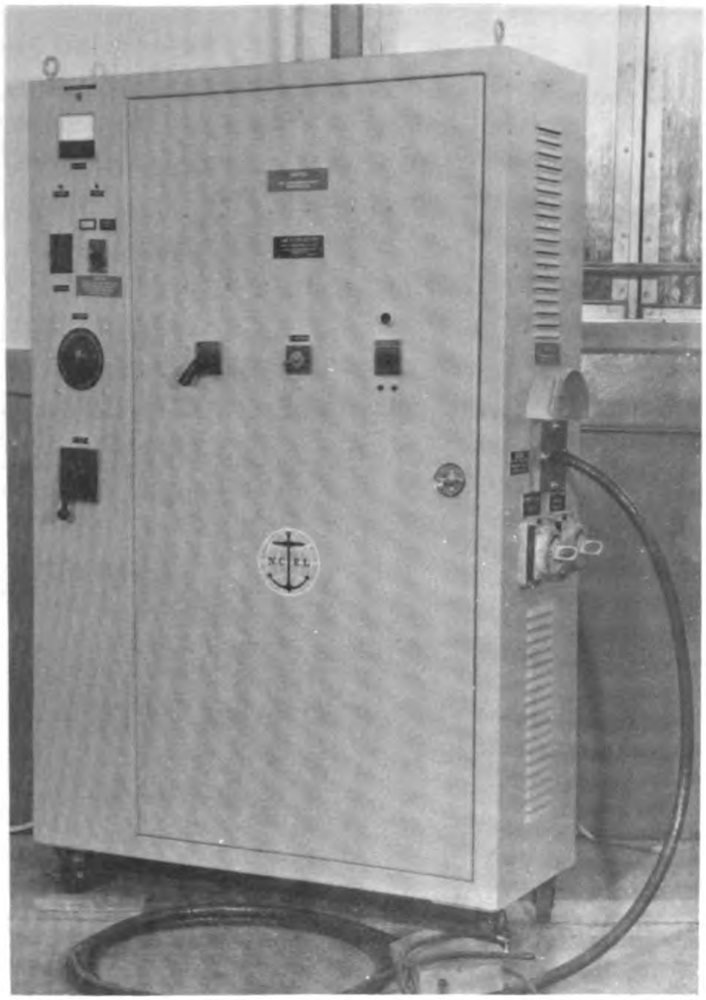

Figure 3 — Pulse generator

For superimposed pulse voltage test, the pulse generator is placed across the line power applied to the test item. To prevent 60 hertz power from flowing into and damaging the pulse generator, capacitive coupling is used for pulses up to 2000 volts, and metal oxide varistor coupling is used for pulses above 2000 volts.

Power System Simulator

The power system simulator, Figure 4, was recently developed to simulate a medium sized electrical power system consisting of 48 transformers and 60 loads of various kinds. The purpose of the simulator is to investigate transient currents and voltages appearing on power elements of an electrical system under dynamic conditions.

The simulator consists of transformer modules, load modules, and summer/integrator modules. Each module employs integrated circuits with output and input terminal jacks, and the performance

