# CHAPTER 44

## WAVE RUN-UP IN FIELD MEASUREMENTS WITH NEWLY DEVELOPED INSTRUMENT

Heie F. Erchinger

Coastal Protection Department
D 2980 Norden/Ostfriesland, West-Germany
P.O.-Box 102

ABSTRACT

The height of dikes and other coastal structures can only be calculated after determination of the wave run-up. Several formulas for the calculation of wave run-up are developed after model tests as a rule. But the influences of scale effects and natural wind conditions are practically unknown. To clear these questions further investigations and especially field measurements should be carried out.

By measuring the markerline of floating trash on the slope of the seadikes the maximum wave run-up could be found out after four storm surges in 1967 and 1973. In two graphs it will be shown that on the tidal flats the run-up depends on the waterdepth. The run-up was higher than it could be expected after model tests of 1954.

With a newly developed special echo sounder the run-up could be measured in January 1976. The waves and the run-up could be registrated synchronously during two severe storm surges. As shown in Fig. 9 it was found a logarithmic distribution of the wave height, wave period and the higher part of the wave run-up. The found wave run-up is considerably higher than estimated before. The measured 98 % run-up is found about twice the computed value. That is an interesting and important result of the first synchronous recording of wave run-up on sea dikes.

## INTRODUCTION

For the design of dikes and other coastal structures and especially for the calculation of their height it is fundamental to determine the wave run-up. The run-up can be calculated with several formulas for different conditions relating to the wave characteristics, the steepness and the roughness of the slope and the position of the structure to the wave propagation direction. As a rule the equations are developed after model tests. But nature and magnitude of scale effects are practically unknown. Also the natural wind conditions are not accurately simulated.

As Professor Führböter has found that model tests with breaking waves do not provide quantitative transferable results, when they are carried out with usual model scales, further investigations are to be done. One way is to carry out field measurements.

## THE MARKERLINE OF FLOATING TRASH

Two methods of measuring wave run-up data in the field are usual and carried out at several places:

1. measurement of the markerline of floating trash and
2. visual measuring the run-up of the waves during the storm surge by men on the dike.

Field measurements of the markerline are carried out along the Eastfrisian coast of the German Bight, the south-eastern part of the North Sea. In front of the sea dikes the 5 to 8 km wide tidal flats and the range of sand islands are situated.

After four storm surges in 1967 and 1973 the markerline of the floating trash was measured on the sea dikes in 37 positions. The maximum wave run-up of each position during each storm surge followed from the difference between the storm tide water level and the markerline of floating trash, measured in a

