Shelf-Mounted OTEC Cold Water Pipe Experiment Gets Underway in Hawaii

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The National Oceanic and Atmospheric Administration (NOAA) continues to conduct ocean engineering research for the Department of Energy's Ocean Thermal Energy Conversion (OTEC) Program. The intent of NOAA's work is to investigate critical high technical risk areas and to provide an information base from which industry can develop commercially viable OTEC systems.

To date, NOAA's efforts have resulted in conceptual and preliminary baseline designs for floating (moored and grazing) and fixed (land-based and shelf-mounted) systems, development of hydrodynamic and structural design models, small scale laboratory experiments, larger scale at-sea tests, and development of procedures for inspection, maintenance, and repair.

The tropical island market has emerged as having the greatest immediate OTEC potential because of the modest need for accessible power and the abundance of large temperature gradients needed for efficient operation. These plants will require the installation of cold water intake pipes on steep slopes to depths of 1000 meters. Cold water pipe installations require careful attention to site selection, environmental loading, and geotechnical considerations for foundation integrity. To date, there is very little experience in the offshore industry for large installations on steep slopes.

In April 1984, a major research project was started just offshore of the island of Hawaii to address some of these problems. A section of pipe 2.4 meters in diameter and 24 meters in length was installed using a combination of concrete foundations and steel joints. This pipe is approximately one-third the size required for a 40-megawatt plant. The pipe and foundations are fully instrumented to measure forces due primarily to currents and waves.

Environmental measurements are also being taken in the test area. The measurement data taken over the next year will be used to validate analytical models which will be available to industry for design of OTEC pipes and foundations.

CWP Research and Deployment

A 2.4-meter diameter, 24-meter long section of the fiberglass reinforced plastic cold water pipe (CWP) used in the suspended pipe at-sea experiment (*Sea Technology,* July 1983) was used for the slope-mounted CWP experiment recently deployed off Keahole Point, Hawaii. An experimental design for a 12-month deployment was developed to address critical unknowns for use of large diameter CWPs in shelf-mounted applications. The objectives of this experiment are to:

- Measure hydrodynamic loads on a slope-mounted CWP and the resulting foundation loads and determine hydrodynamic load coefficients
- Calibrate analytical models used in CWP and foundation design
- Investigate long-term (8 to 12 months) immersion characteristics of pipe joint and foundation materials
- Investigate large diameter, pipe-joining techniques using submersible concrete
- Investigate large diameter CWP installation techniques on steep slopes.

The at-sea experiment is being conducted under a NOAA contract to Hawaiian Dredging and Construction Company. The project team includes Makai Ocean Engineering, Edward K. Noda and Associates, G.J. Garrison and Associates, and Dames and Moore.

The deployment operation involved the installation of anchoring chains, an upper foundation, and the mating of the pipe with the upper foundation on a 40-degree slope. The large mass of the foundations and pipe required the use of a heavy-lift barge provided by the U.S. Navy. Heave compensation devices were used on both lowering lines during the deployment. Movement of the deploying barge, the lowering winch, and the final joining of the pipe with the upper foundation were contolled from a command center on the surface using three underwater videocameras. Currents and wave conditions were monitored in real time during the operation to insure that conditions were within deployment design limits. Additional ballast was added by pumping submersible concrete into the pipe joint shells.

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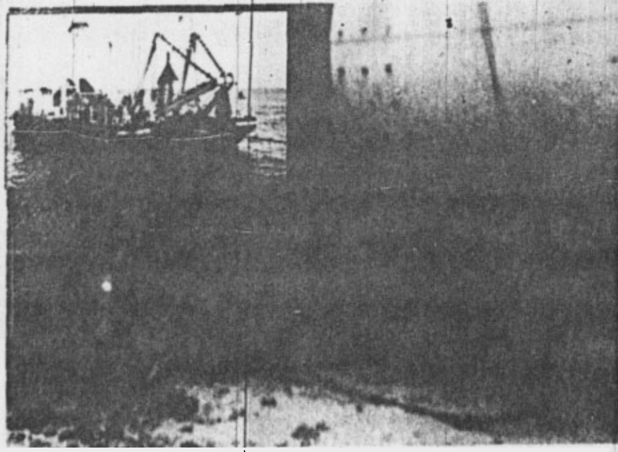
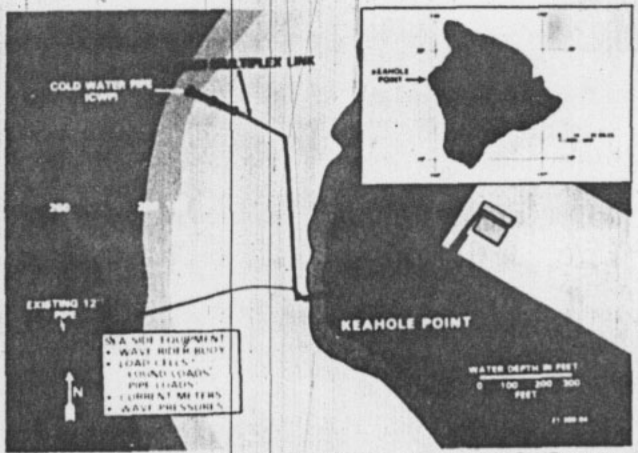


