Chapter 45

COASTAL ENGINEERING RESEARCH

ON THE GREAT LAKES

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ABSTRACT

Collection and study of field data relative to coastal engineering is underway for the following problems: wind over the lakes and its relationship with wind recorded on land; wave characteristics and effect of wind and environment; water level disturbances and mathematical relationship with acting forces; currents in harbors and factors affecting them; littoral transport.

INTRODUCTION

The problems of coastal engineering on the Great Lakes are rather similar to the problems on oceans since the lakes act in many aspects as oceans due to their large size, Fig. 1. However, there are distinct differences between these lakes and oceans. The water itself is different: the Great Lakes contain quite pure fresh water. These lakes also are generally covered by ice each winter for two to four months during which time coastal processes are greatly reduced. The water levels are subject to significant fluctuation; it is known that at high lake levels, the shore erosion is much more active than at low levels; however, it is possible that at low levels (as at present) conditions for high erosion are created by moving the offshore sand bars deeper into the lakes. Not much data is available on the waves in the Great Lakes. It is believed that wave characteristics are different from those of ocean waves due to limited area of generation and the absence of significant swells.

For any kind of oceanographic research, the lakes offer a large variety of conditions. The causative factors are more easily measurable and the costs of research in many instances are much lower than in salt water. It is not surprising that the Great Lakes have been suggested as a proving ground to test theories and to develop and test new instruments and data transmission equipment for both fresh and salt water research.

The research of the Great Lakes is gaining impetus due to the increasing population in their basins in both the United States and Canada, and with the accelerated use of their waters for a variety of purposes. Many universities, state and provincial agencies, and the federal governments of both countries are engaged in research activities.

Through its Research Division, the United States Lake Survey, an agency of U. S. Army Corps of Engineers, is conducting research in the fields of hydrology of the lakes, lake water characteristics, water

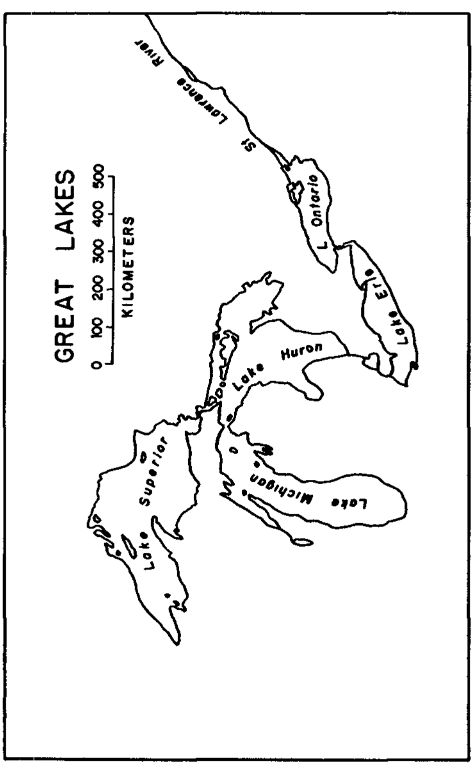

Fig. 1 Outline of the Great Lakes.

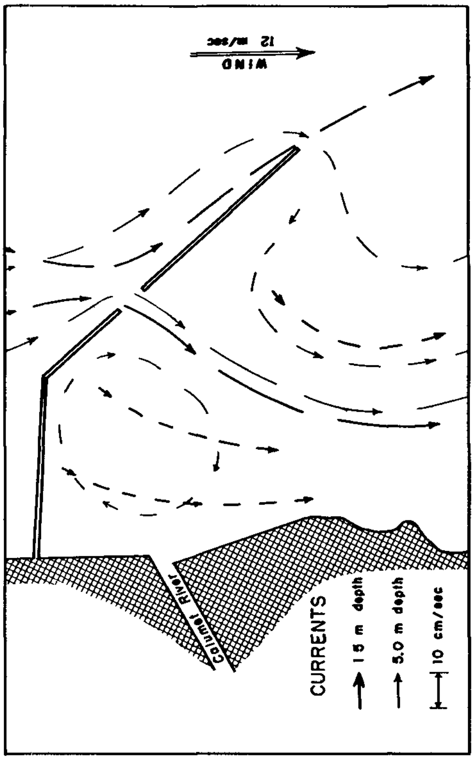

Fig 2 Currents in Calumet Harbor.

