Uninodal Seiches in the Oscillation System Baltic proper — Gulf of Finland

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Abstract

Seventeen cases of regular sea level oscillations with at least four distinctly developed periods recorded at Hamina (Fredrikshamn) in the east part of the Gulf of Finland during the years 1952—1954 were selected and the period corresponding to the maximum amplitude computed numerically. The results show that this period is fairly constant with an average of 26.2 ($\pm$ 0.2) hours. Sea level records at Władysławowo on the Polish coast confirm this period as a uninodal seiche in the oscillation system Baltic proper—Gulf of Finland.

In the paper is also discussed the possible occurrence of transversal oscillations in the Gulf of Finland and the probability of the participation of the Bay of Kiel at the named seiches in the Baltic.

1. General survey

WITTING (1911) was the first to determine an approximate value for the oscillation period of a standing wave in the Baltic proper and the Gulf of Finland. He based his computations on a number of theoretical assumptions and different simplifications of the bottom profile, getting for the particular cases considerably deviating results. The final conclusion made by Witting was that the period of the uninodal oscillation amounts to about 28—31 hours, a result which must be considered a comparatively good approximation. After a lapse of 30 years NEUMANN (1941) took the problem up again, trying to solve it on the one hand with the aid of selected representative sea level records, on the other hand, and this is the most important part of his paper, on the basis of extensive calculations involving the numerical methods developed by DEFANT (1918) and HIDAKA (1936). These two methods require an exact knowledge of the size and depth of the sea basin. The correspondence between the individual results attained at by Neumann in different ways is surprisingly good. Thus, the average value of the oscillation period for the Baltic including the Gulf of Finland determined from sea level records amounts to 27.6 hours, while theoretical calculations on the basis of the two methods mentioned above gave 27.5 hours. The principal condition for the reliability of this value is, however, the assumption that the Baltic is enclosed in the south-west at the Fehmarn Belt.

The results of Neumann's calculations are without doubt excellent, however, a few factors influencing the data may be pointed out in this connection. Only six readings a day were used from the sea level records for the stations on the Swedish, Finnish, Estonian and Latvian coasts. The amplitudes of the oscillation being generally at their highest and the phenomenon as a whole most distinct for the stations situated in the Gulf of Finland, the determination of the period is based mainly on these comparatively incomplete data. In addition, Neumann computed, as a rule, the oscillation period only with the aid of the time difference between the first and last maximum taking into consideration the number of the interjacent extremes. This procedure, in cases with occasional and local irregularities in the course of the sea level variations, especially towards the end of the oscillation period where the amplitudes are generally slight, may cause considerable deviations. In fact, the length of the period estimated by Neumann for the separate cases varies between 26 and 28 hours and is thus only approximate.

The theoretical calculations of the oscillation period with the aid of the methods of Defant and Hidaka form a very instructive and interesting part of Neumann's paper. The complete agreement between the results is, without doubt, the best proof of the exactitude and reliability of the two methods. The principal difficulty in solving the problem lies, however, as Neumann himself pointed out in his paper, in the irregular configuration of the Baltic and especially in the difficulty of determining exactly the limits of the oscillation basin. As already mentioned above, in his first attempt to determine the oscillation period Neumann considered the Baltic to be closed at the Fehmarn Belt. Including the shallow region of the Bay of Kiel in the oscillation system, using the method of Defant, he arrived at an oscillation period of 29.5 hours; the method of Hidaka gave a period 0.2 hours shorter. The excellent correspondence with the results attained with the aid of the sea level records is thus lost in this case. The example suffices also to show the pronounced dependence of the oscillation period on the sea basin and gives a distinct picture of the difficulties involved. It may be pointed out, moreover, that Neumann's tables show, as a rule, a considerable deviation between the computed amplitudes and the corresponding recorded values. The location of the nodal line is also different according to the theoretical results and for the actual cases considered in Neumann's paper.

