CHAPTER 3

STORM SURGE EFFECTS AT LEIXÕES

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ABSTRACT

In this paper, the effects of a storm surge that happened on the 16th-17th January 1973 in the harbour of Leixões are analysed and described. These effects were of two types:

- As the storm surge coincided with a spring tide and rough seas, severe damages occurred in the outer breakwater, mainly in its head.

- Associated to the storm surge range phenomena happened in the nº 2 dock; these movements, acting on a ship berthed in a nodal zone, caused several breakings in the ropes and damages in harbour structures.

The characteristics of the storm surge and of the waves are analysed. Their effects on the breakwater are described.

By comparing the periods of long waves observed in the tide records with the resonance periods of the inner docks it was possible to conclude that the intensity of the range phenomena observed was due to a half wave lenght resonance.

Having in mind the affinities with the phenomena referred to above, the effects of range action in an oil terminal and new damages in the outer breakwater, that occurred in January and February 1974 respectively, are also briefly examined.

1. GENERAL

The Leixões harbour lies in open coast in the northern part of Portugal facing the North Atlantic (fig.1). As this is a reach of the coast with the general alignement north-south, it is exposed to the severe wave conditions of this zone of the Atlantic Ocean, storms with waves of significant height up to 7 to 8 m and individual waves up to 12 to 13 m being relatively frequent (about once a year). The tidal range is about 3.80 m.

At present, the harbour is formed (fig. 2) by an outer basin approximately square shaped, with a side of about 1,000 m, protected by breakwaters, and two inner docks(nº 1 and nº 2),the first being rectangular and the second having an irregular shape. In order to improve the shelter conditions in the approach zone of the entrance of the harbour and in the harbour itself there is an outer breakwater, 900 m long.

The harbour construction started in 1884-1892 ; it was formed at that time only by the outer basin. In 1937-1941 the nº 1 inner dock and the outer breakwater, as a submerged breakwater, with a top elevation of +1 m above datum were built (datum is arbitrary, a few centimeters below the minimum low water level, astronomical spring tides). The cover layer of the breakwater was formed by concrete cubic blocks of 90 metric tons. The construction of the nº 2 inner dock started by the end of the fifties and is still in expansion. In 1971 the outer breakwater was raised until +15 m, in order to create behind it a crude oil terminal for 100,000 tdw tankers. This raising was carried out by means of a sloping mound structure, the cover layer of which, with an upper berm at elevation +11.50 m is formed by 40 metric tons tetrapods (fig. 3); between +11.50 m and +15 m there is a concrete superstructure with a curved face looking seawards.

In this paper the effects of a storm surge that happened on the 16th-17th January 1973 are analysed and described. These effects were of two types:

- As the storm surge coincided with a spring tide and rough seas, severe damages occurred in the outer breakwater, mainly in its head.

- Associated to the storm surge range phenomena happened in the nº 2 dock; these water movements, acting on a ship berthed in a nodal zone, caused several breakings in the ropes and collision of the ship against harbour structures, which were damaged.

Having in mind the affinities with these phenomena, the effects of range action in the oil terminal and new damages in the breakwater, that occurred in January and February 1974 respectively, are also briefly examined.

2. STORM ON THE 16th-17th JANUARY 1973

2.1 - Storm characteristics

Figs. 4 and 5 show synoptic charts of the meteorological situation corresponding to the 16th January 1973 at 00:00 and to the 17th January 1973. Barometric fall of 20 mm Hg started at 00:00 of Jan. 16, the minimum of 740 mm Hg lasted for 12 hours (from 20:00 of Jan. 16 to 08:00 of Jan. 17). Normal atmospheric pressure (760 mm) was reached at 22:00 of Jan. 17 and 770 mm pressure was recorded at 12:00 of Jan. 18 (see fig. 6). As can be seen, the centre of the low pressure associated with strong winds passed just over Leixões, causing a "storm surge".

The following table is formed with predicted and occurred sea levels as recorded by a normal tide gauge (fig. 8) placed within the outer harbour (fig. 2).

Residuals reached a maximum of +53 cm (at 20:00 of 16/1).