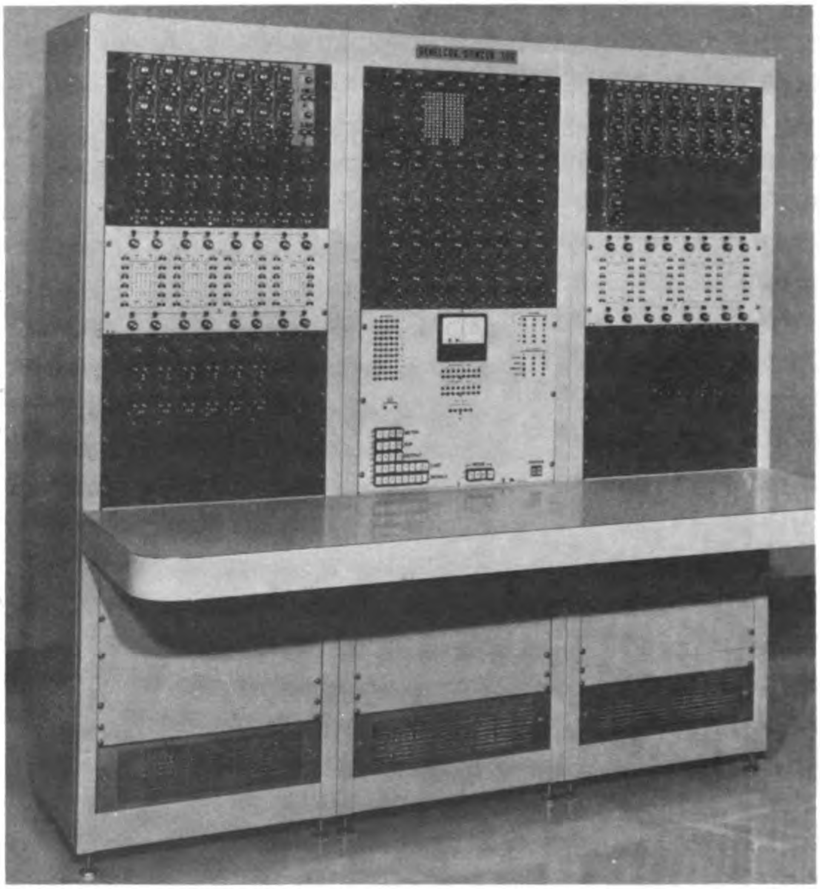

Figure 4 — Power system simulator

parameters are adjustable. As designed, the modules can be interconnected using input output jacks to form a network simulating the actual system. The performance parameters can be varied to match their electrical characteristics to those of the simulated system element. Transient sources or sinusoidal AC power sources can be simulated by the summer/integrator modules using analog programming techniques.

Power Line Disturbance Monitor

A power line disturbance monitor, shown in Figure 5, was recently developed by CEL as a small, readily portable instrument to identify and count the number of typical power input anomalies at critical facilities. The monitor, operating over an input line-to-neutral voltage range of 90 to 140 volts rms, in 3 phase, 50 to 60 hertz power circuits, is now commercially available as a DOD technology transfer item. A similar unit, an adaptation of the CEL design, is available for use on 400 hertz power circuits. Five disturbances may be monitored,

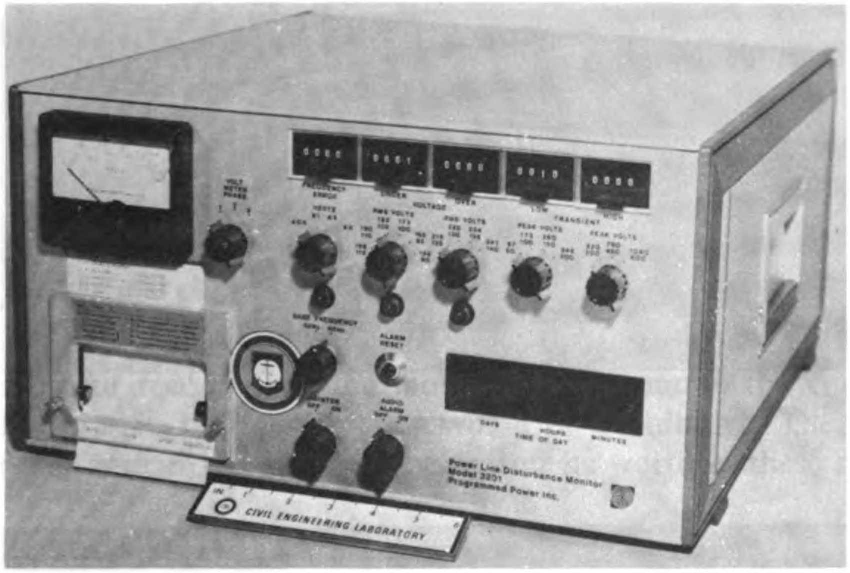

Figure 5 – Power line distrubance monitor

including undervoltage, overvoltage, under- or over-frequency, low magnitude impulse voltage, and high magnitude impulse voltage. Each of these disturbances is counted and presented on a front panel count accumulator. Also provided are controls for selecting the various thresholds for disturbance detection. Audio and visual alarms are activated for undervoltage, overvoltage, and under/over frequency. They are reset by a front panel pushbutton. A printer which incorporates a Julian day, hour and minute clock records the day and time of each disturbance, and its nature. The entire disturbance monitor is packaged in a rugged case, with recessed handles for portability.

Transient Direction Detector

The most recent diagnostic instrument developed at CEL is the transient direction detector shown in Figure 6. This instrument locates sources of electrical impulse voltage transients in power systems, using specially designed sensors to detect the voltage polarity and current flow of each transient. A logic circuit analyzes the information gathered by the sensors and in turn displays the direction of transient propagation along a power line. The detector is small, easy to operate, and does not disrupt the operation of equipment serviced by the power line being monitored. Although capable of functioning independently, the detector can be utilized in conjunction with the power line disturbance monitor, Figure 7, if a record of the source of each impulse transient and the time of occurrence is

