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APPLICATION OF WAVE CLIMATOLOGY AND DATA FOR DESIGN,(U)

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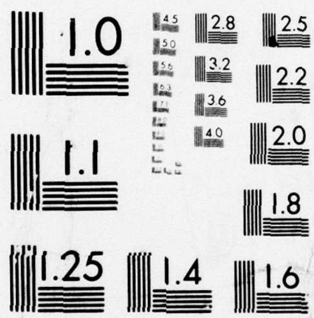

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APPLICATION OF WAVE CLIMATOLOGY
AND
DATA FOR DESIGN

Thorndike Saville, Jr.*

One can not talk about application of wave information to engineering design without talking also about the needs for information, and the type of information needed. Consequently I will be mentioning some of the same material, and making some of the same points, made earlier this morning by Professors Weigel and Dean. However, I will be approaching them in a somewhat different view, and pointing toward a somewhat different end.

I will restrict this talk to wind generated waves. I will not be considering such other types of waves and wave phenomena as capillary waves, astronomical tides, tsunamis and landslide generated waves, storm surge, edge waves and shelf oscillation, and waves generated by moving barometric pressure discontinuities. All of these are important in various areas of engineering design. Most of them have importance in terms of safety and coastal zone management. All of them have certain unknown facets; and statistical data on all of them are needed. However, this conference is pointed primarily at normal wind generated, gravity waves, and I will restrict my discussion to these.

This discussion will also ask more questions than it will answer. In many cases the engineer not only has to make do with inadequate data, but also frequently can only use a method of design which is, at best, not a completely satisfactory one. Of course, that has been the history of engineering, and it is why judgement factors are so vitally important. It is also why a factor of safety is often used.

Actually, in the use of wave data for engineering purposes we are in the somewhat anomalous position of often having better methods of analysis of the data, than of use of the data once analyzed. This is partly because many of the analysis techniques have been borrowed from other scientific disciplines (for example, electrical engineering).

For example, in the design of a rubble mound breakwater, a number of years of instrumental wave data may have been gathered at the breakwater location. (It may not happen often but some people are lucky). In such a case, wave spectrum analyses may have been made at 4 or 6-hour intervals throughout the data gathering period, and thus extensive data are available on the distribution of wave energy throughout the frequency range, and also on the time distribution of this data over a long period of time. The design report will almost inevitably state that these wave spectra were studied, and the design wave was determined to be, say, 24 feet. Yet in reality how was this 24 feet determined? In most cases it will have been that the designer knew from hydrographic surveys what the water depth was, added to it an elevation for astronomical tide and storm surge, and determined that the design depth condition for this structure would be 30 feet. He then multiplied 30 feet by the factor 0.78, which is the accepted average factor relating breaking height and

*Technical Director, U. S. Army Coastal Engineering Research Center, Kingman Building, Fort Belvoir, Virginia depth, and rounded the result off to 24 feet. He might then apply a factor of safety, recognizing that there were assupmtions involved in his calculations which might not be completely correct, and arrive at a figure of 25 feet, which is a good convenient number to use.

Now this case is somewhat overdrawn, of course. But it does point to the fact that the designer for a rubble mound breakwater may have available to him a great deal of high powered analysis of wave data which he doesn't really know how to use for design. In this particular case, the designer may indeed have determined the stability coefficient for the breakwater armor units based not only on wave height, but also on wave period - since this parameter also enters into the stability of the structure, though to a much lesser extent than the wave height. He also likely has looked at the number of times a year that these waves may be expected to occur, and thus made some estimate of the probability of damage, and therefrom the probable maintenance cost over a 40 or 50-year period. Nevertheless, most of what he actually uses could have been determined from a very simple analysis of the wave records for significant height and period alone. At the present state-of-the-art, he just can't make use of most of the additional data provided by spectral analysis.

There are many other cases of design where we don't really know how to use and apply the spectral information we can obtain. And, in fact, one area where major advances today need to be made is in the development of methods to use the data derived from the sophisticated analysis capability we already have.

Now that is not to say that wave spectrum data are not useful, or that they should not be obtained. Not at all. If nothing else, obtention of spectral data means that we will have past years of data available when the techniques to use it are fully developed, as inevitably they will be. We would have a ready made spectral wave climate, so to speak. And better methods of presentation of these data are even now being developed to satisfy engineering needs. Where digital records are used, spectrum analysis may provide the most economical as well as the most objective method of determining wave period. And, there are many areas where we now know how to use wave spectra, and where design would be very crudely carried out if spectral data and techniques were not used. Such areas of design as harbor layouts to prevent undue surging and range action are greatly handicapped without adequate spectral data. Design of structures such as oil rigs for vibrational forces is much more uncertain without spectral data. In these areas our design methods have advanced far ahead of methods for some other applications.

