Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 69 (1993)

Artikel: Dynamic response of buildings on breakwater in Monaco

Autor: Bernander, Stig

DOI: https://doi.org/10.5169/seals-52578

Dymamic Response of Buildings on Breakwater in Monaco

Réponse dynamique de constructions sur une digue projetée à Monaco

Dynamisches Verhalten von Gebäuden auf einer Mole in Monaco

Stig BERNANDER
Adj. Prof.
Technical University
Lulea, Sweden

Stig Bernander graduated at Chalmers University of Technology, 1951. From 1970 to 1991, responsible for all company design and engineering in Skanska Väst AB, Gothenburg.

SUMMARY

This report deals with serviceability problems in buildings founded on a planned breakwater jetty in Monaco. The problems are related to wave induced vibrations in the structure, which is heavily exposed to the Mediterranean Sea. The requirement with regard to acceleration proved to be a crucial factor in the design.

RESUME

Ce rapport traite de l'aptitude au service de bâtiments formant la superstructure d'une digue brise-lames projetée à Monaco. Les problèmes sont dûs aux vibrations résultant de la houle – la construction étant fort exposée au bord de la Méditerranée. Les caractéristiques de l'accélération se sont avérées comme très importantes pour le projet.

ZUSAMMENFASSUNG

Dieser Beitrag behandelt die Gebrauchstauglichkeit von Gebäuden, die auf einer geplanten Hafenmole in Monaco gegründet werden. Ihre exponierte Lage in der Brandung des Mittelmeers verursacht im Tragwerk durch Wellenschlag Schwingungsprobleme. Die Anforderungen bezüglich Beschleunigungen erwiesen sich als entscheidend für die Bemessung.

1. PREAMBLE

The Principality of Monaco comprises a land area of not quite 2 km² – a small urban area which, however, is characterized by expansive economic development, rendering building lots scarce and expensive. Within Monaco there are three harbours of which the main port – Port de la Condamine – is heavily exposed to the Mediterranean Sea in the sector from East/South-east to South/South-west. In order to improve the present conditions in the inner harbour the Monegasque Authorities have long been planning to construct a new breakwater jetty outside the existing moles.

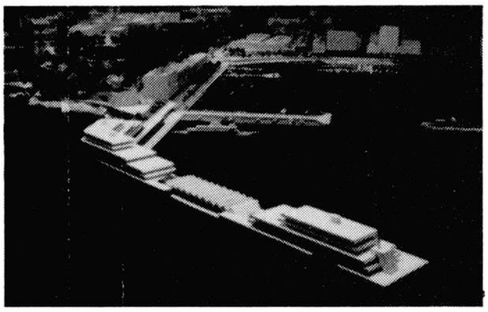


Fig. 1 Model of Port de la Condamine with new breakwater

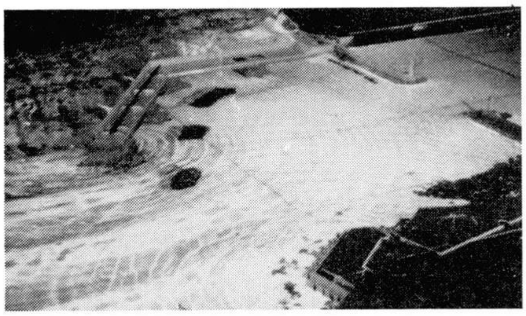


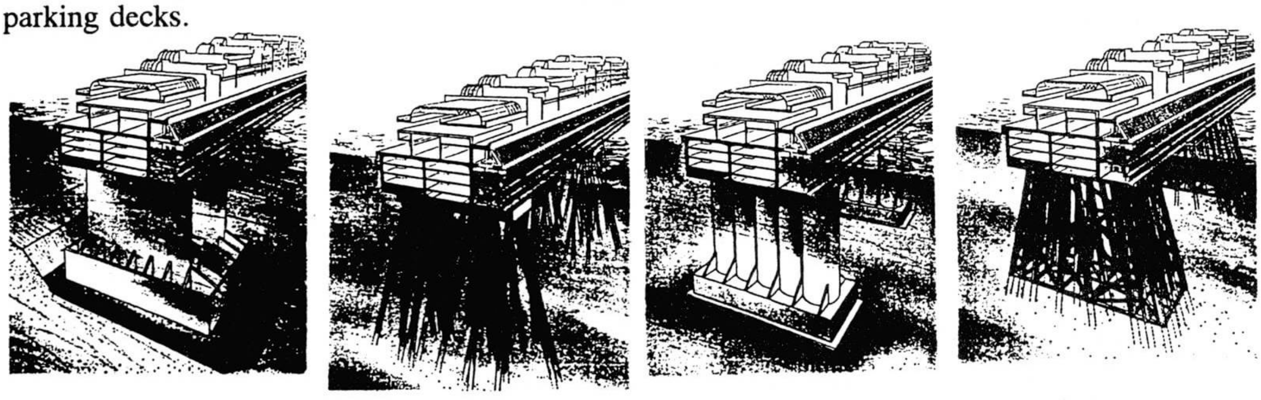
Fig. 2 Hydraulic model test

2. SCOPE OF THE PROJECT

In february 1991 Skanska Teknik AB was commissioned to carry out a preliminary engineering study in order to investigate the feasibility of such a project.