These discrepancies prove that the problem is far from solved. The best way to approach it once more is to base the research on a great number of adequate sea level records. This, however, presents a considerable difficulty. In some of the countries bordering the Baltic, sea level data have not been published since the beginning of the Second World War. The work had therefore inevitably to be planned and carried out with the Finnish sea level records, which in their entierety were at the disposal of the author, constituting the principal and essential part of the research. In a limited number of cases the results for the Finnish coast had, however, to be compared with representative results for the southern part of the Baltic. In this connexion the author expresses her sincere thanks to Commander K. Zagrodzki of the "Zaklad Oceanografii Panstwowego Instituta Hydrologiczno-Meteorologicznego" in Gdynia and to President J. M. Lorenzen of the "Küstenausschuss Nord- und Ostsee" in Kiel-Wik for having supplied her for a few shorter periods with hourly sea level data for Władysławowo (off the peninsula Hel) and Strande (outside Kiel). The institute in Poland also sent supplementary records for the sea level stations Kołobzreg and Swinoujscie.

2. Uninodal oscillation at Hamina

As starting point and basis for the research were chosen the hourly records for Hamina (Fredrikshamn) which is now the easternmost Finnish sea level station in the Gulf of Finland. From the records of the years 1952—1954 a number of cases was selected characterized by a distinct and regular oscillation with an approximate period of 26—28 hours. These cases seem on the whole to be unexpectedly frequent, but only cases which fulfilled the following three main conditions were taken into account in the present research:

a) the number of consecutive, distinctly developed oscillation periods had to be at least four,

b) a rough estimation of the average (double) amplitude of the oscillation concerned had to give a result of at least 12 cm, and

c) in order to ascertain that the phenomenon represented a uninodal standing oscillation, corresponding records were used to check that a more or less pronounced inverse seiche oscillation appeared simultaneously at Ystad situated on the Swedish coast in the south part of the Baltic.

Moreover, the possibility was always kept in mind that a strong wind may induce a new oscillation which could influence the period computed. It was therefore in all the cases with an increase of amplitude during the selected period checked that no apparent dislocation of the extreme values has occurred.

It was rather surprising to establish that uninodal seiches fulfilling the above conditions occur fairly frequently in the oscillation system Baltic proper — Gulf of Finland. For the three years in question, on an average almost nine per cent of the total number of sea level variations, covering an cumulative time of three months, were characterized by a prolonged uninodal oscillation. The number of less pronounced cases or cases with a fewer periods and a more restricted average amplitude is, of course, considerably higher. The distribution of the selected cases over the particular years is, however, fairly uneven. For the year 1952 there were used in this study no less than nine cases with altogether 51 periods, in 1953 only three cases, corresponding to 12 periods and, finally, in 1954 five cases resulting in 25 periods. These cases cover in round figures 15, 4 and 7 % respectively, of the corresponding year.

Once the cases were selected the harmonic constants were computed numerically. Starting from different lengths of the oscillation period the one corresponding to the maximum amplitude could be determined with considerable accuracy. The computed data are collected in Table 1. Although the period lengths used cover a time from 25 to 27 hours, the period connected with the highest value of the amplitude generally varies between 26.0 and 26.4 hours only. In reality, we find in Table 1 only two exceptions from the above statement. For the oscillation recorded in January 1952 the computed period is distinctly shorter than the average, approximately 25.5 hours. The number of consecutive periods used for the determination of the harmonic constants is, however, in this case exceptionally high, reaching 12, against the usual total of 4 or 5 periods. It is thus by no means out of the question that a certain dislocation of the phenomenon occurred in the course of this comparatively prolonged time, influencing the result accordingly. The other exception in Table 1 is the case recorded at the beginning of April 1952, where the maximum amplitude corresponds to a period of 26.6 hours. The deviation from the generally computed period length is thus rather insignificant. Table 1 shows in many cases that the maximum of the amplitude is by no mean

Table 1. The harmonically determined average amplitudes (cm) of a uninodal seiche at Hamina for different lengths of the oscillation period

