Permanent International Association of Navigation Congresses

Association Internationale Permanente des Congrès de Navigation

XIXth International Navigation Congress

XIXe Congrès International de Navigation

LONDON - LONDRES
1957

Section II

OCEAN NAVIGATION

NAVIGATION MARITIME

Communication 1
S. II - C. 1

Origin and effects of long period waves in ports

Ondes de longue période dans les ports.

Paper by

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S. II - C. 1

PAPER

by

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ORIGIN AND EFFECTS OF LONG PERIOD WAVES IN PORTS.

1. Ports and tide gauges, mentioned in this paper.

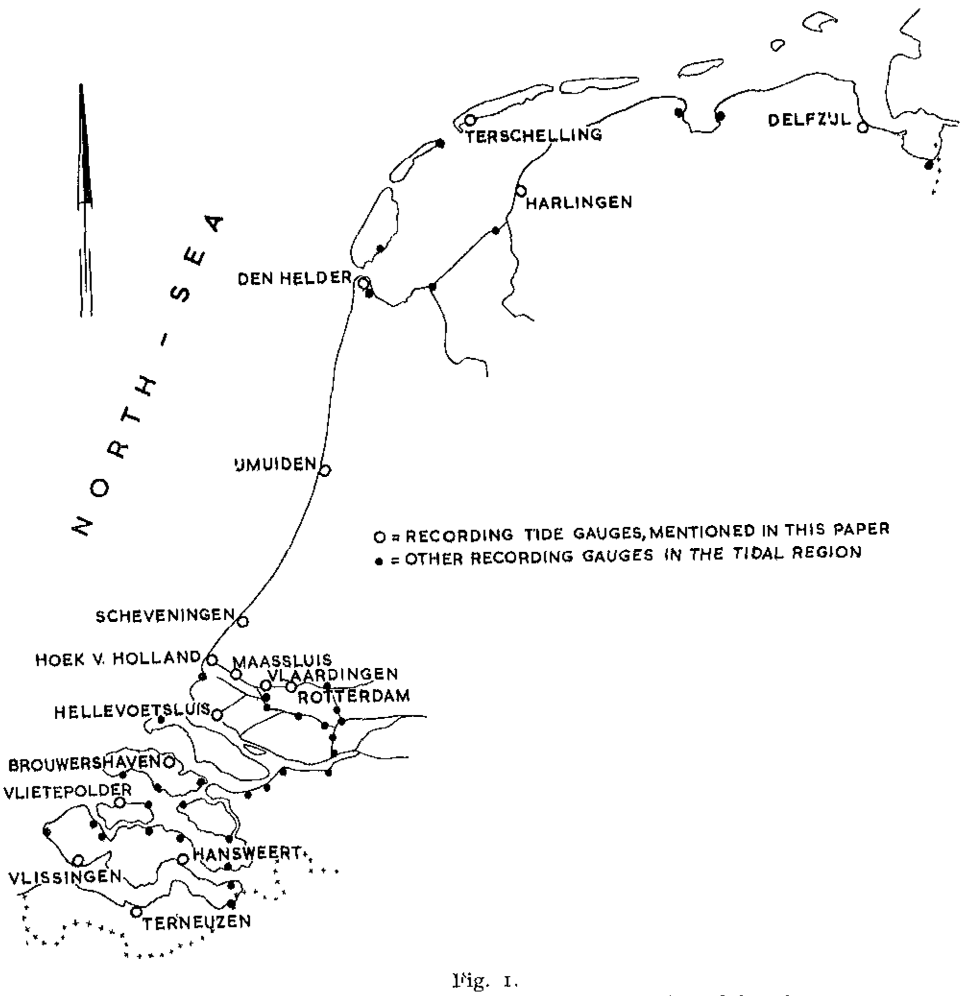


Fig. 1.

Situation of the Dutch coast and self-recording tide gauges in the tidal region.
Plan de situation de la côte néerlandaise et emplacement des marégraphes auto-enregistreurs dans la région soumise aux marées.

(Recording... = Marégraphes enregistreurs mentionnés dans ce rapport.
Other... = Autres enregistreurs dans la région soumise aux marées).

Holland has a North Sea coastline of 400 km in length. Various ports are situated along this sea and along estuaries and shallow border seas. This whole region is exposed to normal tides of a semi diurnal lunitidal character, to wind waves generated at sea and to storm tides.

Moreover, long period waves occur with periods of between a few minutes and 60 to 70 minutes.

The last category of waves is surveyed and examined in this paper.