On account of the considerable depth to firm bottom (up to 60 m) it proved to be necessary to develop an unconventional design for the new jetty. The breakwater proper is planned to consist of 40–44 m wide pontoons submerged 10 m into the water. The total length of the planned breakwater is 426 m. The pontoons rest on fixed supports thus permitting some of the wave energy to pass the barrier. Four different main designs with regard to the supporting piers and their foundations were examined. (Fig. 3).

In order to promote the economic feasibility of the enterprise, the surface areas of the jetty are intended to be utilized as foundations for multi-story buildings accommodating apartments, commercial spaces and a marine terminal. The pontoons themselves accommodate three-story parking decks.



Alt. 1 Alt. 3 Alt. 4 A Alt.4 B

Fig 3 Alternative designs for the breakwater foundations

In view of the novelty of the structural concept and the open exposure to the sea, the planned breakwater belongs to the category of advanced off-shore structures. Considering the locally intense seismicity of the region and the urban development on the jetty it is clear that a number of additional complications and requirements add to those, which are normally present in off-shore engineering.
This is especially true with respect to the dynamic behaviour of the rather complex elongated construction, which may be statically described as a bent continuous beam on spring supports in all three perpendicular directions, cf fig. 5.

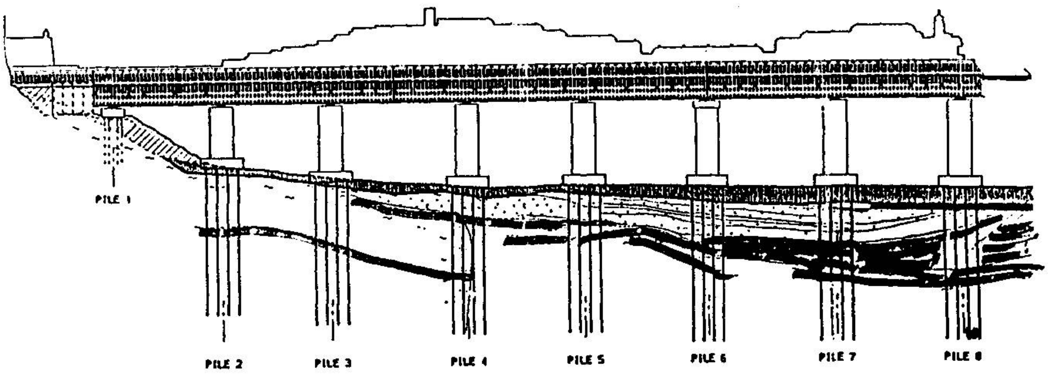


Fig. 4 Alt. 4A

In order to define the seismic effect on the foundations up to 20 modes of oscillation had to be contemplated. In the design of the various alternative solutions for the foundations, seismic action in terms of quasi-static loading proved to be governing the static design.

3. SERVICEABILITY WITH REGARD TO CONDITIONS OF COMFORT

3.1 General

The general design of the breakwater structure and the multitude of interesting issues related to it, will not be dealt with here. This paper will be restricted to problems related to the serviceability of the buildings on the breakwater with regard to dynamic response to the action of regular and irregular waves. As mentioned, four different foundation designs were studied. Although the dynamic properties varied *quantitatively* between the different designs the main features with regard to dynamic response were basically similar. Therefore data and diagrams will refer only to one of the most favourable of the alternative designs, namely alt. 3. (Fig. 3).

3.2 Dynamic properties

For the analysis of the response of both wave and seismic action it is imperative to study the dynamic behaviour of the structures. These studies were carried out with the aid of a version of the program BV STRUDL, developed by Bureau Veritas, Paris. Except for alt. 1 the integral structure was modelled in three dimensions.