Length of the period, h.	1952									1953			1954				
	I 16. — 29. 12 periods	II 10. — 14. 4 periods	II 16. — 21. 5 periods	III 16. — 21. 5 periods	III 26. — 31. 5 periods	IV 2. — 8. 5 periods	IV 15. — 20. 5 periods	VII 31. — VIII 5. 5 periods	XI 18. — 23. 5 periods	III 23. — 27. 4 periods	X 22. — 26. 4 periods	XII 2. — 6. 4 periods	I 15. — 20. 5 periods	VI 27. — VII 1. 4 periods	X 14. — 21. 7 periods	XI 10. — 15. 5 periods	XI 27. — XII 1. 4 periods
25.0	7.9	17.5	—	8.9	—	—	—	—	—	—	—	—	—	6.4	—	—	11.7
25.5	8.8	18.1	—	9.1	7.0	—	—	—	8.3	—	7.6	—	—	7.0	18.5	26.4	12.5
26.0	7.4	18.7	7.3	9.3	7.9	8.9	8.9	5.6	9.0	12.1	7.8	26.9	14.9	7.1	18.8	28.2	12.6
26.2	6.6	18.7	7.5	9.1	7.6	8.8	9.4	5.8	8.5	13.1	7.6	28.2	15.2	6.8	18.9	27.8	11.9
26.4	4.7	18.3	6.5	9.0	7.7	9.2	9.1	5.5	7.9	13.3	7.2	26.8	15.0	6.7	18.7	28.3	11.6
26.6	—	—	—	—	—	9.3	—	—	—	12.8	—	—	—	—	17.1	26.8	—
27.0	—	—	—	—	—	9.2	—	—	—	—	—	—	—	—	—	—	—

pronounced, indicating the presence of occasional perturbations. We seem therefore to be entitled to consider 26.2 (± 0.2) hours as the average length of the oscillation period for the seventeen representative cases given in Table 1.

The deviation between the theoretically computed period of Neumann and the result of this paper depends probably on the difficulty to reproduce for mathematical purposes the irregular boundaries of the sea basin.

3. The results for Władysławowo

In order to complete the results and check the character of the oscillation as a uninodal seiche in the Baltic proper and the Gulf of Finland, the Polish sea level records for Władysławowo were considered for four of our cases. The harmonic constants computed are given in Table 2 and compared with the corresponding data for Hamina. This table shows that for Władysławowo, too, the oscillation period referring to the maximum amplitude is in three of the four cases to be found between the limits of 25.7 and 26.4 hours. In addition, the differences between the phase angles for the two stations (last column in Table 2) indicate in these three cases a distinct inversity of the oscillation being fairly close to 180°. The amplitudes for Władysławowo form the 3.0 to 4.7 parts than those for Hamina, which, of course, makes the harmonic constants for the former sea level station less reliable. Concerning the fourth case given in Table 2 (for March

Table 2. Harmonic constants for Hamina and Władysławowo for different lengths of the oscillation period

Length of the period, hours	Hamina		Władysławowo		Phase angle difference
	Amplitude, cm	Phase angle	Amplitude, cm	Phase angle	
		1952, February 10.—14.			
25.2	17.5	354°	4.8	191°	163°
25.5	18.1	344°	5.5	179°	165°
25.7	18.0	336°	*6.4*	171°	165°
26.0	*18.7*	329°	6.0	167°	162°
26.2	*18.7*	322°	5.8	152°	170°
26.4	18.3	315°	5.7	152°	163°
27.0	17.9	295°	5.2	137°	158°
		1952, April 15.—20.			
26.0	8.9	260°	3.1	93°	167°
26.2	*9.4*	258°	3.3	81°	177°
26.4	*9.4*	252°	*3.4*	77°	175°
26.7	*9.4*	238°	*3.4*	67°	171°
27.0	9.3	227°	3.3	60°	167°
		1953, March 23.—27.			
23.5	—	—	3.6	176°	—
23.8	—	—	*3.8*	165°	—
24.0	9.5	354°	3.6	157°	163°
24.5	—	—	3.4	137°	—
25.0	11.7	319°	2.9	115°	156°
25.5	—	—	2.7	97°	—
26.0	12.1	297°	2.2	88°	151°
26.2	13.1	288°	2.1	83°	155°
26.4	*13.3*	285°	1.8	75°	150°
26.6	12.8	279°	—	—	—
		1953, December 2.—6.			
26.0	26.9	108°	5.9	293°	175°
26.2	*28.2*	100°	*6.0*	286°	174°
26.4	26.8	97°	5.9	281°	176°