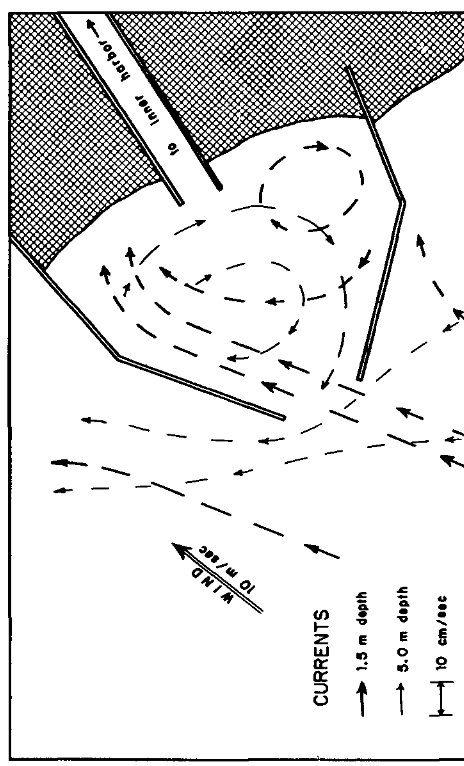

Fig 3 Currents in Muskegon Harbor

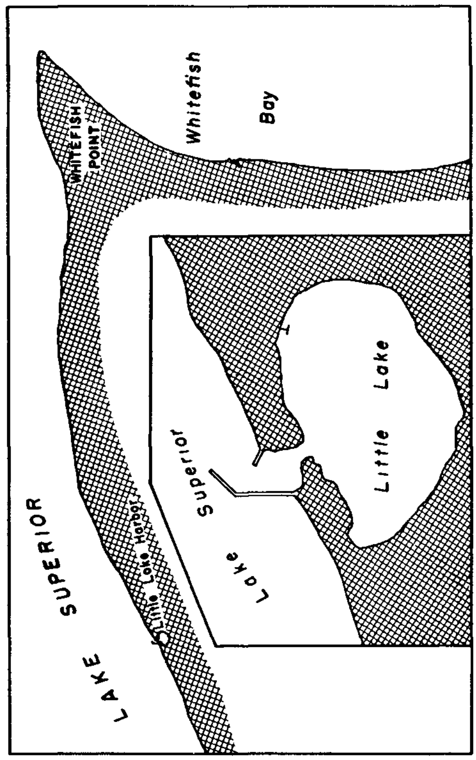

Fig 4. Lake Superior shoreline

motion, shore processes, and ice and snow problems. In this paper, the coastal engineering phases of both the on-going research and the near-future planned research will be discussed.

OVERWATER WIND

The research on overwater wind is conducted in two categories: one to explore the relationship between the wind recorded on shore near the lake with the wind recorded over the lake, and the other to explore the energy transfer from air to water and reverse. The recording of wind speed and direction is being done at weather stations all around the Great Lakes and the records are available for the past sixty years. By comparison with records of overwater winds from vessels having wind recorders on board, it was found that the overwater winds generally have much higher speeds than those recorded by land stations. However, a high variation was observed, depending on the time of day or season. For example, at the same wind speed on land, the recorded overwater wind is about thirty per cent faster during the fall months than during the spring months. Investigation is aimed toward determining if the energy transfer from air to water is subject to similar variation and what factors affect it. The results will improve understanding of the relationship between wind and waves or wind and tides.

To accomplish this investigation, two stations are operated in Lake Michigan which record overwater wind speed and direction, along with many other factors. The first, a tower, was placed in 15 m deep water, 1.6 km from shore near Muskegon. This tower, extending 16 m into the air, supports cup anemometers at the 3, 4, 6, 10 and 16 meter levels. Additional anemometers are placed at 0.5, 1.0, 1.5, and 2.0 meter levels when wave conditions permit. Data are being transmitted to shore and recorded on magnetic tape. The 9 anemometers give good profiles of low winds, and the upper 5 instruments record conditions during storms. Besides the wind profiles, the other recorded factors are: air temperature and humidity profiles, water temperature profile, water current speed and direction, water level, wave height and period, precipitation, water albedo, and exchange of radiation. The University of Michigan and the U. S. Weather Bureau participate in these investigations.