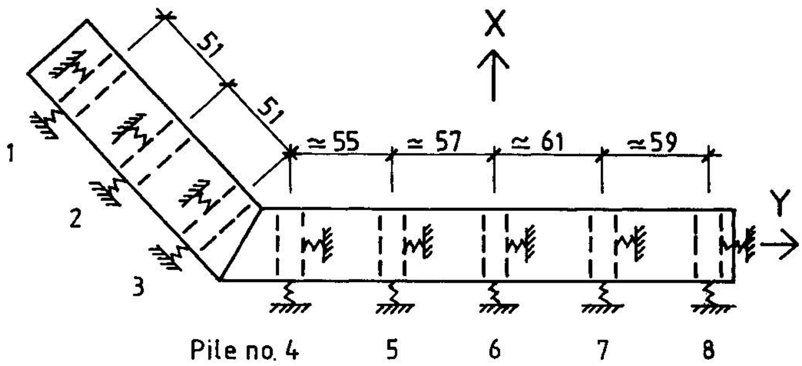


Fig. 5 Plan of model used in the analysis. Vertical springs not shown.

Compared to a structure on dry land, the submerged structure is – from the point of view of dynamic response – encumbered by enormous added masses related to vertical and horizontal movements as well as to water contained in the caissons and the chambers for absorption of wave energy.

For the seismic analysis it was required that in each direction 90% of the total oscillating mass should be included in the analysis. This meant that up to twenty modes had to be considered. Table I gives the corresponding modes for the design alternative n° 3.

Table I Vibration modes considered in the seismic analysis for the design alternative n° 3 .

Mode	*Direction*	*Natural period T sec*	*Modal participa-ting mass %*	Σ %
1	y	2,05	95	$\sum y = 95$
2	x	1,79	96	$\sum x = 96$
7	z	0,47	22	
8	z	0,46	36	
9	z	0,44	8	
10	z	0,43	20	
11	z	0,42	5	$\sum z = 91$

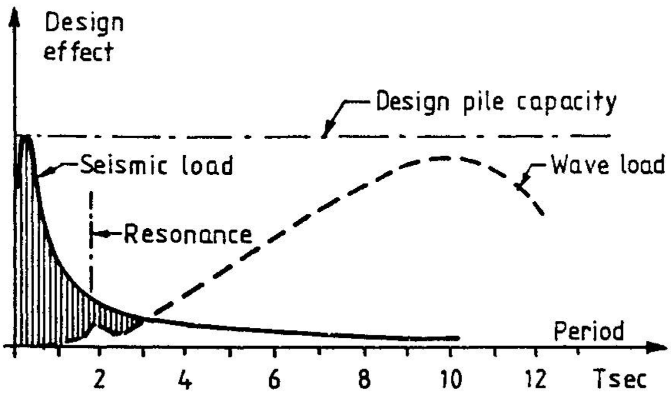


Fig. 6 Design effect on a piled foundation. (Alt. 3).

For the study of wave response, however, only the basic frequencies 1 and 2 were relevant in alt. 3. Fig. 6 shows the 'design effect' on the piles of the foundation (alt. 3) from seismic and wave loading. The diagram illustrates the importance of choosing an optimum stiffness for the integral structure. As may be seen, a fundamental natural period of e.g. 0,5 sec would have been disastrous with regard to seismicity. On the other hand a more flexible structure with a natural period of 6 to 10 sec would have been prohibitive with respect to wave loading.

3.3 Design with regard to comfort in office and living quarters

As shown in figure 6 (and table I) the fundamental mode of vibration in the x direction has a period of about 1,8 sec. This is close to optimum for the design of the foundation, the design effect of seismic and wave loading being almost the same.
There was, however, yet another important requirement to satisfy for this specific structure, namely that of human comfort in commercial areas and apartments. The clients specification prescribed that the acceleration in the most elevated apartment should not exceed 0,005 g during the 1 year storm, defined by H_{max} = 4,5 m and T = 7,0 sec for regular waves.