The heavy mass of the foundation and pipe required the use of a heavy-lift barge (inset). Lowering lines were controlled by three underwater video cameras and barge heave compensation devices, Data are transmitted from the site by an electrical conduit running up the slope.



Keahole Point, Hawaii, served as the location for the CWP experiment. High water quality and calm weather and current conditions were of benefit to the OTEC group. Tropical islands may, in the industry's immediate future, provide the best market for OTEC power systems.

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Following the deployment of the pipe and foundations, divers transferred pipe loads to load cells and started the installation of the data cable conduit. The data will be transmitted from the test site to the data acquisition system in the Natural Energy Laboratory at Keahole Point. Phone lines will be used to transmit the data to Honolulu where analysis will take place.

The deployment of the pipe and foundations required 6 days on site. Weather and current conditions were extremely calm for the Keahole Point area.

The design of the 12-month experiment is based upon a 10-year storm wave height of 7.5 meters and peak currents of 1.6 m/sec. Data collected during the upcoming winter will be the most valuable, since records indicate a large range of conditions will prevail during that period.

Experiments and Objectives

One of the primary objectives of the experiment is the Measurement of hydrodynamic loading forces in the horizontal and vertical planes induced by the combination of waves and currents. Most investigations of forces on pipelines have used Morison's equation but at smaller Reynolds Numbers.

During the experiment, wave and current-induced velocities and load measurements will be taken and used to correlate water velocities along slope to wave height and direction; correlate pipe loads to water velocities and accelerations in all wave conditions and currents to determine coefficients (C_D, C_L, C_M vs. Re, KC); compare the total pipe section loads to those calculated; correlate total foundation loads to those predicted.

Data collection started in April 1984 and will continue for one year. A final report will be available by mid-1985.

In addition to the at-sea experiment of the slope-mounted CWP, smaller scale model tests are also underway. Small scale (1/50 to 1/60) experiments are being conducted by CBI, Inc., to determine the expected wave and current-induced loads on a slope-mounted CWP. Data derived from these tests will cover a large range of test conditions and will complement the large scale test underway off Hawaii. The parameters for the small scale experiment include: wave and current conditions expected at Keahole Point; Hawaii, and Kahe Point, Oahu, with waves ranging from 3.8 meters to 8.5 meters and currents of 0.75 to 1.5 m/sec; variable angles of wave and current approach of 0, 45, and 90 degrees; variable slope inclinations of 0, 40, and 70 degrees; variable spacing between the pipe and the sloped sea floor up to one pipe diameter.

The tests at CBI, Inc., will be completed in the fall of 1984.

Additional CWP Work Needed

The at-sea test of a slope-mounted CWP is the only one of many experiments needed to resolve the technical problems associated with shelf-mounted platforms, CWPs and their foundations. Some of the remaining research needs include:

- Construction and deployment techniques for CWPs and foundations
- Geotechnical measurement techniques and foundations to measure engineering properties associated with soil-structure interaction of slope-mounted systems
- Operational safety, inspection, maintenance, repair, and retrieval of submerged components
- Validated computer codes for predicting CWP loads and responses
- Long-term materials characteristics for CWP
- Hydrodynamics loads on CWP causing vortex shedding
- Anchor hardware for both steep slopes and rock conditions
- Slope and foundation stability for shelf-mounted platform and CWP installations. ▫

Bob J. Taylor (pictured, above) is the technical manager and Joseph R. Vadus, the program manager of the Special Projects Staff in NOAA's Office of Oceanography and Marine Services. Taylor, who has done graduate work in ocean engineering at the University of Miami, was chief of the Ocean Engineering Division in the Office of Ocean Technology and Engineering Services prior to his current assignment. Vadus, who has headed NOAA's OTEC energy engineering program activities since 1976, also has managed the Advanced Technology program in the Manned Undersea Science & Technology Office. Prior to joining NOAA, he held engineering management positions at Sperry Systems Management Division. He received his BS degree in electrical engineering from Pennsylvania State University and his masters in ocean engineering from Long Island University.