Regarding storm wind wave data it is stressed that:

- Unfortunately there are no local data recorded at Leixões.

- Although the storm which hit Leixões more intensely at down of the 17th has not been a F.A.S., as it had mainly local characte

ACTUAL AND FORECAST TIDAL LEVELS															
HW	LW	HW	LW	HW	LW	HW	L.W	HW	LW	HW	LW	HW	LW	HW	LW
ACTUAL VALUES															
2 80	1 35	3 00	1 08	2 82	0 90	2 95	0 96	3 48	1 46	3 78	1 10	3 12	0 44	3 18	0 18
11 30	17 20	23 40	6 20	12 30	18 50	1 20	7 20	14 00	20 00	2 10	8 40	14 30	20 50	3 10	9 10
14th Jan			15th Jan			16th Jan				17th Jan				18th Jan	
FORECAST VALUES															
2 74	1 25	2 85	1 19	2 89	1 13	3 10	0 96	3 08	0 93	3 36	0 70	3 26	0 73	3.57	0 48
11 56	17 23	0 34	6 13	13 07	18 42	1 36	7 28	14 06	19 46	2 28	8 26	14 57	20 37	3 15	9 14
DIFERENCE BETWEEN ACTUAL AND FORECAST VALUES (cm)															
+6	+10	+15	-8	-7	-23	-15	0	+14	+53	+42	+40	-14	-29	-39	-30
									Minim pressure						

ristics, with strong winds which resulted from the low pressure centre passing almost over Leixões, it is noted that on the 16th a 14 m wave height was recorded at K meteorological ship.

- The storm was of exceptional duration (24 hours).

- In fig. 7 wave data referring to Baleeira (Algarve), Sines and Peniche (Portuguese west coast) can be seen. Data were recorded with Datawell waverider buoys. Note that to an increase from south to north in the wave heights there does not correspond an increase in periods, which is evidence of the local character to the north.

2.2 - Occurrence of long period waves

If the tide record is searched (fig. 8) for long period waves and the part of the record that corresponds to the occurrence of the storm surge (fig. 9) is more carefully inspected, it is possible to observe that waves with periods of about 4, 8, 16, 20 and 40 minutes were present, with rather significant amplitude. The more persistent wave is the 4 minutes one, more precisely 220 s.

2.3 - Damages in the outer breakwater

During the storm the outer breakwater was severely overtopped. As a consequence of this overtopping the structures of the oil terminal itself, mainly the steel ones, and the oil leading pipes were bent (fig. 10).

The looking landwards steel doors of a transformer station located inside the concrete superstructure of the breakwater were carried away, apparently by suction action (fig. 11). Some tetrapods of the cover layer of the breakwater were broken. But the most severe damages occurred in the head of the breakwater that was practically destroyed: many tetrapods were broken or carried away; the end concrete block of the superstructure supporting the lighthouse and the neighbouring one fell down by undermining action of the waves, that carried away the small rock blocks of the underlayer over which they were placed, and the following concrete block was slightly displaced laterally (fig.s 12, 13, 14, 15). To this effect strongly contributed the presence of the cilindrical concrete monolith that supported the lighthouse of the submerged breakwater before the raising operation, though the upper part of this cilindrical block was mechanically destroyed during the raising works, as this block originated a concentration of strong currents from the breaking waves on the damaged zone.

Model test were run after the accident in order to obtain a better knowledge of the destruction process and the best solution for the repairing works, to be carried out during the summer 1973.

2.4 - Disturbances caused by long period waves

2.4.1 - Damages on the bridge between nº 1 and nº 2 docks

A 160 m long freighter with general cargo berthed between bollards nº 26 and 36 of the north quay (nº 2 dock) broke the ropes at 23:00 on Jan. 16, 1973. Thrown adrift she then hit at 23:30 the abutment of the Leixões cantilever bridge and broke bollards nº 26 and 33. The bridge was damaged. At 10:30 of Jan. 17/1/1973 bad weather conditions persisted and the same ship, though secured by two tugs, was lurching so heavily that springs and a bollard (nº38). were broken (fig. 16).