Data are mainly derived from tidal diagrams recorded by self recording tide gauges. In the region described there are water level gauges provided with float driven recorders.

The shaft formed cellar underneath the tide gauge cabin is connected to the sea or river by culverts below lowest low water. The culvert section is chosen in such a way that winds (waves at the Dutch coast with periods of 6 to 8 seconds during a storm and with 10 to 12 seconds during a hurricane) are not recorded.

The situation of the tide gauges mentioned in this paper is shown in fig. 1.

2. Harbour seiches.

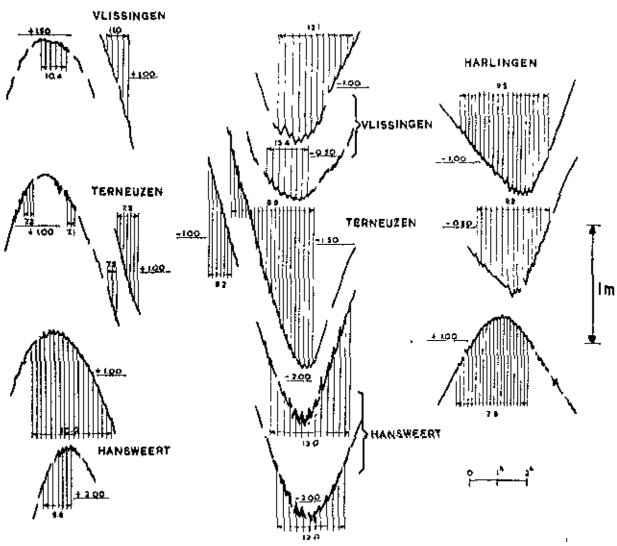


Fig. 2.
Harbour seiches at Vlissingen, Terneuzen ,Hansweert and Harlingen.
Seiches dans les ports de Flessingue, Terneuse, Hansweert et Harlingen
(Tide gauge = Marégraphe).

Only 9 of the tide gauges in the tidal region are situated in harbours in such a way, that they are able to inform about harbour oscillations.

Fig. 2 gives samples of such harbour seiches occurring in the harbours of Harlingen, IJmuiden, Vlissingen, Terneuzen and Hansweert. The three last mentioned are situated along the same estuary; the Wester Schelde. The different periods clearly indicate the profound difference between harbour seiches and long period oscillations generated at sea.

Shape and scale of these five harbours and the location of the tide gauges are reproduced in fig. 3.

Harbour seiches, shown in fig. 2, often occur during stormy as well as during rather quiet weather.

Frequently these oscillations are extremely persistent. Sometimes 20 of these oscillations in succession can be observed. They are keeping water level in a perfectly regular oscillation. They are entirely independent of undulations of the estuary. Of course the first impulse comes from the river or from the sea. Especially when the wind is blowing, such disturbances are continuously generated.