The other wind installation is on South Manitou Island, a small island in the northeastern part of Lake Michigan. The instrumentation at this installation is more simple than that on the tower; however, it has the advantage that it stays in operation year round, while the tower must be removed before winter and reinstalled in the spring. A small wooden platform near the island was also erected to support the instruments recording water level and temperature, and to test the effect of the island on overwater winds.

LAKE WAVES

At the present time, nine wave gages are in operation in lakes Erie, Michigan, and Superior. Their purpose is to collect data for the statistical determination of lake wave spectra and to correlate wave characteristics with wind speed, duration, and lake bottom geometry. Of these nine wave gages, four have pressure cells for the sensing unit. The pressure cells do not properly depict the smaller waves; however, they are easy to mount on submerged tripods, require only low power supply, and are not affected by icing. The other type of sensing unit is the step resistance gage developed by the Coastal Engineering Research Center of the Corps of Engineers. This gage is being used for the installations near harbor entrances where shallow water allows fairly easy installation. Comparison is being made of the two sensors to establish accuracy limits for the pressure cell.

In remote regions of Lake Superior where commercial electric power is not available, sensors of the relay type are used. They are more expensive, but their power demand is much smaller than that of the step resistance unit. A thermoelectric generator of 15 watt capacity having 12 VDC proved to be a very handy power supply under these conditions, with no maintenance problems and a minimum supply of liquified propane gas for fuel. In the near future an inertial-type wave sensor will be procured and used for investigations of waves further away from shore to establish the environmental effects on wave growth and propagation.

Extensive investigations were made on the methods of recording the waves. From the several choices (paper chart, paper tape, magnetic tape), the magnetic tape was selected as the basic recording method. Waves in analog form are continuously recorded on magnetic tape at a speed of 1.2 cm per min on a reel that lasts for about four weeks. In the office, an osciloscope is connected to a tape recorder for visual inspection of the record and for selection of portions of the record for wave analysis.

Up to the present time no studies have been made of the wave records that have been collected. A brief analysis indicates that the Great Lakes act more like oceans than inland reservoirs. Heights exceeding 2.5 meters and periods of 10 seconds were recorded during the first two months of operation of the gages. There is some indication that the fetch effect on wave formation is less pronounced than that generally employed by some wave forecasting schemes.

WATER LEVEL DISTURBANCES

Shifts of water mass by wind and by variation of barometric pressure raise some portions of lake levels and lower others, although the mean level in the lake remains the same. These disturbances, called wind tides, surges, or seiches, are of importance to coastal engineering problems because they require more height for the shore protection structures and occasionally create strong currents. Lake Erie is widely known for having the largest disturbances of this kind. Wind-caused water setups on Erie have been recorded exceeding 4 meters in height. The extreme displacement of Lake Erie water is attributed to both the lake's shallow depth and its length lying in the direction of prevailing winds. All the other lakes have similar phenomena and, although not as frequent or as pronounced as on Lake Erie, they are occasionally severe.

The investigations aiming to derive physical laws and mathematical models for such disturbances and their propagation into harbors are made by the Lake Survey in conjunction with data being collected by the Public Health Service. The Public Health Service operates buoy stations to measure wind speed and direction, air and water temperature, and water velocity at several depths. The Lake Survey is making detailed water level recordings at shore stations and at several points in the lake. During 1963 the main effort was directed to Lake Michigan, where 22 water level recorders, 31 buoys, one tower and one island station were in operation. This year the emphasis was shifted to Lake Erie and later will be extended to Lake Ontario.

HARBOR CURRENTS

The initial purpose of these investigations was to collect information on the existence of currents in harbors, and their magnitude and persistence. Due to lack of significant astronomical tides in the lakes, it was believed that only a few exposed harbors have significant water movement inside the harbor. However, surveys have indicated measurable currents in all the harbors measured. The next step in this research is to derive a mathematical model establishing relationships between acting forces and water movement, and closely depicting the observations. Such a mathematical model would allow forecasting the effects of proposed harbor modifications without going through the expensive and time-consuming testing procedure on a physical model.