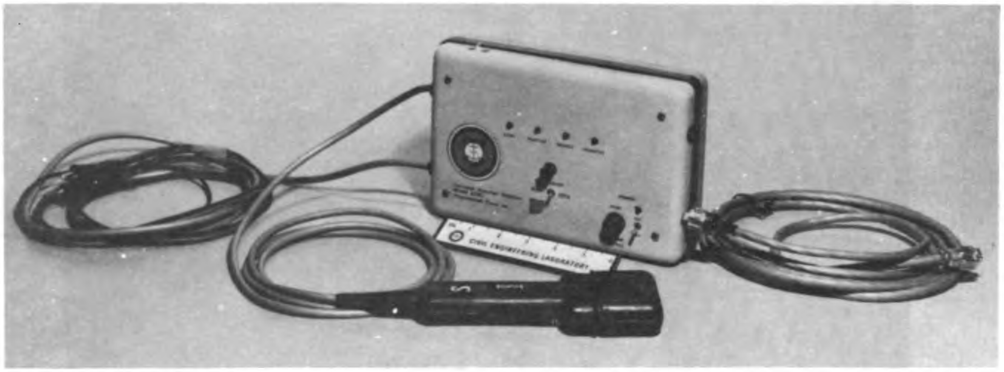

Figure 6 – Transient direction detector

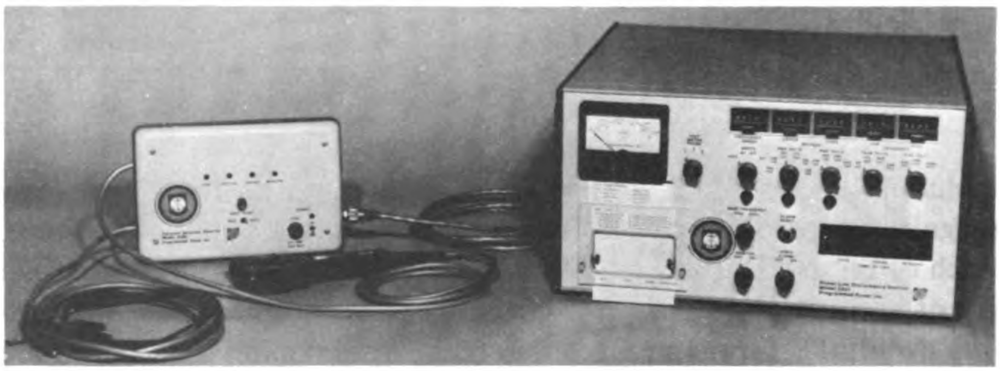

Figure 7 – Transient direction detector used in conjunction with the power line disturbance monitor

desired. When used with the monitor, the detector functions automatically in that it detects, records, and clears itself as each transient occurs.

Typical Applications

The effectiveness of the transient data acquisition monitor was demonstrated recently in two typical situations. The Defense Communications Agency (DCA) planned to install ten Uninterrupted Power System (UPS) Bypass switches at its overseas communication stations. The first installation was made at Coltano, Italy. To insure that the system was functioning properly, CEL was asked to monitor it. It was soon established that failures occurred during transfer from the Bypass to the UPS system, and an analysis of the power monitor data traced the fault to a design deficiency in the input portion of the Bypass system. The deficiency was corrected.

In a later Bypass installation at Croughton, England, unexplained failures occurred at random intervals. Contractor personnel were unable to pinpoint the cause, and again CEL was asked to assist. The power monitoring system was delivered to Croughton, where its 12-channel data recording capability was put to full use. It was learned that the failures were not caused by the commercial input power, but rather by improper design of the logic control board in the static inverter portion of the UPS Bypass system.

Problems of this kind would be very difficult to solve without transient data recorded by the monitor. Furthermore, the cost of such diagnosis in time and money would be prohibitive. The CEL monitoring system has successfully proven its worth in these situations.

The power system synthesizer was most recently used in a project sponsored by the Naval Security Group Headquarters, Washington, D.C., to determine the susceptibility limits of the AN/GYK-3(V) Digital Data Processing System to input power anomalies. The objective of these tests was to establish the quality of electrical power required by this system so that appropriate power conditioning equipment could be specified. The findings generated by this effort proved to be extremely useful, in that not only were power input parameters established, but several design and operational deficiencies were uncovered. A major deficiency was noted in the AC power input sensing unit which shuts down the system when anomalies appear on the input power supply. The sensing unit was found to be overly sensitive, causing numerous and unnecessary operational disruptions of the AN/GYK-3(V) system.

Since its development, the power transient synthesizer has proven to be an invaluable diagnostic system, not only for determining the input power requirements for critical equipment, but also for establishing its susceptibility to power supply anomalies before the equipment becomes operational. The synthesizer, as well as the 10KV pulse generator, are also extremely useful as laboratory test equipment for validating conformance to military specifications.

The CEL 10KV pulse generator was recently used in evaluating the effectiveness of commercially available transient suppressors. On the basis of this test program and results of in-service evaluation at a selected site, the Naval Security Group Headquarters has since directed all their field activities to install metal oxide varistors (MOV) on AC power circuits supplying critical equipment. In addition, the same activities were requested to desensitize DC power supplies using techniques developed by CEL as a result of susceptibility testing of solid state circuits common to a majority of critical electronic systems.

The small power line disturbance monitor together with the transient direction detector have already been widely accepted by both military and commerical activities. These two units have been particularly useful in applications involving computer complexes where down time was attributed to disturbances on the input power circuits. With these instruments, a quick determination can be made as to whether power anomalies do exist, causing computer malfunctions and failure. Most often, operational failures were pinpointed as being caused by the critical equipment rather than by anomalies on the input power supply. This monitor is an example of products developed through CEL research that lend themselves readily to technology transfer. They have been accepted by the industrial community. The Transient Direction Detector currently undergoing in-service evaluation at selected Naval shore activities is the next candidate for technology transfer and is expected to have a wide application not only within DOD, but industry as well.