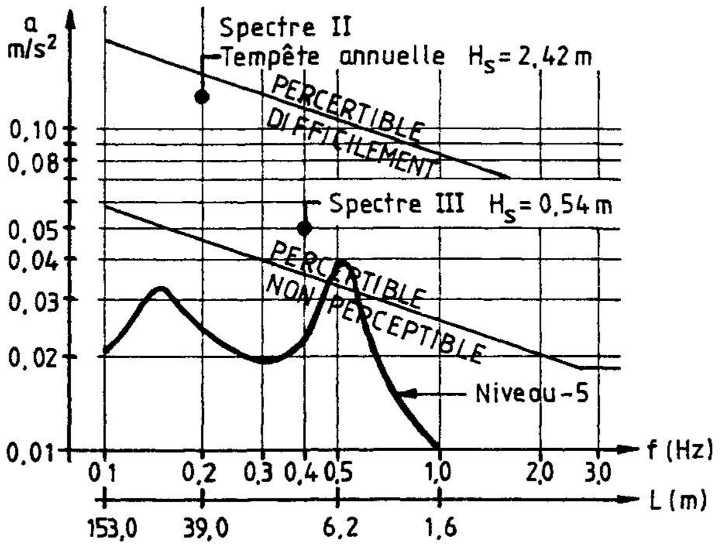


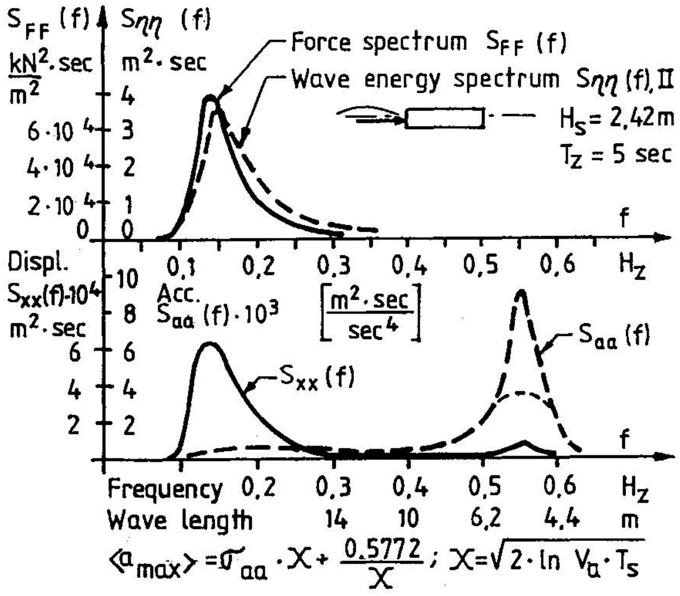
Fig. 7 Maximum acceleration for regular waves and for spectra II and III

Fig. 7 displays the relationship between regular wave frequency and maximum acceleration.
The non-exceedence criterion (a_{max} ≤ 0,005 g)is fulfilled in this case. The curve indicates, however, that the contribution of smaller waves in an irregular sea could possibly be important. Hence it was found necessary to perform a supplementary *spectral* analysis.
The irregular sea state was defined as a Pierson-Moskowitz spectrum with the following data:

H_{max} = 4,5 m
H_s = 2,92 m
T_z = 5 sec

Fig. 8 depicts the basic wave elevation spectrum, the corresponding force spectrum and the displacement as well as the acceleration response spectra. As may be seen from the diagram the response force spectrum, which is directly proportional to the displacement spectrum, retains the main features of the wave energy spectrum, reflecting the moderate effect of resonance on the design forces on the structure.

However, the conditions for human comfort are linked with the maximum velocity (shear forces in the building) and acceleration. It is therefore interesting to note the tremendous increase of spectral density in the acceleration spectrum near the natural frequency of the breakwater structure. Table II gives the results of spectral analysis for the breakwater structure for two wave spectra of which spectrum n° II corresponds to the sea state specified by the client with respect to comfort criteria.
Spectrum n° III represents a sea state where the maximum spectral density of the wave energy spectrum is located near the natural frequency of the structure.



As may be seen in fig. 8 the response spectrum for maximum acceleration shows a marked displacement of the peak spectral density from the frequencies of maximum wave energy spectral density to the band of resonance frequency. This implies that the contribution of smaller waves – with wave lengths in the order of 6 m – to maximum acceleration is of major importance. As indicated in fig. 7 the limit acceleration of 0,005 g is exceeded for both spectrum II and III. It is even likely that any chosen spectrum with an appreciable content of smaller waves in the resonance frequency band would generate unacceptable accelerations.

Fig. 8 Spectrum n° II, sea elevation and force
Spectrum n° II, acceleration and displacement response spectrum

Table II Maximum acceleration at level +24,2 (top story). Alternative 3, wave direction East/South–east, spectral analysis

Spectrum	H_{max} *m*	H_{sign} *m*	T_z *sec*	*Displace-ment mm*	*Accele-ration m/sec²*	*Storm duration hours*
II	4,5	2,42	5,0	32	0,120	4
IIIA	1,0	0,54	2,5	7	0,050	4

The accuracy of this prediction is, however, subject to the validity of the basic assumption that the time–force history of the irregular sea is identical and simultaneous for every section of the c:a 400 m long structure. This is probably not very true for wave lengths of 5–8 m. For this reason the finally predicted acceleration was based on a modified response spectrum where the spectral density of smaller waves had been reduced on the basis of engineering judgement.
A continued study of the serviceability of the structure with respect to vibrations and comfort would therefore have to address the probability of the simultaneousness of impact from smaller waves on a structure longer than about 50 times the crucial wave lengths.

4. CONCLUSIONS

In the design of the various alternative solutions for the foundation, seismic loading was governing the design. However, with regard to the relative feasibility of the different alternatives, spectral analysis of dynamic wave response demonstrated, that the *serviceability* requirement related to the comfort in living quarters, was a strongly decisive factor with a potential of eliminating some of the alternative designs.