During the summer of 1963, four harbors in Lake Michigan were instrumented and the water movement traced. At the present time similar surveys are underway in two harbors of Lake Erie. Instrumentation consists of recorders to make continuous records of wind speed and direction, barometric pressure, wave height and period, water level, water temperature, and direction and speed of water movement. A Savonius rotor is used to sense the speed and a vane for direction. Some of the current measurements are recorded on film with readings at 20-minute intervals. Such current recorders remain submerged for six weeks, at which time the film must be removed and a new roll inserted. There is no indication if the instrument is operating properly while submerged, which is the disadvantage of such an instrument. When a submerged instrument stops, all subsequent records are lost. This year improved meters were added, which transmit the water speed and direction by submerged cables to recorders on shore.

The continuous recordings of the current meters are supplemented by tracings of the water movement at several depths inside and outside the harbor. Drogues adjustable for different depths are used for these tracings, and a survey lasts for 3 to 6 weeks. Also rhodomine dyes were tested for this purpose, releasing them between prior established markers and photographing movement. Plans are underway to survey currents by stereo photography as soon as an airplane and a camera equipped with a wide-angle lens is available. The vertical distribution of water velocity is measured by Price current meters.

Samples of harbor current surveys are shown in Figs. 2 and 3. In Calumet Harbor near Chicago, a strong current caused by 12 m/s wind from the north crosses the harbor and flushes it. The fresh lake water removes the polluted water which enters the harbor from Calumet River. In Muskegon Harbor, the current structure is quite complex. Note that the current measured at a 5 m depth crosses the entrance to the inner harbor against the wind.

LITTORAL TRANSPORT

Data are being collected at the present time for establishment of the relationships between energy and movement of shore materials and their characteristics. For this task a reach was selected on the southern shore of Lake Superior, between Little Lake and Whitefish Point, Fig. 4. Due to its exposed location to the predominantly northwest winds, this reach has quite a large movement of shore material, with the net movement from west to east. A small harbor was recently constructed at Little Lake, which produced at least a temporary check point for the sediment movement. Another natural check point is at Whitefish Point, where the shoreline turns sharply southward. These sites are now the subject of detailed surveys.

Two towers placed in water 5 m deep are each equipped with a wind speed and direction recorder, a relay-type wave gage with magnetic tape recorder, and a water-level recorder. One pressure cell for deep-water waves was placed on a submerged tripod in water 15 meters deep. In the breaker zone, at 1.5 m depth, two tripods are used for ducted-type current meters and direction sensors, with shore-based strip chart recorders. All these instruments are in continuous operation.

Periodic topographic surveys are made for establishing the rate of sediment deposition or removal. These surveys consist of measurements of bottom elevations at preselected locations marked by plastic rods inserted into the bottom along sixteen ranges at each site. Also, sediment samples are taken for preliminary analysis on shore and for detailed physical analysis in the laboratory. The following sediment characteristics will be determined: phi mean diameter, sorting coefficient, kurtosis, and skewness.

Data collection is restricted by ice to the open-water season, which in this northern region is rather short. It is planned to make resurvey of the sites next spring, although the effect of ice cover on energy transfer will make the problem much more involved.

FUTURE OUTLOOK

The present program for coastal engineering research in the lakes is oriented toward immediately useful results. Of necessity, applied research will continue to have higher priority over basic research. However, research progress is limited until there is a better understanding of the basic fundamentals and relationships.

In the research on waves, work will be expanded in the study of the shape of lake waves as a function of length, steepness, and propagation speed. Charts will be prepared indicating the wave characteristics in each of the lakes. Work is also planned on investigations of the interrelationship between lakes and rivers. The water in the outflow rivers is extremely clear, except during storms when the lakes supply shore material to outflow rivers, causing detrimental effects on water quality and silting of navigation channels and water intakes. Tracer techniques are planned for study of the movement of material from lakes to rivers. Further research will include the energy transfer from air to water and reverse, and the distribution of energy in the waves.