(Continued from Page 22)

(8) Attaching and directing the explosive forces of shaped charges used in underwater excavation and mining.

Two general formulations have been developed by CEL researcher Dr. Richard W. Drisko, one for curing at 20°C and the other for curing at 5°C. Both are of the two-component epoxy type. The 5°C formulation has a lower viscosity to permit easy mixing in cold waters.

For curing at 20°C, bonding strengths of 280 psi after 1/2 hour and 570 psi after 2 hours were typical. For curing at 5°C, bonding strengths of 30 psi after 1/2 hour and 280 psi after 2 hours were achieved.

A method of heating underwater with a powdered chemical mix to accelerate curing was investigated. Using this heating system, bonding strengths of 280 psi after 10 minutes and 500 psi after 1/2 hour were typical at 20°C, and bonding strengths of 185 psi after 10 minutes and 260 psi after 1/2 hour were typical at 5°C. With prolonged curing or heating underwater, bonding strengths did not exceed 710 psi consistently.

A plastic cartridge system was found for mixing and extruding the adhesives underwater. A displaceable diaphragm separated the two components which were later mixed using a piston rod. Divers found that this system worked very well. Early bonding strengths were greater with dry, hand-mixed adhesives than with the cartridge-mixed adhesives, chiefly because the mixing of the latter was not so thorough.

Storage life tests indicated that the adhesives retained good bonding characteristics for well over one year when stored in metal cans.

Materials Science Research

Willis S. Haynes*

The primary mission of the Civil Engineering Laboratory is "to be the principal R&D center for shore and seafloor facilities and the support of Navy and Marine Corps construction forces". Consistent with this mission, the materials science phase of the Laboratory program is based on the following four precepts:

1. Conduct RDT&E to determine which of many uses of materials and techniques will provide the best and longest service for structures or systems exposed to severely deteriorating environments.

2. Develop new information for the design engineer to use when entering "uncharted waters" that would otherwise represent areas of ignorance and would lead to gross errors that could, in some cases, bring catastrophic results.

3. Provide short term responses to requests from Naval shore facilities for information on which they can base procurement, design, and operational decisions to assure that necessary maintenance procedures and costs are acceptable, and to provide increased service life with accompanying lower life cycle costs.

4. Supply information and research concerning suitable materials and methods in support of structural, environmental, electrical, mechanical and energy programs at the Laboratory.

For the past 10 to 15 years, many universities have recognized the need for a school or department that will pull together different engineering and scientific disciplines in support of a new academic objective. Their aim is to train some of their students in the application of diverse principles and techniques to achieve goals or solve problems in the field of materials science. Facing a similar need, the Civil Engineering Laboratory organized a unit made up of chemists, biologists, metallurgists and concrete materials engineers. They are currently fulfilling the four objectives outlined above.

Several on-going projects are directed at increasing useful lifetimes and performance of structures, with decreased per annum costs. They

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involve such investigations as: (a) protective coatings for structures in various environments (seawater, intertidal, salt spray atmospheric and on-shore atmospheric); (b) roofing materials and systems for improved maintenance; (c) use of expansive cement concrete for greater separation of expansion joints and to substantially reduce the development of cracks during the curing process; (d) minimum thickness of concrete necessary to protect reinforcing steel in floating piers to prevent seawater access and subsequent corrosion and spalling of the concrete; (e) comparison of proprietary materials and their ease of application in the field to protect and sheath insulated cable splices; (f) available materials that can be used to meet conductive flooring requirements in explosives handling at Naval ordnance activities. In the latter case, failure to provide a flooring with conductance within an acceptable range can have lethal consequences, initiated by unintentional static discharges.

These are typical examples of the wide variety of projects undertaken by the CEL materials science group, which may have as many as forty such studies in operation at any given time.

The protective coatings and roofing projects are diversified and extensive enough to justify further comments. The Laboratory has available for its use three sea spray atmospheric test sites at Kwajalein, Marshall Islands; Kaneohe, Hawaii; and Port Hueneme, California. These sites provide environments with a range of deteriorating severity from tropical sea spray at Kwajalein to temperate coastal at Port Hueneme. Comparative performance evaluations of products are first available at Kwajalein, generally in one to three years. Commercially available coatings for steel, masonry and wood have been exposed at these sites on appropriately designed test specimens. In addition, commercial samples of plastic-coated rigid steel conduit have been exposed for relative evaluation at Kwajalein and Port Hueneme. One particular product and its patching compound definitely outperformed the others in an environment similar to conditions prevailing on or under piers. In another case, by comparing the performance of several different commercial products for coating or wrapping under-pier piping of larger diameters (4 to 12 inches) in actual field installations, it was determined that for environmental conditions where heavy sea spray exists, one proprietary product yielded superior long term maintenance protection for lines used in support of docked ships. A specification material, on the other hand, was found to be adequate (and cheaper than some competitive candidates) where there is less sea spray exposure. Insulating materials and coatings to protect under-pier steam lines are also being tested in actual field situations (Figure 1).