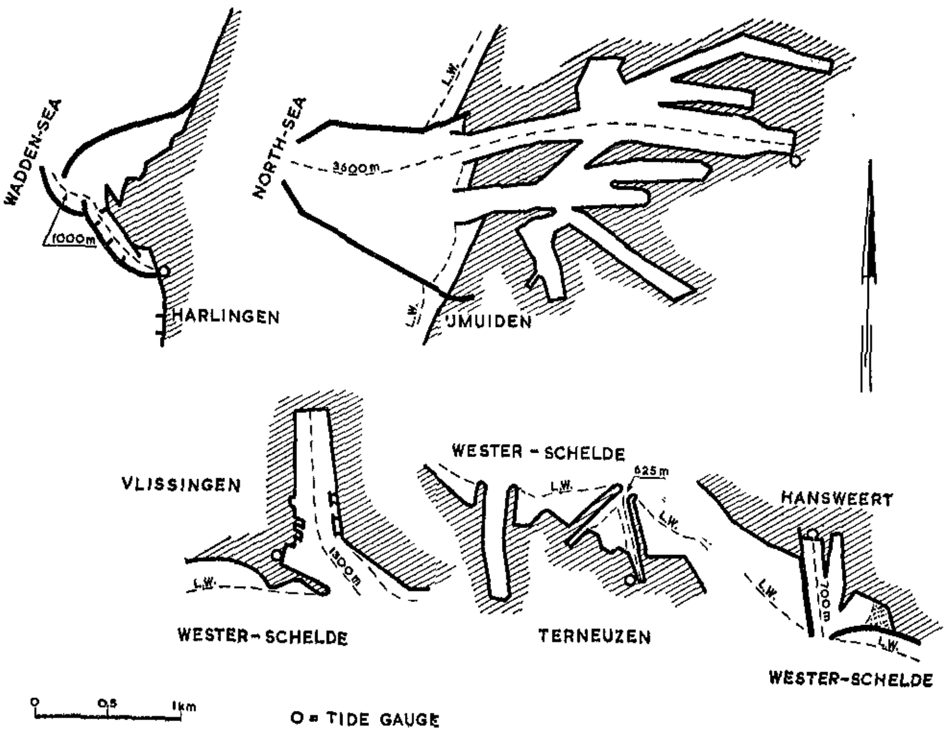
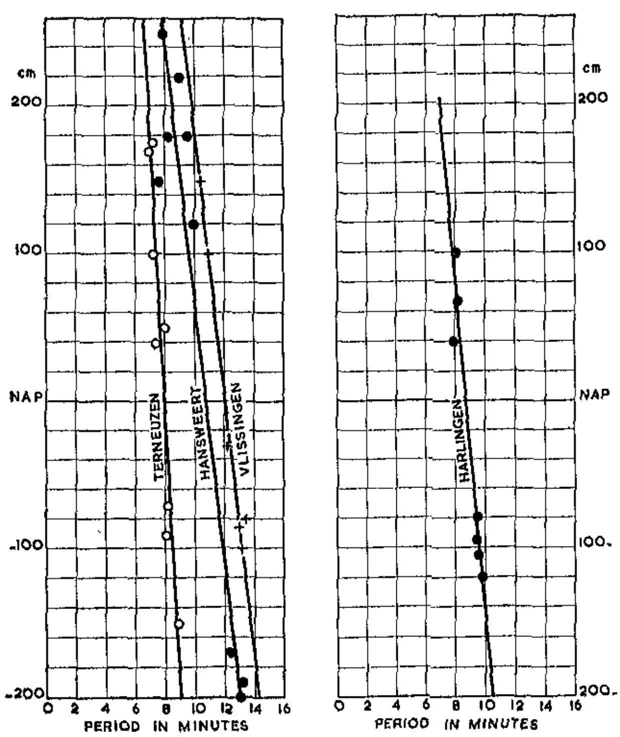


Fig. 3.
Harbours of Harlingen, IJmuiden, Vlissingen, Terneuzen, Hansweert.
Les ports de Harlingen, IJmuiden, Flessingue, Terneuse, Hansweert.



In by far most cases harbour seiches are not kept up by external effects. They are nearly always found too in small scale models. But in such models the wave machine never generates waves of periods similar to those of harbour seiches.

Harbour seiches in small scale models are generated by the small disturbances and irregularities. And so it is in reality.

The periods of seiches have been detected as a function of the momentary water level.

Fig. 4.
Periods of harbour seiches as a function of the water level.
Périodes des seiches des ports en fonction du niveau d'eau.

Results are plotted in fig. 4. The water levels related to N.A.P. (approximately mean sea level) are abscissae, the mean periods of the oscillations (fig. 2) are ordinates.

It shows two important characteristics of harbour seiches. In the first place the periods of the 3 harbours along the Wester Schelde differ considerably. At the mean water level (approx. N.A.P.) these periods are :

Vlissingen 12 minutes.
Terneuzen 8 minutes.
Hansweert 11 minutes.

It will be clear, that the characteristic periods of these oscillations are neither generated on sea nor caused by longitudinal oscillations of the Schelde.

Of course, it is true, the oscillations are first started by a disturbance coming from the sea or the Schelde bringing about free oscillations of each harbour in the own period. It should be noted that measuring points are strikingly situated on a straight line in fig. 4.

So a strong dependence on water level and consequently on depth exist when D and aL are the hydraulic depth and the oscillatory length of the harbour, then the period T of a free oscillation having its mode at the entrance and its loop at the end, will be given by the formula :

$$T = \frac{4\ aL}{\sqrt{gD}}$$

The factor a grows according to the area of the harbour, participating in the oscillatory movement.

The slope of the straight lines in fig. 4 gives direct information about D and aL, without any detailed knowledge of the harbour.

Out of fig. 4 can be read period T_{+2} belonging to a depth of D + 2 m as well as T_{-2} belonging to a depth of D — 2 m. Both values of T being related to each other by the formula :

$$\frac{T_{+2}}{T_{-2}} = \sqrt{\frac{D-2}{D+2}}$$

Out of this D can be calculated and can be used to calculate aL :

$$aL = 1/4\ T\ \sqrt{gD}$$

The values of D and aL thus calculated are reproduced in the table below. The table contains furthermore the depth of the navigable channel, of course considerably larger than the hydraulic depth D, and the distance L between the harbour entrance and the closed end of the basin.