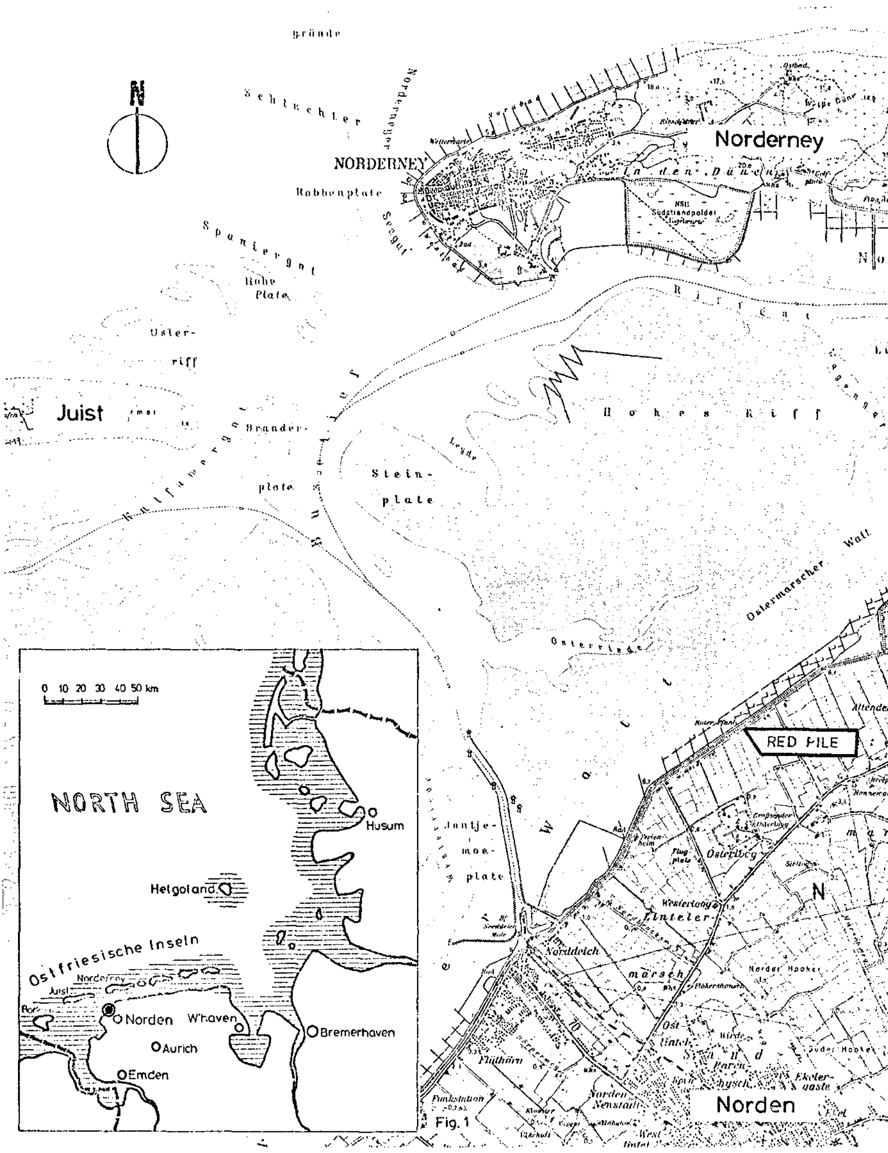
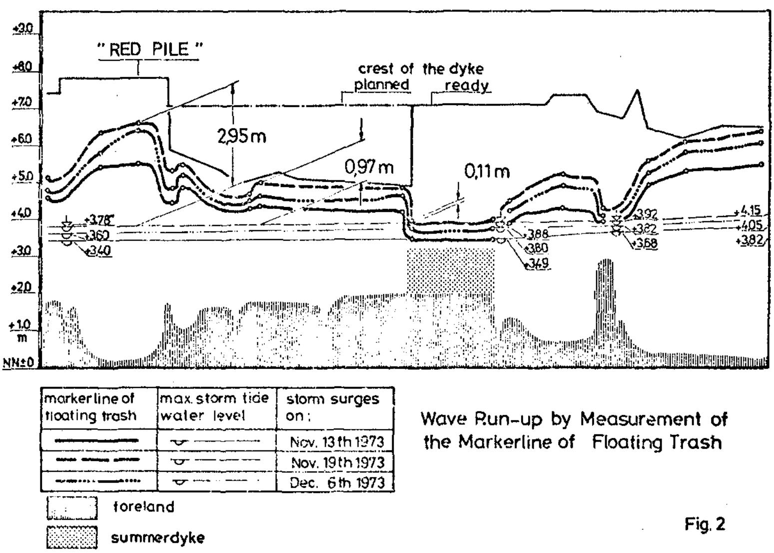



Fig. 1 LAY-OUT PLAN: POSITION "RED PILE" WITH THE TIDAL FLATS AND THE INLET BETWEEN THE ISLES OF JUIST AND NORDERNEY

perpendicular line. Fig. 2 shows the height of the markerline, the highest storm tide level in several locations and the height of the foreland or the tidal flat in front of the dike. It shows further that the markerline is simular to the reflected image of the section through the ground in front of the dike. In three different positions the values of wave run-up during the highest storm tide of this period on Nov. 19th 1973 are specially marked:

| | waterdepth near the dike | wave run-up |
|---|---|---|
| 1. dike without foreland position: "Red Pile" | 3.60 m | 2.95 m |
| 2. dike with 250 m wide foreland | 1.87 m | 0.97 m |
| 3. dike with 250 m wide foreland with a summer-dike, 0.57 m waterdepth on its crest | 1.87 m | 0.11 m |




Wave Run-up by Measurement of the Markerline of Floating Trash

Fig. 2

These data show the influence of the waterdepth near the dike and mark out the importance of the foreland and the summerdike in reducing the wave run-up and the wave-wash on the dike. The summerdike is a dike on the foreland with a height of approximately 1.5 m, which prevents the inundation of the land behind during lower summer storm surges.