In many ways climatic wave data is the single most important item of information required for any design in the coastal engineering field, or for any structure near or at the water surface. Yet we have surprisingly little information on the wave climate. There is scattered data available from a few shore stations, both from instruments and from visual observations. Yet the shore sites where data has been systematically collected for a sufficiently long time (at least a year) to be of real use barely number 100 for the approximately 36,000 miles of shoreline in the conterminous United States. There are, in addition, a very few instrumentally obtained data available from platforms and data buoys in waters on the continental shelf. There are virtually no systematically gathered instrumental data in the deeper waters of the oceans, other than from a few weather ships. There are scattered instrumental data obtained from oceanographic scientific cruises, but they are so few and scattered as to hardly be of importance in trying to determine a wave climate. Probably the greatest number of observations are the visual ones made from ships at sea, which have been accumulated in various data centers across the world. In the United States these form part of the Surface Synoptic Meteorological Observations (SSMO) which are available from the Weather Service. But these observations have severe quality problems and several systematic errors have been identified. In addition, these observations are of necessity concentrated in the shipping lanes which means that many areas are insufficiently covered to show real climatic or seasonal differences. And since ships attempt to avoid the heaviest seas, there tends to be a paucity of data in the upper extreme. For some areas there are available hindcast, or forecast, data made from standard weather charts. The US Navy and Weather Service are now beginning to provide forecast data routinely for some ocean areas, and in a few years this data may well represent the best available climatic material. But a vast network of wave gathering stations is badly needed. Such a network would compare with the network of weather stations on the land. Some countries are beginning to try to meet this need with an increase in shore stations, and both the Permanent International Association of Navigation Congresses and the Engineering Committee on Oceanic Resources have established working committees to show where wave data is compiled, what format it is in, how it may be made available, and to encourage the systematic collection of wave climate data in a more or less standardized form. You will be hearing more about both of these later during the conference.

With deep ocean data, there is the possibility of combining data from a number of different locations to give an average for a particular area, such as a Marsden Square. This combination can be quite valid unless parts of the area are sheltered by land forms as behind an island. However, it must be remembered that wave data for one general area are by no means apt to be the same as wave data for another general area. And that in turn means that both design and construction practices which are good in one area may be unreliable in another For example, conditions in the North Sea are greatly different from those in the Gulf of Mexico and the Persian Gulf, which some have learned the hard way with damage or failures resulting from using design criteria and practices completely acceptable in other areas.

I am reminded here of the weather forecaster a number of years ago brought up and trained on the east coast. He worked in east coast offices with a phenomenal prediction record of success. Later transferred to the west coast he found it virtually impossible to make a correct prediction. When he predicted sun, it was cloudy; when he predicted clear, it rained; when he predicted morning fog, it was clear as a bell. After about six months the forecaster requested transfer back to the east coast. Upon being asked by headquarters as to why, his reply was "the climate doesn't agree with me". Now the remark itself may be amusing, but it was very definitely to the point. West coast climate <u>is</u> different from east coast climate, just as the forces and phenomena affecting the west coast are different from those affecting the east coast. These are much better understood now, and a properly trained meteorologist today would have much less difficulty. Waves, like weather, are different on our east and west coasts, and also different on the Gulf and Great Lakes coasts. Thus one who is seeking to apply wave forecasting techniques, or even measured wave data, to engineering problems on our various coasts needs to be aware of these differences and to take them into account in his applications. A design or a system which works in waters of one coast, may well not be directly transferable to waters of another coast.

The wave climate in deep water offshore may be nearly the same over a large distance, such as a hundred miles. However, as one approaches the shore, applicability of this wave climate data frequently becomes quite restricted. Waves at the shore, or at shore structures, may vary appreciably within several miles and, in some cases, within fractions of a mile. These changes must be considered in such factors pertaining to engineering design as longshore transport, structure stability, and scour. They are also of great import in considering management of the coastal zone, and determination of preferred usage. This variation mitigates greatly against the establishment of broad zones for which particular structural or usage criteria should apply. Because the wave activity at the shore line can differ appreciably in relatively short distances, engineeing or zoning requirements may also change in relatively short distances.