	T_{+2} (min)	T_{-2} (min)	D (M)	aL (M)	depth in navigable channel(m)	length of basin L (m)
Vlissingen . .	9,8	14,3	5,70	1.350	8,5-13	1.300
Terneuzen. . .	6,9	9,0	7,70	1.050	5,50	625
Hansweert . .	8,5	13,0	5,00	1.150	6,25	700
Harlingen . .	7,0	10,2	5,50	950	6,40	1.000

In Vlissingen and Harlingen the value of a is nearly equal to 1. In Terneuzen and Hansweert a is about 2, due to the areas of the harbour, participating in the oscillatory movement.

As a rule the amplitudes of harbour seiches don't exceed a few centimetres. By way of exception they may rise to 15 or 20 cm as a maximum. Inconveniences for navigation or loading and discharge, as far as I know, have never been noticed. It is almost certain that no control of harbour seiches or means of limiting its effects in any harbour have ever been considered or carried out in Holland.

It is evident, however, that harbour seiches increase the exchange of water between river and harbour basin.

Silting up of the harbour basin may be accelerated. This has been observed in practice as well as during small scale experiments.

Whereas the reduction of water exchange is one of the principal purposes of design, the harbour seiches give rise to no new problems.

3. **Long period waves on the Rotterdam Waterway.**

Besides harbour seiches long period oscillations of quite another character are observed on the Dutch coast. They are generated at sea, as will be demonstrated.

The general characteristics of the long period waves may be described by the tidal diagrams, recorded during the storm tide of December 30-31, 1943, reproduced in figures 6, 7, 8 and the storm tide of December 29-30, 1942, reproduced in fig. 9.

Fig. 5 shows tidal diagrams recorded at 4 stations along the Rotterdam Waterway during the storm tide of December 30-31, 1943. Oscillations from the sea with amplitudes of 20 cm reach the tide gauge at Hook of Holland. These

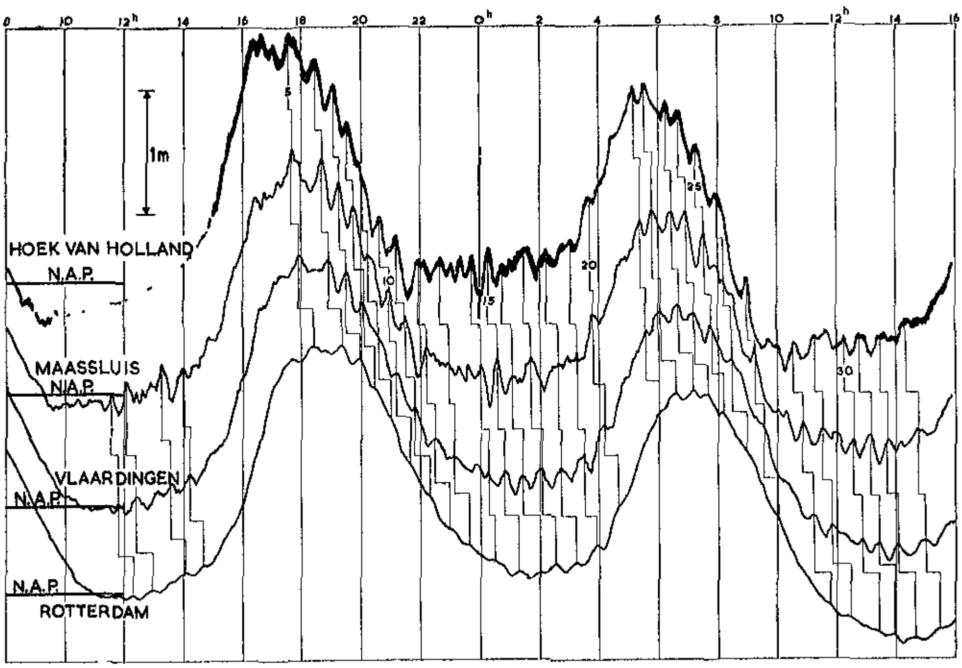


Fig. 5.

Storm tide, December 30 - 31, 1943. - 33 oscillations of the sea move as independent phenomena from sea to Rotterdam, distance 31 km.

Marée-tempête du 30 - 31 décembre 1943 - 33 oscillations de la mer se déplacent comme phénomènes indépendants de la mer à Rotterdam, soit sur une distance de 31 km.

oscillations show a remarkable regularity, especially between 5 p.m. and 10 p.m. on December 30th and between 6 a.m. and 10 a.m. on December 31st. This regularity is similar to that of harbour seiches. In this case, however, it is out of question, for the tide gauge station at Hook of Holland is established in the river, beside a straight bank.