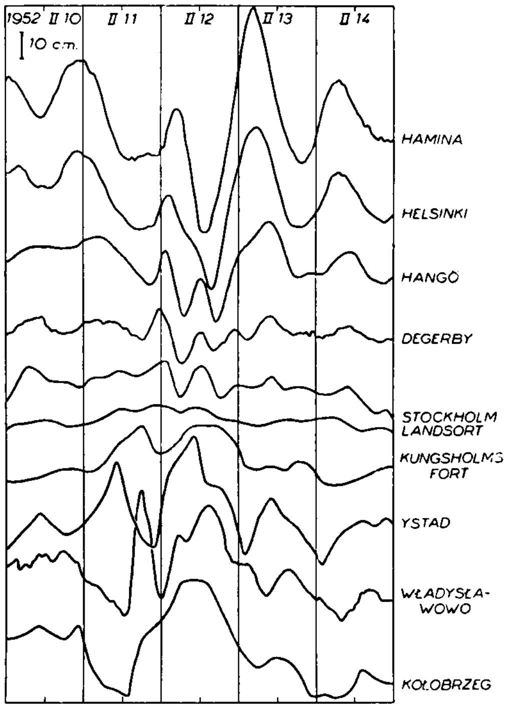

Figure 1. Sea level variations 10—14 February 1952.

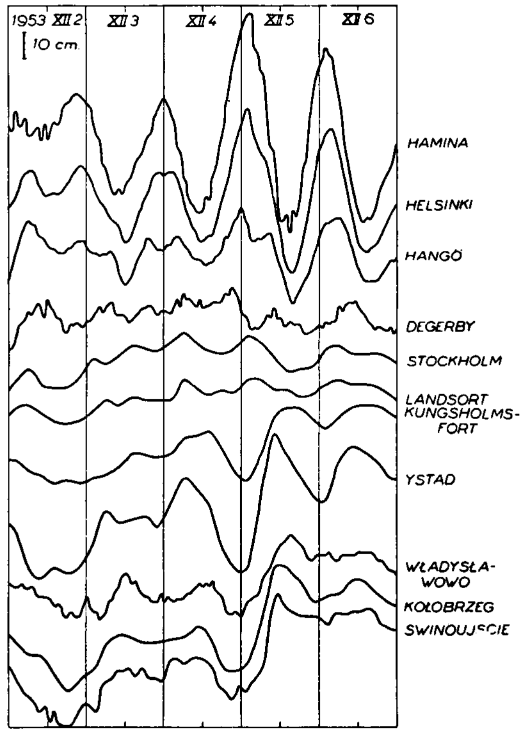

Figure 2. Sea level variations 2—6 December 1953.

1953), the correspondence is not quite satisfactory. On the one hand, the oscillation period for Władysławowo is considerably shorter than for Hamina, amounting to 23.75 hours only, on the other hand the condition for inversity of the phenomenon at the two stations is fulfilled only approximately. As, finally, the amplitudes for Władysławowo are comparatively small in this case, the presence must be presumed of a more or less local factor disturbing the regular course of the phenomenon and influencing the results.

In order to give a graphical representation of the data used above, the sea level records for 10—14 February, 1952, and 2–6 December, 1953, are reproduced in Figures 1 and 2, respectively. Besides the values for Hamina and Władysławowo, the figures give the hourly records for three additional Finnish sea level stations: Helsinki (Helsingfors), Hangö (Hanko) and Degerby. The curves representing the Swedish stations Stockholm, Landsort, Kungsholmsfort and Ystad and the Polish station Kołobrzeg are based on six readings daily and the curve for Swinoujscie in Figure 2 on twelve readings daily. The position of these stations appears in Figure 3.