As wave characteristics on the tidal flats depend on the waterdepth the run-up data were related to the waterdepth in front of the dike. They could not be related to wave data as no wave measurements are carried out on the Eastfrisian tidal flats during these storm surges in 1967 and 1973.

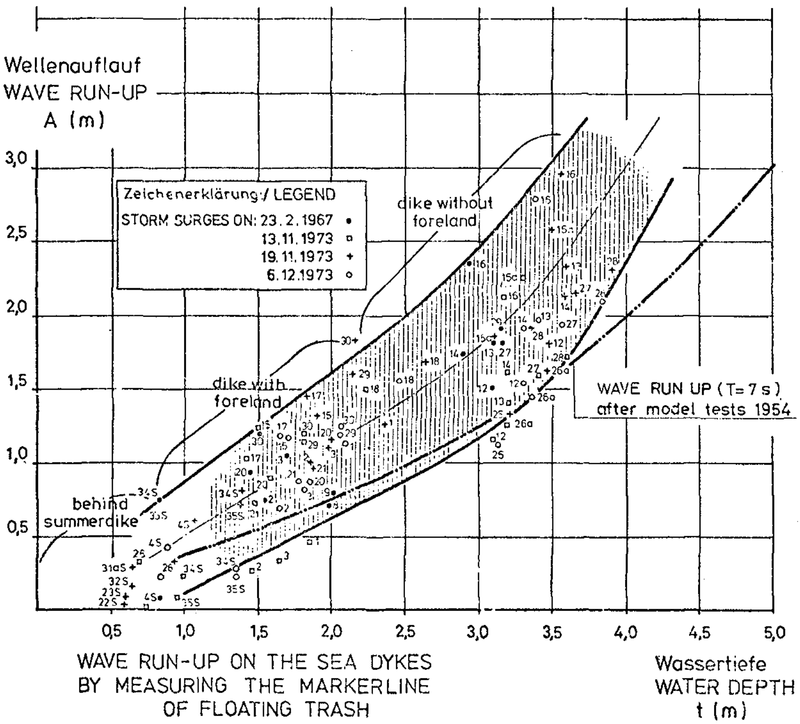



Fig. 3

The graph Fig. 3 shows the "wave run-up" dependent on the "waterdepth". Three groups of data are to be distinguished:

1) on dikes without foreland,
2) with foreland and
3) behind a summerdike on the foreland.

After researching the relation of the values of one place in the four storm-surges the bordering lines with most of the data between them were drawn. We found that wave run-up on the dikes behind a tidal flat with shallow waterdepth and the protection by a range of islands was higher than we could expect after model tests of 1954.

But this measuring of the markerline of floating trash only shows the maximum wave run-up and not the scattering of the values. But the variability is important to know for the determination of the 50 %, 98 % and other values. It is unfavourable, too, that in severe storm surges the trash will be thrown onto the crest or even onto the inside slope of the dike in some places. Sometimes the trash will be scattered by high wind velocities.

Therefore, further study of wave run-up by field measurements was necessary. It would be desirable to get wave and wave run-up data for several positions with different conditions during storm surges and to record synchronously the waves and the wave run-up in these positions.

## THE WAVE RUN-UP RECORDER

In December 1975 a special echo sounder record was mounted on the dike near the position "Red Pile". The Red Pile is situated on a dike without foreland, with a low tidal flat in front of it and comparatively high wave action during storm surges as the position lies in a distance of 8 km from the inlet between the isles of Juist and Norderney in south-eastern direction. The normal on the slope of the dike has a direction of approximately North-West, exactly 324 degrees to North.