The tide gauges at Maassluis, Vlaardingen and Rotterdam are also situated in the river and here harbour seiches are quite impossible too.

Corresponding wave crests are connected by means of shifting lines. Thirty-three clearly visible waves occurred during a 28 hour term. The individual course up the river of each of these can be traced. The time of transmission from Hook of Holland to Rotterdam appears to be a function of the water level. As an average 59 min is measured. The mean water level during the term concerned was 0.70 M + N.A.P.

The hydraulic depth at N.A.P. can be calculated from the formula :

$$\sqrt{g\ (D + 0.70)} = \frac{\text{distance Hook of Holland-Rotterdam}}{\text{time of transmission}} = \frac{31260\ \text{M}}{59 \times 60\ \text{sec}}$$

$D = 7.25$ m.

The wave velocity at N.A.P. level is :

$$u = \sqrt{gD} = 8.4 \text{ m/sec.}$$

It is noteworthy that wave velocity of these long period oscillations exceeds those of the tidal motion. It is shown in the table below. The times of transmission for the distance Hoek of Holland-Rotterdam are :

Long period waves	62 min.
M 2 tide 53° or	110 min.
High water	109 min.

4. Similar oscillations along the whole coast.

Fig. 6 shows an arbitrary term of 12 hours (8 p.m. on December 30th until 8 a.m. on December 31st) of the storm of December 1943. Tidal diagrams of 9 tide gauge stations, spread along the 400 km coast line are reproduced.

These graphs induce to the following views :

a) All diagrams show long period oscillations; however, the amplitudes of the stations in the West of the country are much larger than those in the North Of course this can be explained by the fact, that it is almost impossible even for long period sea waves to reach stations such as Harlingen and Delfzijl.

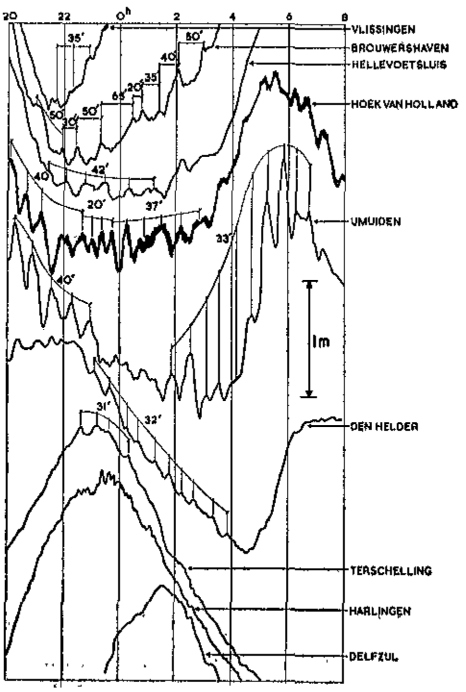


Fig. 6.

Simultaneous tidal diagrams of the storm tide of December 30/31, 1943. — 9 tide gauge stations equally spread along the North sea coast.

Diagrammes de marée simultanés de la marée-tempête du 30/31 décembre 1943 — 9 stations marégraphes disposées à des distances égales le long de la côte de la mer du Nord.

b) The figures in the graph represent the periods of many individual waves. They range rather arbitrarily between 20 minutes and 65 minutes. The average of all periods amounts to approx. 35 minutes.

c) It is important that sometimes these oscillations may fall in a total arbitrariness of succession, as shown in the diagram of Brouwershaven. On the other hand the oscillations may have a remarkable regularity.

For instance the tide gauge of Hellevoetsluis shows a series of 5 wave periods of 42 minutes; Hook of Holland 4 waves of 40 minutes period and 5 waves of 37 minutes period; IJmuiden has 4 periods of 40 minutes and 9 periods of 33 minutes; Den Helder has 9 periods of 32 minutes.

d) Practically no correlation at all can be shown between the periods recorded in one tide gauge station and periods recorded in stations to the South or to the North of the station concerned. In respect of the amplitudes, no correlation can be shown either.

Besides this sample there are many others. They all prove clearly that this second kind of long period oscillations (periods roughly speaking between 25 minutes and 50 minutes) are generated on the North Sea.

Meanwhile the phenomenon concerned shows yet an extra accent at IJmuiden. Long period waves occur frequently at IJmuiden. The amplitudes are often larger than at other places or harbours. Among experts they have a certain reputation and they are considered to be harbour seiches of this extensive harbour.