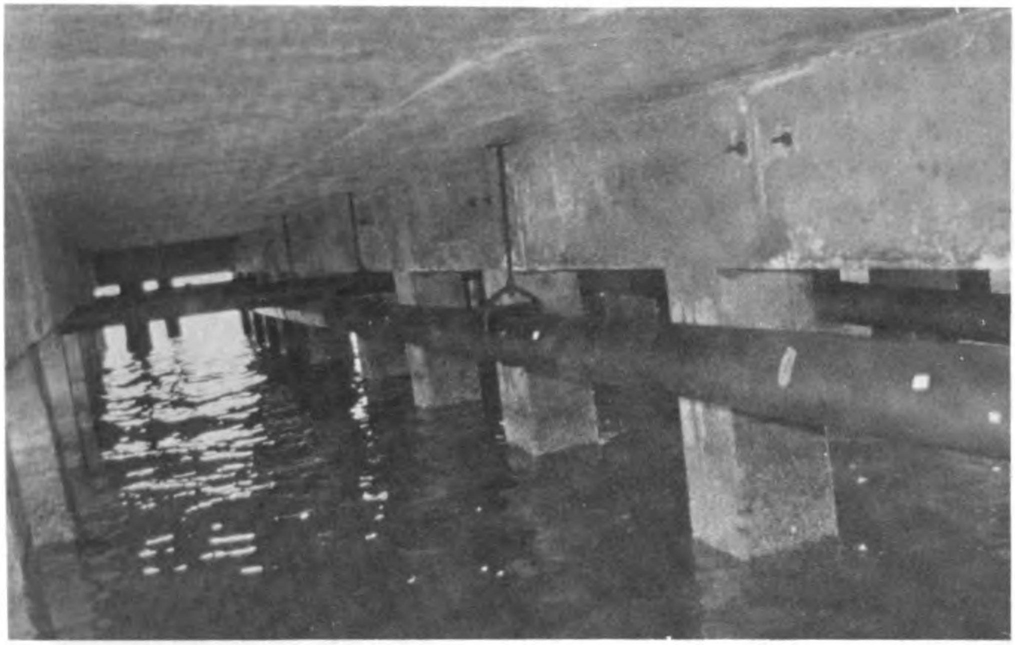


Figure 1 – This under-pier fuel line at Pearl Harbor is a test bed for different types of protective coatings being evaluated

For the Navy to protect fixed or floating structures used in harbors, commercial products have been investigated and new formulations developed for divers to apply and cure underwater. This will protect structures on which previous coatings have deteriorated or have been abraded to bare steel. Such a product has also been used to seal gashes in small floating structures before they become swamped and sink. A related material is undergoing field investigations to validate its potential as an adhesive for underwater applications. A cofferdam was developed for sand-blasting and spray-painting steel piling to two feet below the mean low tide mark. This will enable the Navy to maintain such piling and considerably extend its service life at an economical cost (Figure 2).

In the area of coatings for on-shore structures, one project involves field experimentation to reduce maintenance painting costs through the use of new and improved cleaning and surface preparation techniques. These procedures also lengthen the service life of paints and are shown to give superior performance (Figure 3). In semi-tropical areas in the continental United States and in tropical locations in the Pacific area (e.g., Guam), painted buildings often become severely stained by dark fungal growth. Some fungicidal products such as mercury-containing compounds have been used successfully to control the growth, but these may become darkened by exposure to atmospheric contaminants such as hydrogen sulfide. Also, there are

Figure 2 – The CEL cofferdam permits sand blasting and maintenance painting of steel piling to 2 feet below the mean low water mark

Figure 3 – A steam cleaning system was evaluated during the investigation of new and improved methods for cleaning and maintenance painting of Navy structures

environmental objections to the use of some of these additives. Research is being conducted on the development of a product that will eliminate these objections and provide fungicidal protection through a chemical union of fungicide and paint resin.

An extensive investigation is being made of the various types of problems connected with leaky roofs on Naval structures. Once a leak has developed, the source can be extremely difficult to locate, and corrective procedures to assure satisfactory results can be very expensive. Factors that must be considered include the type of materials and the quality of workmanship that went into the existing roof (as well as past unsatisfactory efforts at patching that may have been made), the slope and underlying substrate of the roof, and moisture penetration and migration through underlying layers of the roofing material. Unless these factors are properly considered in any effort to repair the damage, remedial efforts may fail. Two types of roofs receiving particular emphasis at this time are sloping metal roofs, such as on Butler buildings, and built-up roofing. In-situ experiments with foamed-in-place polyurethane and different coatings to protect it from ultraviolet degradation are being performed on several buildings with metal roofs. With proper care in application, and as long as the trapping of water underneath is avoided, this roofing maintenance system shows considerable promise of becoming a relatively inexpensive, rapid procedure to correct many problems. An added bonus with this type of roof is its excellent insulating quality. It is highly beneficial in reducing heat loads from the sun in summer (and so reducing energy requirements for air conditioning), and in preventing heat losses via the roof in winter. Data is being collected for quantitative determination of these benefits.