Figures 1 and 2 show that the oscillation is fairly distinct at Hamina and Helsinki; at Hangö the phenomenon has on the whole a similar character, but the amplitudes are slight and a disturbance in the feature of a supplementary maximum can be noted, for instance, in Figure 1 on 12 February. At Landsort the

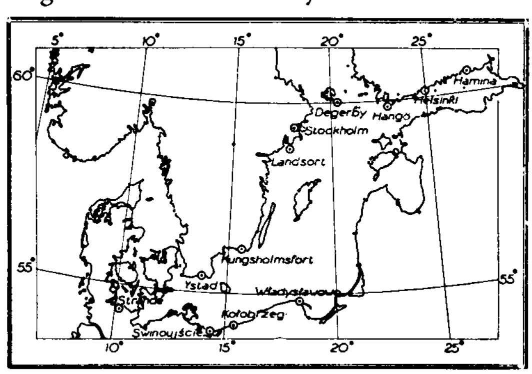

Figure 3. Position of the sea level stations.

oscillation is hardly perceptible owing to the proximity of this sea level station to the nodal line. The inversity of the phenomenon in the south part of the Baltic is indisputable, but the number of different local and regional perturbations is considerable, as appears from the curves given in Figures 1 and 2.

4. Transversal oscillation in the Gulf of Finland

Following the coast from east to west, the general outline of the seiche oscillation in the Gulf of Finland indicates a slight retardation of the occurrence of the extreme sea levels. This retardation can be explained only with the aid of transversal oscillations in the basin caused by the effect of the Coriolis force. In order to obtain some idea of the average value of the time lag the harmonic constants for an oscillation period of 26.2 hours were computed for Hangö for all the cases given in Table 1, however with the exception of the case noted in April 1954 which is missing from the records at Hangö. Table 3 reproduces these constants and the corresponding data for Hamina. Also to be found in the table are the ratios between the amplitudes and the differences between the phase angles. The general impression of Table 3 is the lack of conformity in the individual cases. Thus the ratio between the amplitudes for Hamina and Hangö varies from 1.7 to 10.1. According to the theoretical determinations made by Neumann this ratio should be about 2.5. The limits for the fluctuations of the phase differences are 33° and − 25°. The cases where the extreme sea levels at Hangö appear earlier than at Hamina must be omitted in this connexion as they can not be caused by a transversal oscillation but are due to other disturbances, probably of more local character. The remaining cases are, without doubt, also influenced by disturbing effects. The average value for the positive phase differences in Table 3 is 12°, corresponding to a time lag of approximately 55 minutes. This value is self-evidently a rough approximation only, as the number of cases is far too restricted to allow a more exact determination. It is, for instance, about 35 % too low in comparison with the time lag attained by NEUMANN (1941). This author, on the basis of theoretical determinations, com-

Table 3. Harmonic constants for Hamina and Hangö corresponding to an oscillation period of 26.2 hours

Time	Hamina		Hangö		Ratios of the amplitudes	Phase angle difference
	Amplitude, cm	Phase angle	Amplitude, cm	Phase angle		
1952						
I 16.—29.	6.6	86°	3.9	108°	1.7	22°
II 10.—14.	18.7	322°	4.7	355°	4.0	33°
II 16.—21.	7.5	233°	3.7	235°	2.0	2°
III 16.—21.	9.1	210°	1.4	202°	6.5	— 8°
III 26.—31.	7.6	159°	3.3	146°	2.3	—13°
IV 2.—8.	8.8	108°	2.9	117°	3.0	9°
IV 15.—20.	9.4	258°	3.9	269°	2.4	11°
VII 31.—VIII 5.	5.8	64°	2.8	78°	2.1	14°
XI 18.—23.	8.5	332°	3.3	331°	2.5	— 1°
1953						
III 23.—27.	13.1	288°	5.9	274°	2.2	—14°
X 22.—26.	7.6	130°	3.1	137°	2.5	7°
XII 2.—6.	28.2	100°	2.8	103°	10.1	3°
1954						
I 15.—20.	15.2	235°	3.8	233°	4.0	— 2°
X 14.—21.	18.9	250°	5.1	264°	3.7	14°
XI 10.—15.	27.8	176°	7.0	151°	4.0	—25°
XI 27.—XII 1.	11.9	27°	5.4	32°	2.2	5°