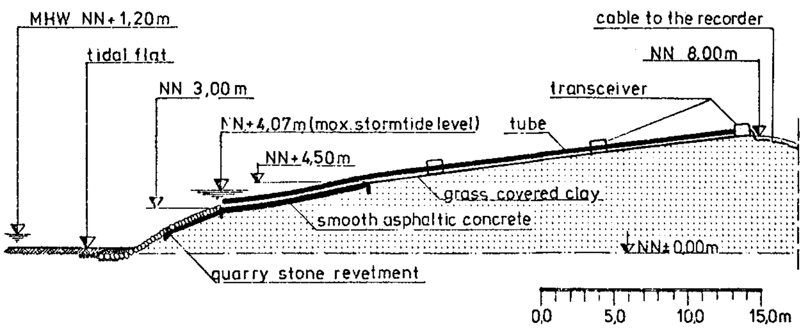



Fig. 4 Slope of a Seadyke with Instruments for Wave Measurement

The dike is covered with a revetment at the outer toe up to NN + 3.0 m that means 1.8 m above MHW, then a slope of smooth asphaltic concrete with an inclination 1 on 6 up to NN + 4.5 m and the upper part with grass covered clay up to NN + 8.0 m also 1 on 6.

Fig. 5 THE STEEL BOX WITH THE TRANSCEIVER AND THE TUBE WITH THE HOLES

The instrument consists of a waterproof steel box with the transceiver, a small stainless steel tube with a bore of 1 inch and 4 to 8 mm wide holes with a distance of 2 m between each other, and a recorder in a shed at the inside toe of the dike. The tube is fastened on the slope of the dike. Its length is limited at 12 m and, therefore, on the 30 m long slope the system was needed three times. Each second the echo sounder sends 3 pulses into the tube. The pulses are reflected at the non covered holes and each hole is registered in a separate line by the recorder. When the hole is covered by water of the wave uprush the registration is interrupted. The highest interruption shows the maximum run-up of the wave.

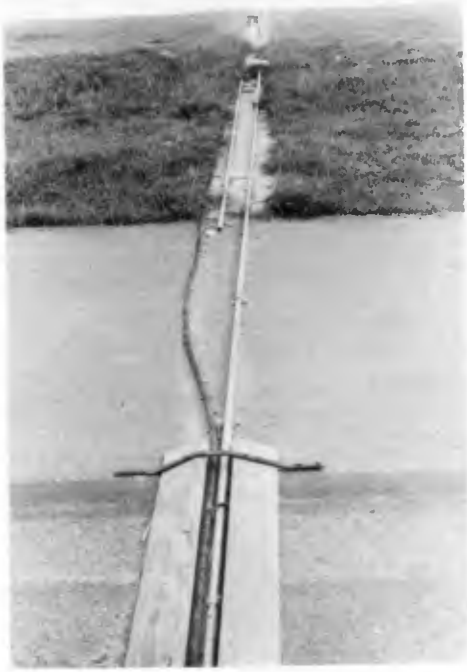


Fig. 6 STEEL BOXES AND TUBES FASTENED ON THE SLOPE OF THE DIKE

The echo sounder for wave run-up is combined with a supersonic echo sounder for wave measurement. Its receiver is mounted on a frameof steel and placed on the ground of the tidal flat in front of the dike with a distance of 50 m. The time interval between the generation of the sounding signal and the return of its echo after striking the bed is automatically recorded by the instrument and shows the waterdepth in that moment. The values of both instruments are transmitted by cable to the recorder in the shed inside the dike.

Fig. 7 THE "RED PILE" AND THE SHED FOR THE RECORDER

In the foreground the Red Pile, which formally has signed the border of two sections for the maintainance of the dike.

This wave run-up recorder and the wave recorder are developed by Dr. Fahrentholz in Kiel / West-Germany.

Another type of wave run-up recorder is developed by the Bundesanstalt für Wasserbau in Hamburg. At the lower side of the quadratic steel tube inductive approximity switches are mounted. When they are touched by the wave uprush they give an impulse to the recorder. As the instrument was mounted this year in springtime no results could be registrated by this recorder to date.

REGISTRATION IN JANUARY 1976

Therefore, only the before explained instrument was able to registrate wave run-up in the severe storm surges on January 3rd and 21st 1976. In these storm surges the water level increased 3 m higher than MHW due to wind set up. The following interesting values could be recorded during the hour of the highest water level at station "Red Pile".