Among the many projects in the materials science area conducted by CEL in the past few years, two others are worthy of particular comment. One program resulted in the collection of basic corrosion rate data for more than 400 different alloys exposed to the ocean environment. With this, dependable information became available for the first time to design engineers. To obtain this information, six Submersible Test Units (STU's) containing 3000 specimens each and weighing four tons, were emplaced on the ocean floor at depths of approximately 6000 and 2500 feet (Figure 4). They were recovered after exposures ranging from 123 days to three years. Additional specimens were exposed in near surface seawater as controls and to acquire data in ocean water with high oxygen content and low hydrostatic pressure. Metallurgical examination of the specimens and the determination of corrosion rates as a function of such parameters as depth, oxygen concentration, time of exposure and alloy components

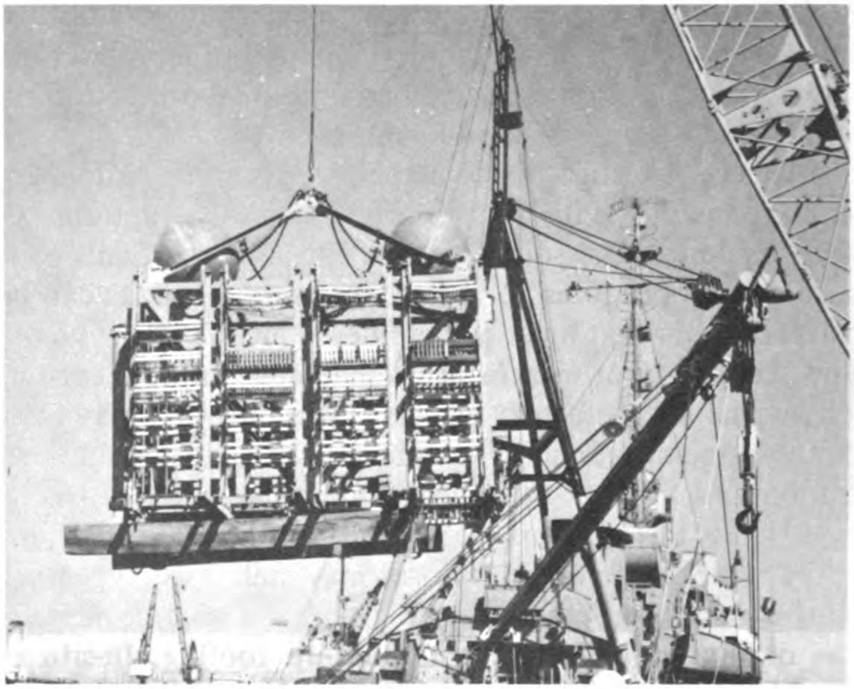


Figure 4 – CEL Submersible Test Units (STU) containing hundreds of samples of metal, wood, plastics, wire and rope have been exposed on the ocean floor at varying depths and for varying lengths of time

has provided valuable information to engineers planning for construction in the relatively unexplored frontiers of "inner space". An exhaustive compilation of this data organized by different types of alloys, such as iron, nickel, copper, aluminum, stainless steel, and titanium, will be available shortly.

The second project involved close cooperation with a Navy field activity (Navy Public Works Office, San Diego) to compare the performance of several different coating systems applied to well sandblasted steel mooring buoys for use by the Fleet (Figure 5). Different possibilities using cathodic protection for the buoys, to supplement coating protection, and for the expensive mooring chain assemblies, were investigated through in situ testing and evaluation. Results could be obtained only after several years of experimentation and exposure. As a result of this work, it has been possible to extend the annual buoy retrievals and refurbishing to once every three years. Also, with the use of sacrificial anodes and electrical continuity to the links supplied by interwoven cables, it has been possible to give excellent protection to the chain assembly for more than five years. These reductions in costly maintenance procedures represent a saving of many hundreds of thousands of dollars as the procedures are instituted throughout the Navy.

Figure 5 – A mooring buoy with an experimental protective coating is washed down for an annual inspection

Of the many requests for assistance or advice received from Naval shore facilities, many can be answered by information already available from earlier or existing CEL projects in materials science. In the few cases where this is not possible, aid is given by contacting other research and testing laboratories or manufacturers and forwarding the information so obtained, along with appropriate additional advice. Occasionally, personnel of the materials science group must launch a rather extensive effort before an answer can be supplied. In some cases, they may arrive at a satisfactory solution by developing a cooperative in situ experimental project with the asking agency.