2.4.2 - Interpretation of the resonant mechanism

If the two docks are considered as a sole rectangular dock 1220 m long it is seen that a half wave length resonance may occur with a nodal zone on the ship's position, with a fundamental resonant period of 212 to 225 s, embracing that of about 220 s whose presence was noted at the tide record.

Thus the disturbances caused by the ship which damaged the bridge and the bollards at about 23:00 of the 16th and 10:30 of the following day are explained. The nodal zone positioned in the berthing zone of the ship has horizontal movements which in turn are aggravated by the constriction between the two docks. Horizontal movements and corresponding velocities can be easily calculated, for selected values of d, T and H (d = 12 m. T = 225 s, and for instance, H=0.5 m):

Excursion (horizontal movement):

$$\frac{\sqrt{g}\ HT}{\pi\sqrt{d}} = 32 \text{ m}$$

Maximum velocity:

$$\frac{\sqrt{g}\ H}{\sqrt{d}} = 0.45 \text{ m/s}$$

3. SIMILAR PHENOMENA IN 1974

3.1 - New damages in the outer breakwater (February 1974)

A storm occured in February 1974, after the head of the outer breakwater had been reconstructed. During this storm no major damages happened. However several tetrapods of the zone near the head were broken or carried away (fig. 17, 18).

3.2 - Disturbances caused in berth nº 1 of the oil terminal by long period waves

3.2.1 - General

Frequent problems have occurred after ships are berthed in nº 1 berth of the oil terminal, caused by long period waves (fig.19 shows berth nº 1 inside view).

A possible hypothesis for predicting the resonance period consists in considering the water mass limited by the outerbreakwater, the north breakwater of the outer basin and the end of its south breakwater as a triangular wedge (fig. 20). For d = 16.5 m and l = 650 m

$$T_1 = 1.308 \times \frac{2\,l}{\sqrt{g d_1}} = 133\ \mathrm{s}$$

is the fundamental resonant period of the wedge water mass*, which is compatible with the existence of a nodal zone in the region of berth nº 1. However, pure reflection non-resonant situations caused by the corner between the two breakwaters may occur for a wider range of periods. In the generated stationary system for some periods a node line can appear near berth nº 1.

3.2.2 - Disturbances caused in January 1974 in a tanker moored at berth nº 1

A brief report will be made of a typical accident which happened with a 137,000 dwt tanker ("Ortins de Bettencourt") on the 21st and 22nd January, 1974.

An analysis of the rapid rotation tide records of those days shows that there were waves with periods of 2 to 4 minutes with amplitudes up to 50 cm, probably amplified (fig. 21).

It is expected that the situation will be worse for periods near 2 min (for instance the 133 s period above mentioned) as it was admitted that this could be a resonant situation. As the triangular wedge is quite wide it is expected that the response curve will be smooth, corresponds to a poorly selective situation.

The accident which happened with the "Ortins de Bettencourt" was as follows:

"At about 23:30 hours of the 21st this ship, which was unloading, started moving, going as far as 10 to 15 m ahead and astern 3 to 4 m from the berth. Two tugs assisted the ship, which reduced those distances to respectively about 8 and 2 m. At 3:30 our tugs were assisting the ship and the two kinds of movement were reduced to 5 m and 1 m respectively. Meanwhile five ropes has been broken".

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* - Wilson, B. Hendrickson, J.A. and Kilmer, R.E."Feasibility study for a surge-action model of Monterey Harbour, California", Cont. Report nº 2-136 U.S.Army Corps of Engineers, Waterways Experiment Station, Vicksburg, U.S.A.

4. PREVIOUS STUDIES ON RANGE PHENOMENA AT LEIXÕES

Previous studies on range phenomena at Leixões have been presented by C.K.Abecasis (XVII th International Navigation Congress, Lisbon, 1949, Section II. Subjet 4) and F. Abecasis et al. (XIX th International Navigation Congress, London, 1957. Section II. Subjet 1). In these papers two strips of long periods of waves are referred to as existing frequently at Leixões and in other zones of the Portuguese coast: the first one between 2 and 5 minutes (120 to 300 sec) with predominance of 3 to 4 minutes; the second one between 15 and 20 minutes, mainly in the zone of the upper limmit (20 minutes). The occurrence of long period waves of both strips is often associated with atmospheric depressions and rough seas. This is in accordance with the long period waves recently observed and described in this paper.