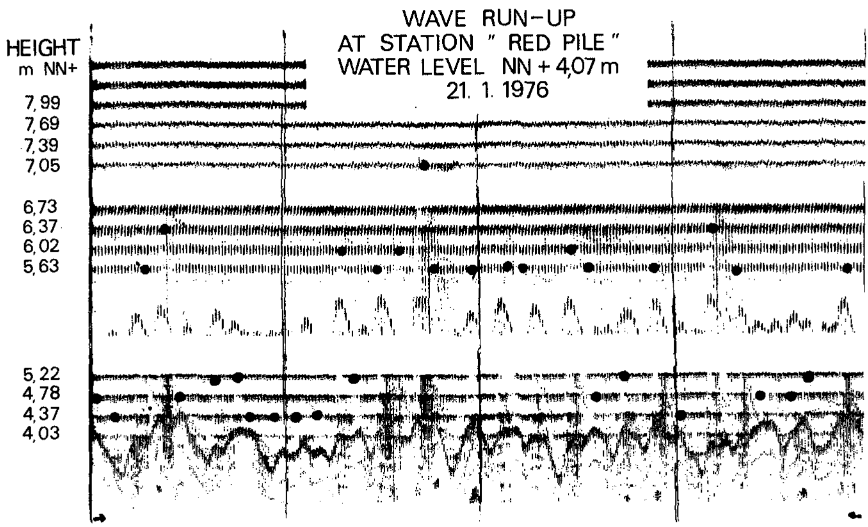



Fig. 8 RECORDING PAPER WITH REGISTERED VALUES

Fig. 8 shows the registration. Three pulses each second are reflected at the holes in the tube. After receiving the pulses they are recorded in a line. Three recording systems with the transceiver and the tubes with holes can be distinguished. As the tubes are open at the low end the water level in the lower tube gives echos, which are recorded too. The single wave uprushes on the slope cover the holes and hence follows an interruption of the line. The upper interruption gives the highest hole covered by that wave. Hence follows that the run-up reaches the following interval. The plotted black point marks the highest hole covered by water.

During both storm tides the wave run-up data were registered continually but we did not succeed in recording the waves during the high storm tide level without interruption following from two reasons:

1. By the strong movement of the water much silt and fine sand of the ground was kept in suspension and gave an echo which was recorded so that no clear echo of the waves could be distinguished. This trouble will be repaired by varying the transceiver.

2. Near Red Pile the radio station Radio Norddeich for ships broadcast is situated. By a strong radio long-wave transmitter the echos of the wave recorder are influenced and as during storms this transmitter is in action very often this second trouble is to be repaired by varying the transceiver.

From these teething troubles follows that only 40 % of the record of waves on January 21st could be analysed and we hope that this part gives a representative section. The wave run-up data have been registered without interruption.

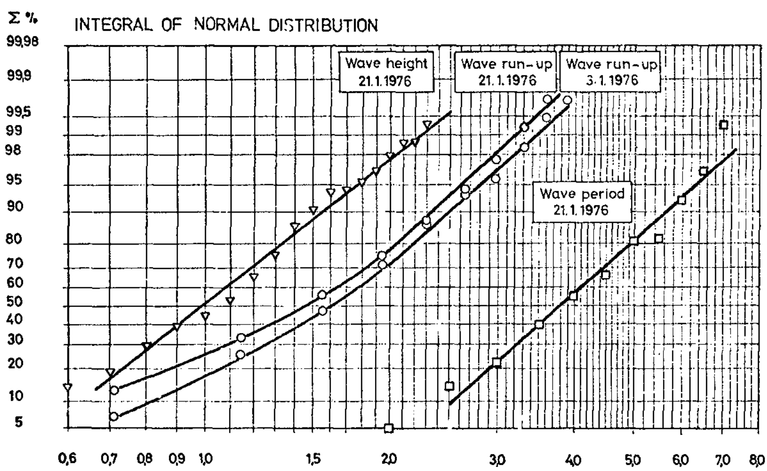



Fig. 9 FIELD MEASUREMENTS OF WAVES AND WAVE RUN-UP AT STATION " RED PILE "

FIRST RESULTS

Fig. 9 shows the analysis of the wave run-up and wave recording during the hour of highest water level. The data of the run-up are prepared after the method of WEIBULL. The curves are plotted with abscissa representing the logarithm of the data of wave height, wave run-up and wave period and with ordinates representing the integral of normal distribution. As the curve of wave height and period approximately follows a straight line we find a logarithmic distribution. The higher part of the run-up data follows a straight line too; only the lower part follows a curve becoming flatter to the low end.