On the other hand, there are some coastal areas with long straight beaches, and relatively similar offshore contours, where the same wave climate conditions may be expected to apply for a considerable distance. In applying available wave climatic data, the engineer must take into account this possibility of variability, as well as the possibility of uniformity, over a distance.

If one wishes to use wave climate data from deep water offshore for application to shore structures and shore problems, this offshore data must be transformed into a nearshore wave climate. That requires the application and engineering evaluation of the processes of shoaling, refraction, diffraction, sheltering, partial reflection by a sloping bottom, bottom friction and percolation, and the actual breaking process. At times, it may involve the continued generation of waves by wind action blowing toward the shore while the waves refract or diffract. The wind, as well as the bottom slope, may also affect the type of breaker, and hence the forces exerted by it, or the effects of its runup. There are standard techniques for considering most of these processes, but they are by no means as accurate as one would desire. The assumption can be made that these techniques can be applied to separate components of the wave train and these components added at the completion of the computations to give a resultant wave climate at the shore point. Such assumptions may not always apply. And, in fact, we find, for example, that wave refraction patterns revealed by aerial photographs do not always follow exactly those determined by engineering techniques.

It has also been found through examination of a large number of aerial photographs of the sea surface that multiple wave trains are common. This fact is also shown, though to a lesser degree, by the visual shipboard observations, particularly those which report both sea and swell occurring simultaneously. As is discussed in some detail in a forthcoming paper by McClenan and Harris ("Wave Characteristics as Revealed by Aerial Photography") the relative dominance of distinct wave trains which may be visually identified may change significantly from the open sea to the beach. The waves dominating the breaker region, often of longer period, may be nearly invisible some distance from shore. On the other hand, the shorter waves which frequently dominate the sea some distance from shore are often not visually identifiable in the surf zone. Spectral determinations and analysis of the waves in deeper water will aid the engineer in predicting the type of wave which would be important at or near the breaker zone, particularly when each component of the spectrum is treated separately and combined to estimate an inshore spectrum. But the application is difficult and time consuming, even with computers, and much work needs to be done to provide adequate means of application.

Application within the surf zone is subject to further problems since we do not know with any real degree of accuracy the distribution of breaker heights there. The Gaussian distribution applied to open sea waves in deep water is often used, and probably with some degree of accuracy, to represent the distribution of wave heights in shallow water seaward of the surf zone. The same distribution may be assumed to apply within the surf zone, but that is a rather gross assumption. The distribution at any one specific point in the surf zone is affected by how many of the waves have already broken, as opposed to how many are still in an unbroken condition. If the slope is relatively flat, reforming of broken waves may also materially affect both the height and period distribution at a specific point in the surf zone. Likewise, since the waves break at a number of different depths and locations in the surf zone, we have virtually no measure of the true distribution of breaker heights, since this is a spatial distribution, rather than one at a particular point. Yet this distribution becomes critically important in applications dealing with sediment transport, wave runup and overtopping. Systematically gathered data from a large number of wave gages located in a line perpendicular to the shore extending through the entire surf zone is needed to give information on this distribution. And not just the distribution at one time, for one set of wave conditions, but for a number of times for differing sets of wave conditions. (Some information could be gathered from wind wave tanks. But its applicability to prototype conditions would be somewhat suspect.) Such a group of prototype measurements is planned to form one of the first experiments to be carried out at the CERC Field Research Facility planned for construction on the North Carolina coast, which will include an instrumented research pier. Actually, it is surprising that, with all of the information on surf which was obtained during World War II in conjunction with planning for amphibious operations, so little is really known about the distribution of waves within the surf zone. This need is one of the major "questions" which I earlier stated I would be pointing out.

I have used the phrase "wave climate" a number of times. And yet "wave climate" is not a well defined term. Partly that is because we need different parameters for application to different types of design problems, and partly because it is such a general term that it is difficult to define it specifically. It is also difficult to provide in any one summarization of wave occurences all of the particular information which may be desired at some time for every application. Wave climate in its simplest terms can be characterised just by the number of occurences of waves of a particular average, or significant height. From such a listing, the frequency with which waves of a particular height may be expected can be estimated, and this can be applied directly to many types of engineering design. For many years that is about all the engineer had. Yet it is certainly also desirable to have some measure of the wave period or frequency. But, different measures of wave period can be, and have been, used. For example, is the period important for engineering use the average of the time intervals between all waves? If not, which waves does one eliminate? Is it the average period of the groups of higher well formed waves, that is, the significant period? Is it defined by the number of upcrossings on a wave record? Is it defined from the wave spectrum as the frequency of the greatest energy content, or just how? If there is more than one wave train present, and this is frequently the case, how do we then define the climate? Do we try to define each major wave train separately, or as some average parameter combining the two; or do we set up a number of typical categories of wave spectra and define the wave conditions as a type 1 or type 2 condition? In actuality the fact that two or more distinct wave trains co-exist may be nearly as significant to the engineer as total energy.