ACKNOWLEDGMENTS

The help of Administração Geral dos Portos do Douro e Leixões (Harbours of Douro and Leixões Authority) in suppling the data about the phenomena described in the paper and in giving permission of their publication is gratefully acwnowledged.

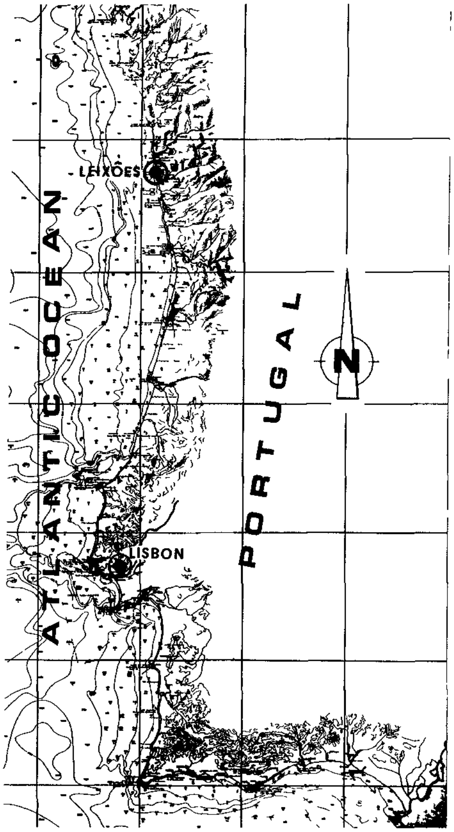


Fig. 1 - Location of Leixões

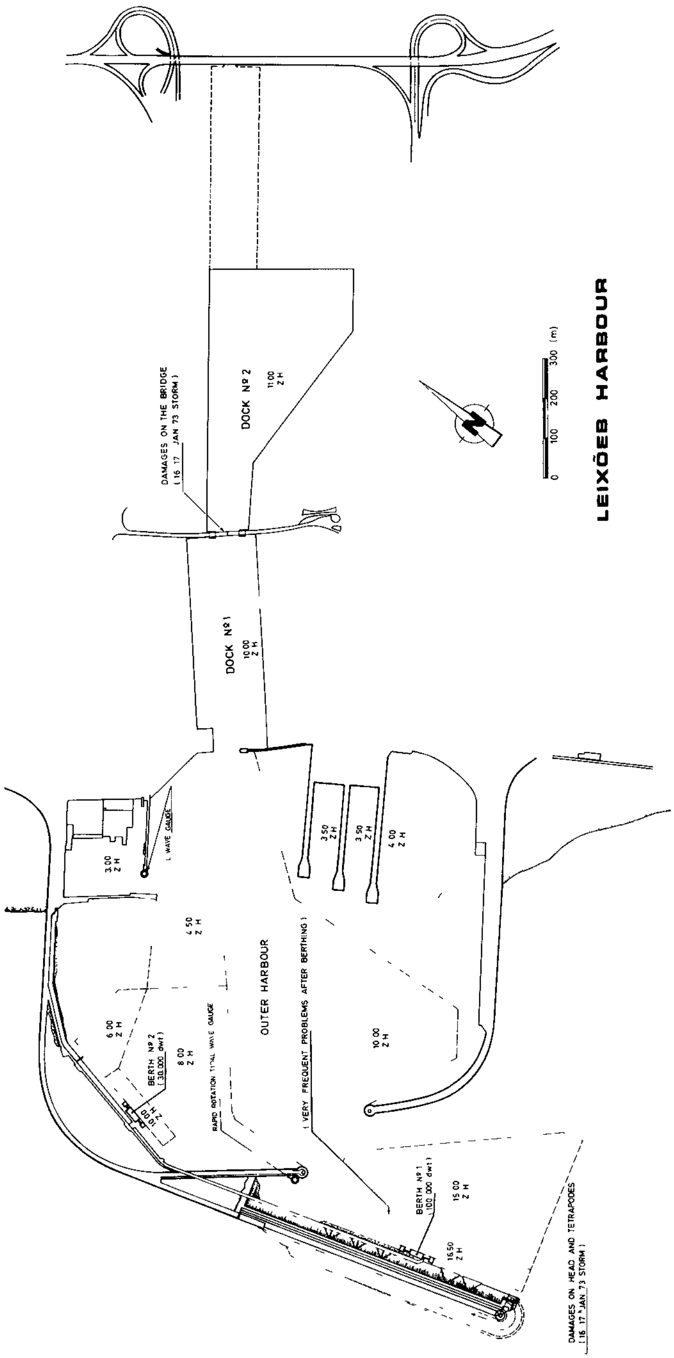
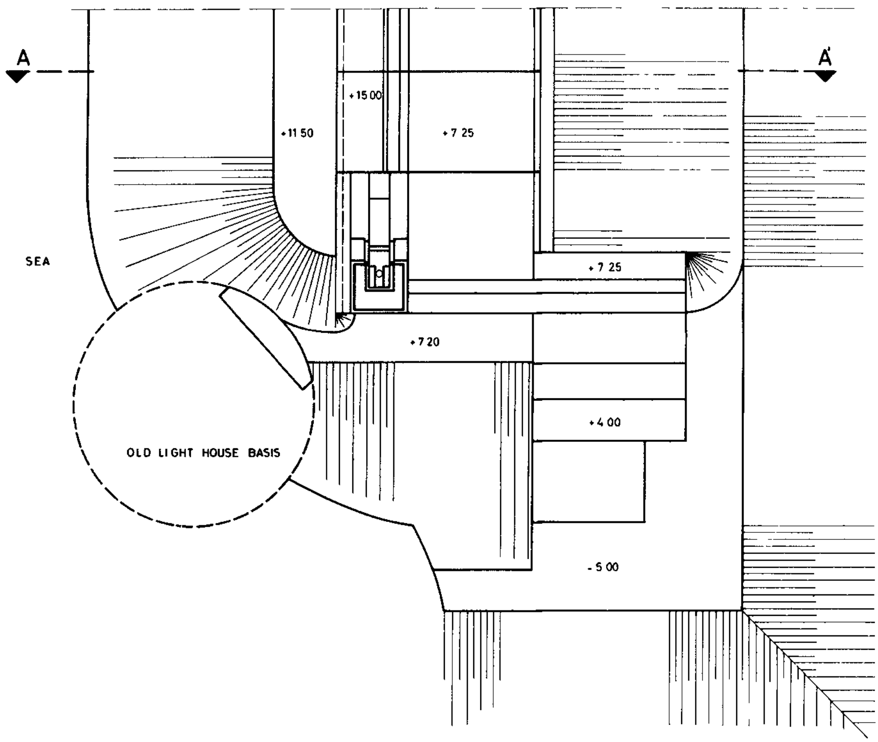


Fig. 2 - Lay-out of Leixões Harbour

PLANT VIEW



CROSS SECTION A-A'