The records reproduced along the whole coast however make it clear that the oscillations in IJmuiden have a quite different character from those mentioned in para. 2 harbour seiches.

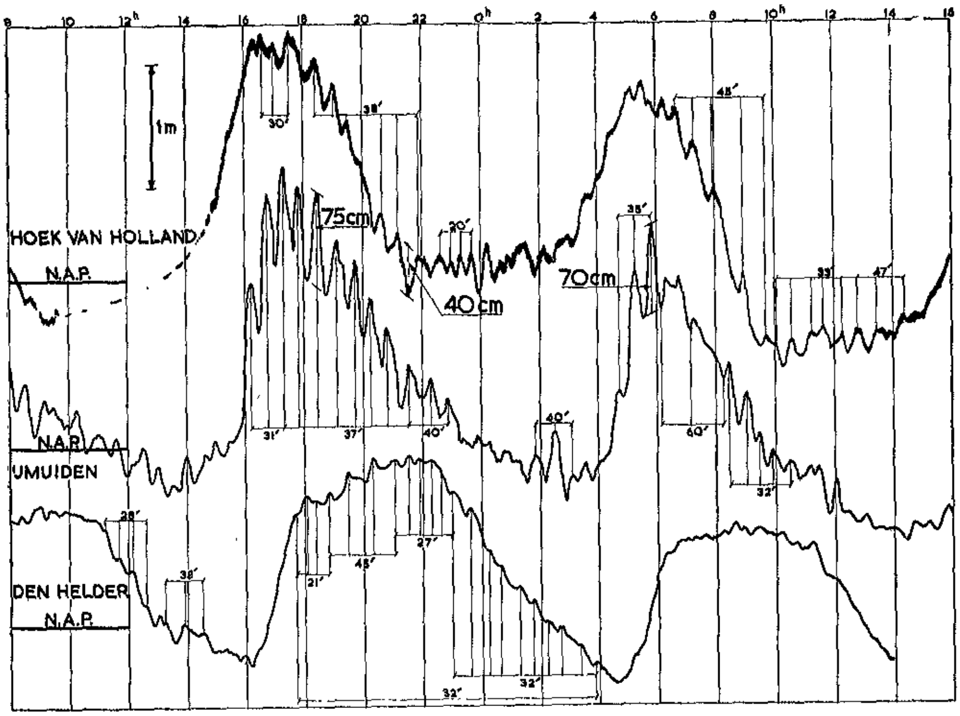


Fig. 7.
Striking oscillations of the sea at Hoek of Holland, IJmuiden and den Helder — Storm tide December 30/31, 1943.
Oscillations remarquables de la mer à Hoek van Holland, IJmuiden et den Helder — Maréetempête du 30/31 décembre 1943.

In the record of the tidal impulse at IJmuiden during the storm of December 30-31th, 1943, the extremely regular and powerful series of long period waves between 4 p.m to 10 p.m. attracts attention. Anyone, looking at the waves at IJmuiden apart from other phenomena, would be inclined to consider these waves to be powerful harbour seiches.

Comparing the record at IJmuiden with those between 4 p.m. and 10 p.m. at Hook of Holland, we find here too a strong and pronounced series of oscillations. The manner in which these waves moved up the Rotterdam Waterway to Rotterdam is shown in fig. 5.

Even the periods at IJmuiden and Hook of Holland are practically equal, namely 38 minutes as an average of 6 waves at Hook of Holland and 37 minutes as an average of 7 waves at IJmuiden. These facts unambiguously show, that the extreme regularity of the waves at IJmuiden cannot be put down to the ground plan or the dimensions of the harbour there.

One would be inclined to give identity to 7 waves of a 36 minute period at Hook of Holland and 7 waves of a 37 minute period at IJmuiden. Fig. 7 is a warning to be careful enough not to do so. At IJmuiden the series in question is preceded by 2 waves, whereas at Hook of Holland a wave period of nearly one hour occurs. On the other hand the diagram of Hook of Holland shows a powerful oscillation at midnight, in the mean time the sea at IJmuiden is relatively quiet.

It is worth mentioning that the mean value of all measured periods in these diagrams amounts to approx. 35 minutes. The wave heights of the largest waves at IJmuiden are 75 cm. The amplitudes at Den Helder are much smaller. This may be caused by the situation of the tide gauge along the Marsdiep which is a junction channel of North Sea and Waddensea. The oscillations of the North Sea are rapidly reduced to nothing in the Waddensea.

Another instructive example of long period waves is reproduced in fig. 8.