Somewhat surprisingly aerial photographs taken at elevations between 5,000 and 10,000 feet indicate that ocean wave patterns which appear mixed and confused at low elevations, often are highly organized. This organization may well persist even though several distinct wave trains are present. The use of wave spectrum analysis to provide an indication of the individual wave trains, with summaries of these as individual trains, may be a means of obtaining data needed for engineering applications. Again, this condition observed from aerial photography is discussed much more extensively in the forthcoming McClenan and Harris paper.

Directionality also is an important part of the wave climate, particularly when coastal structures and effects are involved. But as yet we have no way of adequately and accurately obtaining directional statistics continuously over a long period of time. This again is one of those major problems on which further research is required. Some of the papers to be given at this conference do discuss this problem and some of the methods and use. And, of course, Professor Weigel has discussed the subject earlier today.

But even if we arrive at a satisfactory definition of wave climate, and can satisfactorily obtain statistics from a large network of stations, we still face the fact that as engineers we need different outputs from this information for different problems. We need extremes as well as averages. And that involves the low end, as well as the high end. In particular, we need expected durations of these extremes, as well as of the average conditions. And just as we need to know the durations of the extremes, we need equally to know the duration which may be expected between occurences of extremes. For example, it makes a great deal of difference in a dredging operation whether the 120 hours of waves over 5 feet that may be expected in the month of April should occur all in one 5-day storm, in two 2-1/2-day storms, or in five 1-day storms scattered throughout the month. The duration between high wave occurences determines the amount of continuous operating time available, and hence has tremendous impact on both safety and economic feasibility. And while, as engineers, we may *think primarily in* terms of direct engineering operations, these durations also importantly affect the economics of shore use. Whether or not, for example, a particular location is a good one for development of a recreational establishment because it provides long periods of good wave conditions for swimming and surfing interrupted by occasional weekly unusable periods, or has virtually daily oscillations between usable and unusable conditions.

For other engineering applications it is important to know whether the individual waves will vary slowly one from another or whether they vary radically. Best surfing conditions often occur where high waves come in groups, rather than where a high wave is always preceded and immediately followed by a very low wave. Such direct engineering applications as estimation of wave runup and overtopping are likewise importantly affected by the way in which the waves change one from another in succession.

At times wave length, or at least the distance between successive crests, is of importance. Particular application here can be to navigation conditions, or to forces on pile structures where a critical determination may be whether two crests are acting simultaneously on two pile members, or a crest and a trough. The wave length is often predicted from linear wave theory. Yet from observations we know that often the distance between successive wave crests is significantly less than predicted by this theory. Since wave length is not one of the parameters generally measured in the field, and since it would be exceedingly difficult to measure on a statistical basis by other than photographic means, an adequate method of estimation from wave period and/or spectrum information is needed.

The duration of wave conditions, and the number of waves of individual characteristics which can be expected over a given period of time are important for other than operational reasons. First, they enter into economic considerations, and determination of the degree of maintenance which one may expect, thus feeding into the economic analysis of a problem solution. Second, and this is again an area in which little work has been done, these numbers enter into structural fatigue determinations. Not enough is known about the failure of structures in the ocean because of fatigue. However, it must become a consideration when one approaches close limits of design, and considers the millions of waves to which any structure is subjected within a one-year period. For example, if one assumes that a structure is subjected to 10-second waves throughout the year, it is subjected to over 3 million of those waves in the year. Each of these causes stress reversals, and the cumulative effect may indeed lead to fatigure problems.

In some cases the shape of the wave may become important. Yet we have no really satisfactory way of measuring this, other than photographically or by visual estimation. Most measurements are made of the change in elevation of the water surface at a particular point, and this change reflects the wave shape only if the wave travels with little change in shape. Wave shape is of particular importance in applications where breaker conditions are used, and can materially affect wave forces and stability of structures, as well as wave runup. Prediction of shape change based solely on depth changes can be made, but the effects of winds and currents, and particularly the random combinations of different individual waves, cause problems.