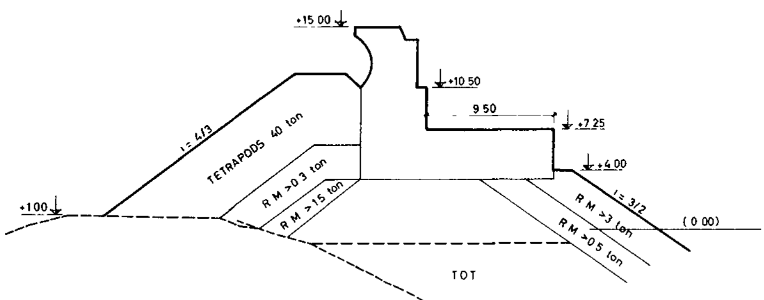


Fig. 3 - Head and cross-section of North breakwater

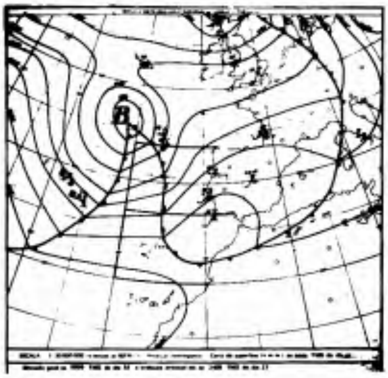


Fig. 4 - Synoptic chart (16/1/73,00:00)

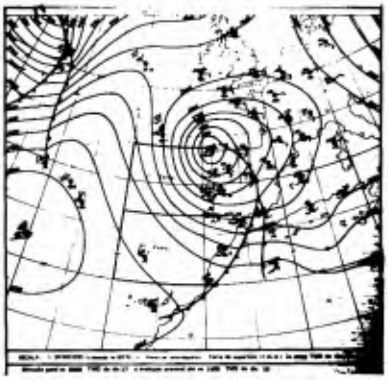


Fig. 5 - Synoptic chart (17/1/73,00:00)