Local conditions at station Red Pile:

Slope of the dike : smooth asphaltic concrete up to NN + 4.5 m; the upper part: grass covered clay; inclination 1 on 6

| | Jan. 3rd | Jan. 21st |
|---|---|---|
| Storm tide mean high water level during measurement | : NN + 4.07 m | NN + 4.07 m |
| Waterdepth in front of the dike | : ~ 4.0 m | ~ 4.0 m |
| Angle of incidence of waves | : ~30 degrees | ~30 degrees |
| Wind conditions (Beaufort force) | : W 10 - 11 | W 9 - 10 |

The main data are:

Wave run-up (m)

| | | | | |
|---|---|---|---|---|
| | angle of incidence | | | |
| | 30 degrees | | reduced to rightangled (115 %) | |
| | Jan. 76, 3rd | 21st | 3rd | 21st |
| max. wave run-up | 3.80 | 3.50 | 4.35 | 4.05 |
| 98 % " " " | 3.20 | 2.95 | 3.70 | 3.40 |

sign. wave height Jan. 21st: $H_s = 1.44$ m ($H_m = 1.07$ m)

sign. wave period Jan. 21st: $T_{Hs} = 4.9$ s ($T_m = 3.9$ s)

The found wave run-up is considerably higher than estimated before, even with the probable maximum water level, which is 1.3 m higher than the storm tide level during the measurements.

And at the end an example, controlling some of the numerous formulas for wave run-up:

HUNT VINJE:

$$Z = 1.56 \cdot \sqrt{H_s} \cdot T_{Hs} \cdot \frac{1}{n} = \underline{1.53 \text{ m}}$$

BATTJES:

$$Z_{0.98} = 2.3 \sqrt{H_s} \cdot T_m \cdot \frac{1}{n} = \underline{1.79 \text{ m}}$$

DELFT:

$$Z = 8 H_s \cdot \frac{1}{n} = \underline{1.92 \text{ m}}$$

In fact we measured a 98 % run-up, reduced to rightangled incidence of

$$Z_{0.98} = \underline{3.4 \text{ m}},$$

that is wellrounded about twice the computed value.

That is an interesting and important result of the first synchronous recording of wave run-up on sea dikes. Further investigations will be necessary in several positions with different wave conditions on dikes with foreland and without foreland.

REFERENCES:


| | |
|---|---|
| Dette, H.H. | Wellenmessungen und Brandungsuntersuchungen vor Westerland/Sylt<br>Mitt. d. Leichtweiß-Instituts, Heft 40, Braunschweig 1974 |
| Erchinger, H.F. | Land Reclamation and Groin-Building in the Tidal Flats<br>Proc. 12th Coastal Engineering Conference,<br>Washington 1970, Vol. II |
| Erchinger, H.F. | Küstenschutz durch Vorlandgewinnung, Deichbau und Deicherhaltung in Ostfriesland,<br>"Die Küste", Heft 19, 1970 |
| Erchinger, H.F. | Wellenauflauf an Seedeichen - Naturmessungen an der ostfriesischen Küste.<br>Mitt. d. Leichtweiß-Instituts, Heft 41, Braunschweig 1974 |
| Franzius, L. | Wirkung und Wirtschaftlichkeit von Rauhdeckwerken im Hinblick auf den Wellenauflauf<br>Mitt. d. Franzius-Instituts, Heft 25, Hannover 1965 |
| Führböter, A. | Der Druckschlag durch Brecher auf Deichböschungen<br>Mitt. d. Franzius-Instituts, Heft 28, Hannover 1967 |
| Führböter, A. | Air Entrainment and Energy Dissipation in Breakers<br>Proc. 12th Coastal Engineering Conference,<br>Washington 1970, Vol. I<br>German draft: "Die Küste", Heft 21, 1971 |
| Hensen, W. | Modellversuche über den Wellenauflauf an Seedeichen im Wattengebiet<br>Mitt. d. Franzius-Instituts, Heft 5, Hannover 1954 |
| Siefert, W. | Über den Seegang in Flachwassergebieten<br>Mitt. d. Leichtweiß-Instituts, Heft 40, Braunschweig 1974 |
| Technical Advisory Committee on Protection against Inundation | Wave Run-up and Overtopping<br>Government Publishing Office<br>The Hague, Netherlands 1974 |