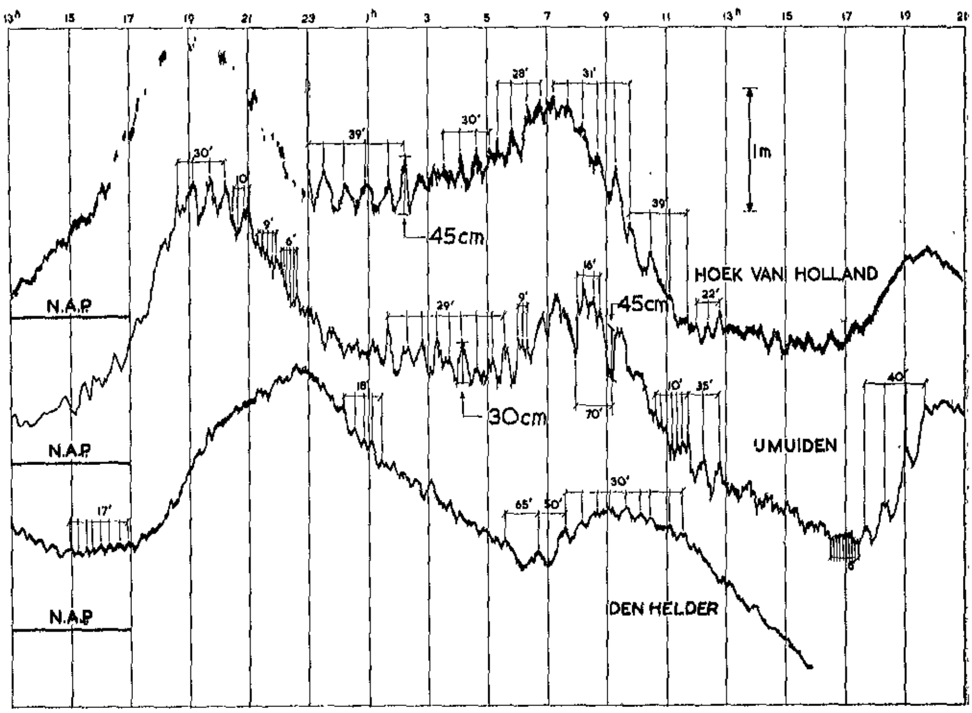


Fig. 8.

Long period North Sea waves during the storm tide of December 29/30, 1942.
Ondes de longue période sur la mer du Nord pendant la *marée-tempête* du 29/30 décembre 1942.

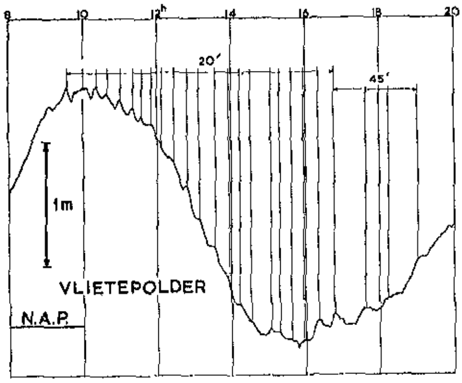


Fig. 9.
Diagram of tide gauge at Vlietepolder situated at a straight coast.
Diagramme du marégraphe de Vlietepolder, *situé sur une côte droite.*

Many periods are to be observed. The number of short periods surpasses that of the storm tide of 1943. Attention is drawn to the series of powerful oscillations between 11 p.m. and 3 a.m. at Hook of Holland, coïnciding with a rather quiet period at IJmuiden. The same facts occur in the period between 2 p.m. and 5 p.m. on December 30th. On the other hand IJmuiden shows some very regular waves between 5 p.m. and 8 p.m. on December 30th, whereas Hook of Holland shows a diagram without long period waves.

Finally an example is given of North Sea waves, recorded by a pneumatic self recording tide gauge at Vlietepolder, fig. 9.

This gauge is situated on the shore line of a straight coast where it is impossible to ascribe the oscillations to any effect of harbours.

In this case amplitudes are only 5 to 10 cm. Between sea and tide gauge there is an area of vast sand banks being responsible for the reduction of the oscillation coming from the open sea.

5. Resonance at IJmuiden.

The harbour of IJmuiden (fig. 3) is a complex of channels and basins. The outer harbour has harbour seiches of approximately 6 minutes with amplitudes of a few centimetres. The largest distance in this harbour as a whole, from the heads of the piers to the outer gates of the famous lock, amounts to 3,6 km. It might be this length that is brought into oscillation by the long period waves of the sea.