Some examples will illustrate how these special cases are handled. Some Navy communication stations use as many as 41 miles of 1 to 3 inch diameter cables to support critical VLF antennas. They must be suitably maintained, but the cost of cleaning and greasing the cables manually would amount to millions of dollars . . . if contractors could be found who would accept such a job. CEL, working in close cooperation with a manufacturer, succeeded in procuring two devices that show promise of solving the problem. Both move up and down the cable, trolley fashion. One removes rust and scale from the guy line cable. The other applies a proprietary protective grease to the cable. The grease had earlier been found by the materials science people to give excellent protection to steel exposed to a sea spray atmosphere.

There are many examples of cooperative projects. In one, foamed-in-place polyurethane was applied to a badly leaking Butler building roof at a Naval Reserve Unit, and covered by test sections of five different coatings to protect the foam from deterioration by ultraviolet radiation. The foam roofing has been in service for more than a year, and a report on the first annual inspection is being written. It will include a comparision of the weathering performance of the coatings, plus temperature data obtained from thermocouples placed under and over the roofing material at different stages as the materials were being applied. This will emphasize the excellent insulating properties of the foam, and its capabilities in reducing fuel consumption during the winter months.

In another case, a Naval aircraft repair facility had a need for improved illumination from below for repairmen working on the underneath and interior parts of aircraft. Overhead lights in the hangar were insufficient, and dropcord auxiliary lighting was not permitted. Four different light reflecting paints were applied to the floor and lower walls of the facility. White coating systems applied for evaluation have markedly improved illumination from below into the body of the aircraft by reflectance. Although it is doubtful that cleanup procedures have been followed with the frequency recommended, at the time of the last inspection by CEL personnel, two years after the paints were applied, it was clear from photographic evidence and from illumination readings taken after a cleanup operation that light in the working areas had been improved by a factor of about four. This should decrease the energy requirements for lighting, and improve working conditions for greater efficiency.

We have attempted to give the reader an overview of some of the materials-oriented activities at CEL, and an appreciation of their practical aspects and benefits to Naval facilities. CEL personnel engaged in this effort have naturally become sensitive to the applied nature of their investigations, and are prepared to respond to Navy needs wherever they can be of assistance to either the shore facilities or the Fleet.

Research Notes

Hydraulically-Driven Marine Outboard Propulsion Units

Naval Amphibious Construction Battalions have used propeller-driven outboard propulsion units since World War II to move NL pontoon craft such as lighters, barges and floating cranes in harbors, and for warping tugs in amphibious operations. Now CEL has developed an improved type of propulsion unit featuring a hydraulic motor to drive the propeller directly.

The primary advantages of the CEL unit, in order of importance, are (1) the propeller axis remains horizontal rather than tilting as the propeller is moved up and away from the hull into the position for shallow water operations, resulting in greatly improved thrust and maneuverability, and (2) the possibility of damage if the propeller or tailpiece strikes the bottom or a submerged object is reduced. Hydraulic transmission of power from the engine to the propeller drive offers the least complex mechanical arrangement for achieving these advantages.

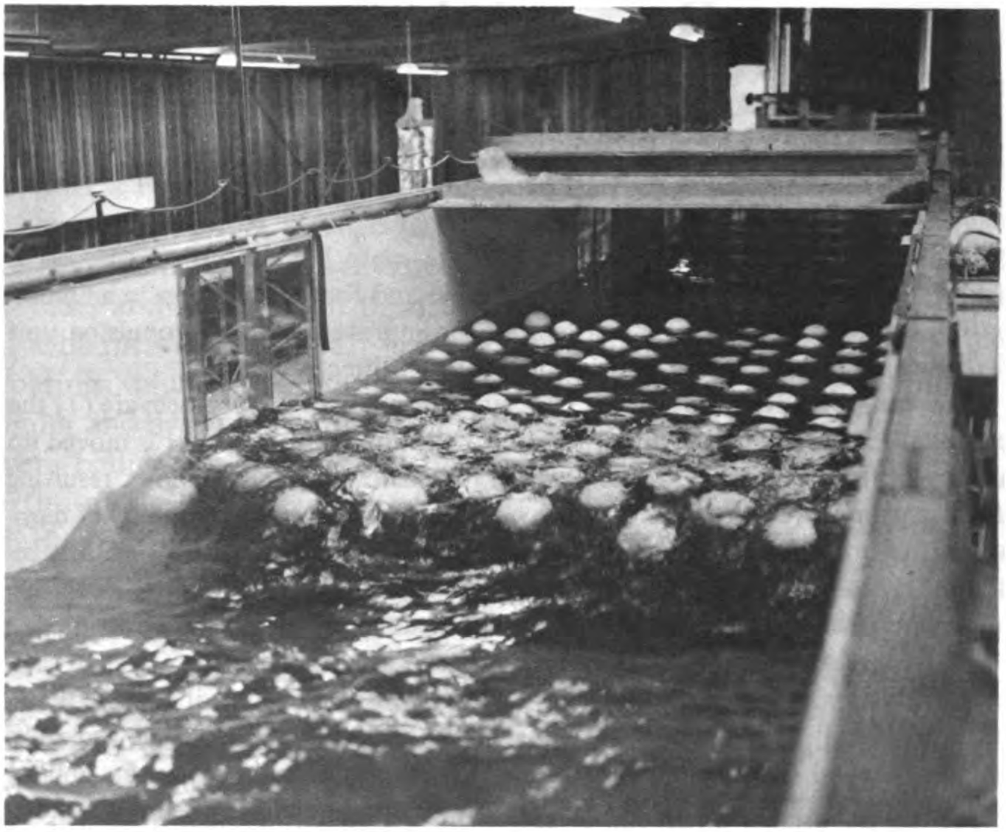
A prototype system was fabricated under contract. The complete system consists of two propulsion units and one remote steering and control console. Each propulsion unit is a power package assembly and an outboard drive assembly with an integral steering and control system. The design requirement for bollard thrust of the two units working together was 10,500 pounds. In preliminary testing with the system mounted on an NL pontoon warping tug hull, they achieved a bollard thrust of 11,500 pounds. Indications are that the prototype units will meet all specified performance requirements.