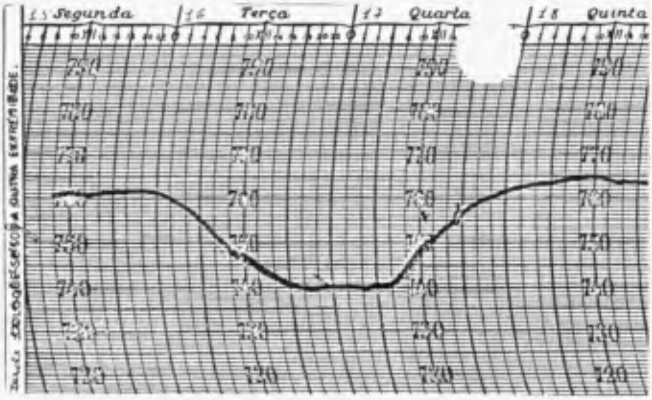


Fig. 6 - Barometric record

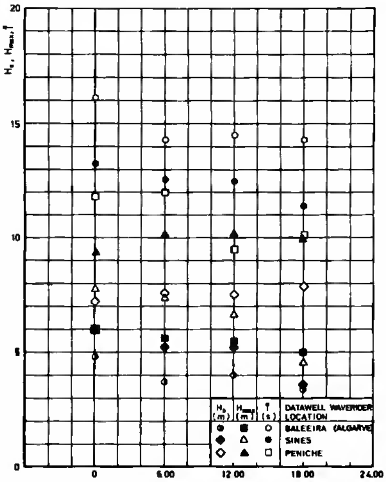


Fig. 7 - Wave data

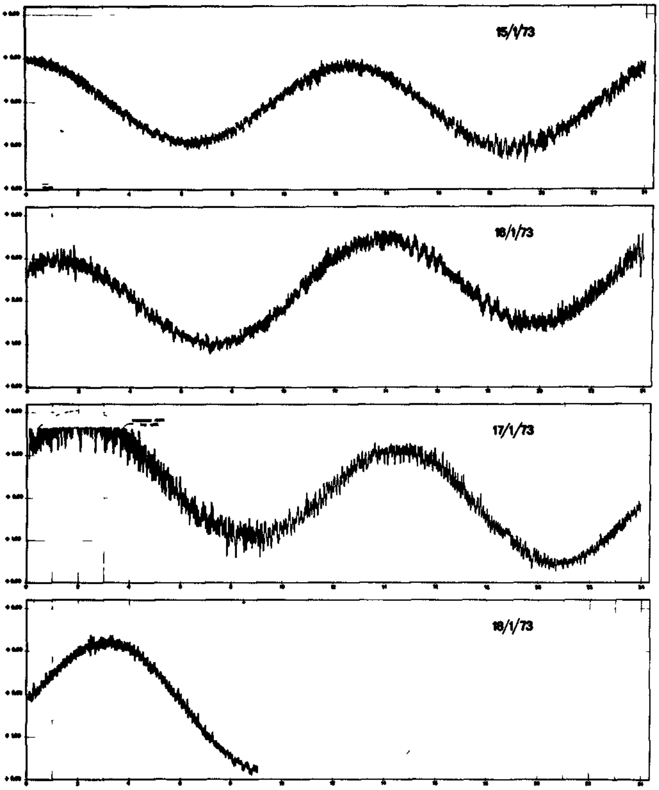


Fig. 8 - Tide record

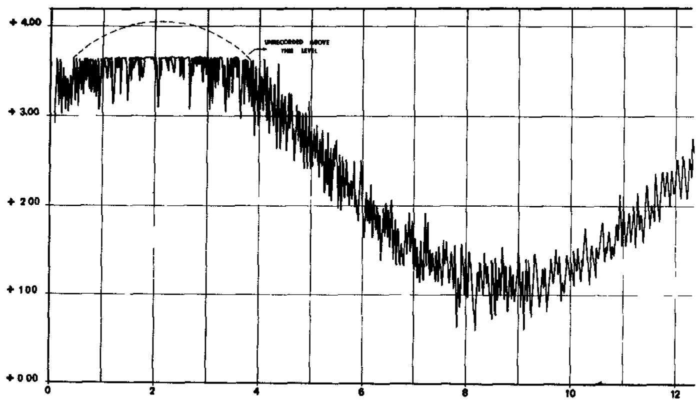


Fig. 9 - Tide record (close-up)

Fig. 10

Fig. 11

Fig. 12

Fig. 10 - Damages caused by overtopping

Fig. 11 - Damages caused by overtopping (cont.)

Fig. 12 - Damages at the head

Fig. 13 - Damages at the head (cont.)

Fig. 14 - Damages at the head (cont.)

Fig. 13

Fig. 14

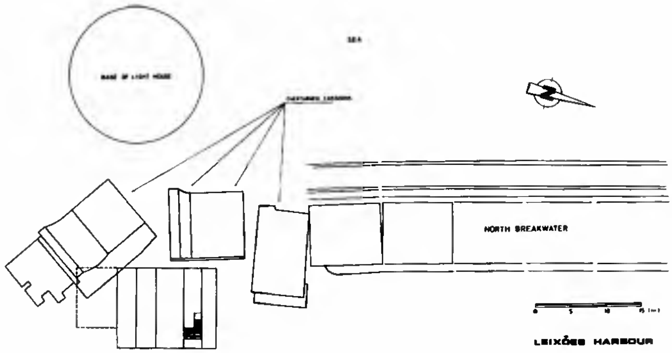


Fig. 15 - Damages at the head (cont.)

Fig. 16 - Damages on the bridge

Fig. 17 - New damages at North breakwater

Fig. 18 - New damages at North breakwater

Fig. 19 - Berth nº 1 (view)

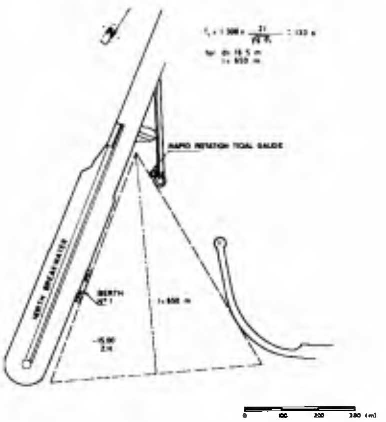


Fig. 20 - Hypothetical ressonant area

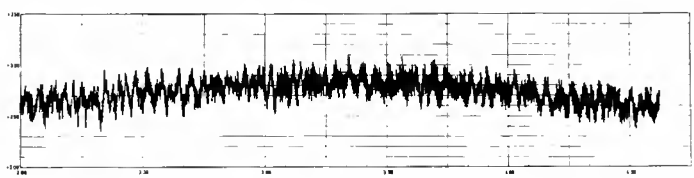


Fig. 21 - Rapid rotation tidal gauge record (22/1/74)