From the records of many tide gauges, the period of the oscillation of the sea can be calculated to be about 35'. This period has shown itself independent of any harbour or basins. The periods in IJmuiden too are approx. 35' and obviously of the same origin. The amplitudes, however, are often very large. It is clear that some resonance is due to this. Perhaps the resonance is not critical. But as far as can be seen the proper period of the harbour seiches is just the same as the mean value of the North Sea oscillations.

In our case the result of resonance is a large amplitude. The mean period of 80 selected waves of large amplitudes (i.e. waves in good resonance) proved to be 36'. The mean value of 720 unselected waves was 35'. So there is no reason whatsoever to suppose that the own period of the harbour of IJmuiden will be different from that of the North Sea oscillations.

So it may be admitted that the amplitudes of the oscillations of the sea, reinforced by favourable resonance circumstances, are recorded at the tide gauge near the outer gates of the great lock. In this case one should not consider the long period waves as harbour seiches as is done in para. 2 for Vlissingen, Terneuzen, Hansweert and Harlingen. In these harbours the seiches are independent oscillations. They show among other things a particular regularity.

At IJmuiden, however, regularity appears only when the oscillations of the sea show occasionally equal and regular periods. Continued oscillation in a free period seems practically to be absent. Presumably the ground plan of the harbour is unfavourable for a 35 minute period. Probably the *decrement* is rather strong. Nevertheless these oscillations at IJmuiden may amount to a wave height of 75 cm (1943) whereas the wave height at Hoek of Holland does not exceed 40 cm.

6. Squalls as a cause of oscillations of the sea.

In paragraphs 3 and 4 it is shown that long period waves generated on the North Sea reach the coast during stormy weather. Periods may range from 25 to 50 minutes. Succession of oscillations is generally chancy. Direct correlations of the long period waves observed at different tide gauges are absent.

It is obvious to suppose that the horizontal extensiveness of the oscillations is not very great. The order of magnitude may be smaller than 30 km.

The origin of these oscillations may be caused by squalls during storms. It is a well-known fact that wind velocities during storms show no stable character. Besides rapid changes of gusts there are slow pulsations called squalls. They are connected to the instability of the movement of the air and the more or less periodic penetration of air masses of faster velocities from higher layers of air to the level of the sea. The arbitrariness in the succession of oscillations of the sea level, according to intensity as well as period, is in good concordance with this.

The existance of remarkably regular and persistent waves, as shown, is a surprising element. As a matter of fact macroscopic waves between higher layers of air and lower ones of a natural period of 25 to 50 minutes are possible. At slow velocities of wind undulations are general. Different cloud formations make this evident.

7. The significance of the long period waves described for the Dutch harbours.

In Holland harbour seiches are only known to scientists from laboratory experiments and from tidal records. But practically in all Dutch harbours they are of little importance. Maritime navigation authorities and harbour administrations pay no attention to them. Measures to diminish harbour seiches and to remove harmful effects have never been considered or taken.

Oscillations of the sea as described in this paper are till now unknown. At least they have never been observed as such. Sometimes oscillations are considered to be an unbreakable part of a gale. A limited number of persons have knowledge of these waves, which in the case of IJmuiden however, are considered to be harbour seiches. No works have been carried out nor measures taken to diminish the oscillations.

This examination of the oscillations of the sea may be of significance, exactly with regard to the port of IJmuiden. The construction of one or two new piers has been planned. To establish the ground plan of the harbour entrance, extensive laboratory research will be necessary. Small scale models often show harbour seiches in a clear way. If free oscillations only were considered in the present situation, then deceptive conclusions might be drawn in a future ground plan. It is clear that these long wave periods must be included in the initial undulation generated in the small scale model.

In changing the ground plan of the harbour entrance, alterations may be caused in the resonance possibilities. Energy of the long period waves may be able to enter the harbour complex with more or less difficulty. The use of exact figures about these oscillations of the sea in respect of design and laboratory research, will be the first case of this character in the history of Dutch sea harbour planning.

RÉSUMÉ

L'auteur traite des seiches dans les ports néerlandais. Ces seiches sont bien provoquées par des mouvements du niveau de la mer, mais ne sont pas entretenues par eux. A côté de ces mouvements, il existe de nombreuses oscillations du niveau de la mer, certaines ayant un caractère régulier, de période de 20' à 60' — moyenne 35'. Elles sont signalées tout le long de la côte. Elles ont une hauteur atteignant 20, même 40 cm. A IJmuiden, le port entre en résonance avec ces oscillations de la mer. La période moyenne est de 35', et les hauteurs de l'onde atteignent quelquefois 75 cm.