And this brings me to the consideration of the so called freak or "rogue" waves. These waves form as the cumulative result of the superposition of a number of smaller waves occurring randomly, which at one instant reinforce each other to form a sort of "super" wave. When, very occasionally, all the individual crests combine at a single point, an extraordinarily high wave can form. Having formed, the individual components pass on, and the rogue wave disappears. It was such a wave that in April 1966 smashed into the Italian liner Michelangelo in the North Atlantic, at a time when general wave conditions were 25 to 30 feet in height.* Almost unbelievably, in terms of the average sea, this huge wave

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*"The Hazard of Giant Waves" by Dr. Richard James, In Mariner's Weather Log, July 1966.

crushed in bridge windows 81 feet above the water line, and caused massive damage to the bow d bridge structure.

These rogue waves can also be observed as tremendous lows or "holes" through the combination and superposition of a number of component wave troughs. Such a one all but sank the Queen Elizabeth during World War II when the bow plunged into a deep trough with the overriding crest smashing into the ship shattering bridge windows 90 feet above the water line, and washing the quartermaster from the wheel. The ships foredeck was hammered 6 inches below its normal level.*

A number of shipping disasters have occurred from such rogue waves, and some of these, along with a fuller description of the Queen Elizabeth damage, have been described in a recent (May 1974) Profile article in the New Yorker by Noel Mostert. An appendix "Freak Waves" by Draper in a 1967 book "Heavy Weather Sailing" by K. Adlerd Coles also discusses these, and that book shows some fascinating photos of heavy sea conditions. While such freak waves are primarily reported in terms of shipping, there is no question but what they can also affect coastal structures and, particularly, structures located in offshore waters.

The foregoing discussion of freak waves brings up another question of major engineering importance. That is the consideration of risk. In the application of wave data to engineering design, or to economic considerations, the engineer must weigh what risk he is willing to take from a safety standpoint, from an economic standpoint, and from an environmental standpoint. Quite obviously one does not apply the same degree of risk to design of a temporary beach cottage as one does to a nuclear power plant, although both may be subjected to the same wave climates. The engineer is learning more about these criteria in his coastal engineering applications, especially as a result of increased concern about environmental conditions. The latter are particularly related to applications with the oil industry (drilling, shipping, and transshipment through pipelines) and the nuclear power industry. However, risk affects to some extent almost every application within the coastal zone.

While I have emphasized the importance of wave climate, essentially every coastal engineering problem is faced with a second major consideration. That is the one of sand transport, whether it be along the shore, or in an on or offshore direction. But this sand transport which occurs, occurs as a result of wave action and the currents generated by that wave action. Tidal and wind currents affect this sediment transport, but in almost every case the main overriding cause is the action of the waves. The estimation of this sediment transport, when it is not known from direct measurements in that precise location, is dependent upon knowledge of wave climate. Methods of using the wave climate to obtain these estimates are available (as for example, in CERC's Shore Protection Manual** or by use of the littoral drift roses discussed by Walton and Dean***)

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*Supertankers" a Profile article by Noel Mostert in the New Yorker, 13 & 20 May 1974 .

** Shore Protection Manual, U. S. Army Coastal Engineering Research Center, 1973.

*** Application of Littoral Drift Roses to Coastal Engineering Problems" by T. L. Walton and R. G. Dean in Proc. Conference on Engineering Dynamics in the Surf Zone, Australia, 1973.

but the accuracy of the estimates obtained can be no greater than the accuracy of our knowledge of the wave climate.

In what I have had to say, I have not attempted to elucidate and itemize in great detail each area of application, much less the method of application, of wave data to coastal engineering problems. I have tried to give some feel of the importance of wave data, indeed the overriding importance of wave data, for coastal engineering considerations and to point out some of the types of application. There are difficulties in the gathering of data, the definition and analysis of the data, even the determination of what is needed in data, and, of course, the final application of the data to design and prediction. Often after the occurrence of some phenomenon and we have compiled and looked at all the data, we can explain why it happened the way it did. But it is difficult to predict in advance. Yet this is the engineer's job in design. He must use the best data and methodology he can, but the application still requires judgement.

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The importance of wave data for coastal engineering considerations is presented, including the gathering of data, definition and analysis of data, determination of the data needed, and the final application of the data to design and prediction. The importance and application of wave climate to the design of coastal structures are also discussed.

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