Table 4. Harmonic constants for Hamina and Strande for different lengths of the oscillation period

Length of the period, hours	Hamina		Strande		Phase angle difference
	Amplitude, cm	Phase angle	Amplitude, cm	Phase angle	
1954, November 10.—15.					
25.5	26.4	204°	—	—	—
26.0	28.2	182°	13.8	310°	128°
26.2	27.8	176°	15.3	306°	130°
26.4	*28.3*	167°	16.5	300°	133°
27.0	28.0	146°	19.2	288°	142°
28.0	27.9	111°	22.0	270°	159°
28.4	26.6	99°	*22.4*	262°	163°
28.8	24.8	83°	21.9	252°	169°
1955, January 7.—12.					
26.0	16.3	321°	8.0	155°	166°
26.2	17.0	313°	—	—	—
26.4	17.6	306°	9.0	132°	174°
26.6	18.7	296°	—	—	—
27.0	20.0	286°	10.0	112°	174°
27.5	21.3	275°	*10.9*	100°	175°
28.0	22.1	256°	10.7	76°	180°
28.4	22.1	245°	10.3	65°	180°
28.8	*22.3*	233°	9.2	46°	173°
29.4	20.9	218°	—	—	

puted that the retardation between Koivisto (Björkö), in the Gulf of Finland about 100 km east of Hamina, and Hangö amounts to 1.8 hours. Using this value, we get by interpolation a retardation of 85 minutes between Hamina and Hangö.

5. The results for Strande

The results of this study have shown that the period of the uninodal oscillation in the system Baltic proper — Gulf of Finland is, according to the sea level records, on an average 26.2 hours, i.e. 1.3 hours shorter than the period calculated by Neumann when demarcating the south-west basin of the Baltic at the Fehmarn Belt. If the Bay of Kiel is included in the oscillation area the correspondence deteriorates still more and the difference between the lengths of the periods increases to somewhat more than 3 hours. It is thus possible that the shallow bay plays, as a rule, no part in the oscillation. Its cooperation may depend on the direction of the impulse. The question, however, requires more thorough study. For this purpose, two series of sea level records for Strande were used. Unfortunately these cases had to be chosen from among records covering a time of one year only, i.e. from 1 November, 1954, to 31 October, 1955. No comparison could therefore be made with the records examined above for Władysławowo which all refer to the years 1952 and 1953. The results of the harmonic analysis for the two cases for Strande and Hamina, each covering five periods, are given in Table 4. The amplitudes are fairly marked, but in spite of this the correspondence between the oscillation periods is not satisfactory. For the case in November 1954, concerning which the results for Hamina have already been studied in Table 1, there is the prolonged maximum of the amplitudes corresponding to periods lying between 26.0 and 26.4 hours. The maximum at Strande, on the contrary, may be located comparatively exactly as corresponding to an oscillation period of 28.4 hours. The deviation between the period lengths is too marked to permit consideration of the two series of sea level variations as an identical uninodal seiche oscillation, especially as the condition for inversity is hardly fulfilled. The second case given in Table 4 is of considerable interest, principally owing to the discrepancy between its oscillation period for the maximum amplitude at Hamina and the results of Table 1. This period amounts to 28.8 hours. We could therefore presume that in this special case a larger part of the Baltic participates in the seiche, i.e. that the Bay of Kiel is engaged in the phenomenon, too. Unfortunately, the records for Strande confirm this supposition only approximately. According to Table 4, the oscillation period for Strande can be determined by interpolation at roughly 27.7 hours.

The available records thus do not suffice to solve the problem. A much more extensive material is needed. The possibility that the Bay of Kiel occasionally influences the phenomenon must nevertheless always be kept in mind. It is just this effect and the occurrence of possible coincident oscillations in the bay, probably with a period of 28.4—28.8 hours, that present the most interesting question concerning the uninodal seiches in the Baltic and should be studied more closely.

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