Tethered Float Breakwater

An unusual Tethered Float Breakwater (TFB) is now under cooperative development by the State of California and the U.S. Navy under an agreement recently signed by both parties. The Civil Engineering Laboratory represents the Navy, and the Department of Navigation and Ocean Development (DNOD) represents California. The development is a cooperative effort with project management assigned to CEL, engineering development provided by the Naval Undersea Center, San Diego, and scientific support provided by the DNOD. The TFB has the potential of revolutionizing harbor and marina protection systems throughout the world.

The TFB consists of rows of floating spheres, individually tethered to a suitable ballast or anchor. Such an array, or patch, of floats reduces the height of incoming waves by dissipating wave energy. Various sizes of installations can be constructed, depending upon the size of the waves encountered and the amount of energy which must be removed from the waves to create the calming effect desired.

The Navy's interest in the TFB is based on the need for transportable breakwaters for military applications. The DNOD interest is related to the need for



A model of the Tethered Float Breakwater (TFB) in a wave tank at the Scripps Institution of Oceanography reduces simulated 16-foot waves to 6 feet in height. The TFB is under cooperative development by the United States Navy and the State of California.

breakwaters as harbors of refuge along the California coast and for the protection of marinas and other boating facilities in inland waters.

Present plans call for tests of scale models in a wave tank at the Scripps Institution of Oceanography, La Jolla, followed by a field installation in an appropriate bay or harbor to obtain further engineering data. By July, 1975, designs for an inland waters scale TFB should be completed.

The concept of tethered floats as a breakwater was originated by John D. Isaacs, professor of oceanography at Scripps. The system was developed by Dr. Richard Seymour of DNOD, first as a graduate student under Isaacs.

Initial support of the research came from the Foundation for Ocean Research and the National Sea Grant Program. Some of the instrumentation to be used in evaluating the TFB will be supplied by Scripps, using Sea Grant funds.

The current agreement includes $100,000 from the Navy through the Naval Facilities Engineering Command, and $100,000 from the State of California to finance studies for the current fiscal year.

If funding is available for further efforts in subsequent years, the construction of larger scale TFB's and open ocean TFB's will be undertaken.

Most conventional breakwaters are constructed of material trucked to the site and placed in the water. The resulting breakwater, although effective in

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preventing storm waves from wreaking havoc in harbors and bays, also interferes with natural movements of the water. In bays or harbors, this interference can prevent the flushing of impurities by tidal currents. The TFB, which presents no such barrier to the water's movement, would stop the wave damage but not the flushing action of the tides.

The concept offers other advantages. Most small scale TFB's could be easily transported and handled. The components could be assembled in one place and carried to a remote site for installation, and thus be a portable breakwater. A tethered float system can also be installed in water too deep for a breakwater which rests on the bottom.

Wave tank tests using 6-inch floats have already demonstrated the calming effect of this breakwater. Data from tests in the Scripps wave tank show that waves of 16-foot height in the ocean would be reduced to 6 feet with 10 rows of 12-foot spheres. Larger floats or a greater number of floats would have a correspondingly greater calming effect.

One goal of the present research is to determine the most economical size and configuration for the TFB components for given operating conditions.

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Note:

These materials have been assembled and edited by Mr. Ray Darby, Code L37, Civil Engineering Laboratory, Port Hueneme, California, 93043.

Cover Caption:

Civil Engineering Laboratory research in diver tools and equipment has resulted in many improvements. Demonstrated here is a new technique for removing or repositioning heavy rocks underwater, using the CEL-developed hydraulic rock drill, rock bolts, and a controlled buoyancy lift bag. The technique is useful for removing rubble after underwater excavation, for diver assistance in constructing breakwaters, etc.

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