The development of the historical harbour of Paphos, Cyprus

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Abstract

The harbour of Paphos originates from ancient times. Various historical structures among which the remainders of breakwater and a fort remain today. Any development of the harbour must spare these structures. Preferably the adaptations and developments should be in harmony with the ancient relics. The harbour of Paphos provides shelter and berthing facilities for fishing boats and pleasure craft. However, the protection presently offered by the harbour is considered inadequate. Furthermore, there is an increasing demand for berthing facilities. An upgrading and an extension of the protective works is planned by the CYPRUS PORTS AUTHORITY in order to provide adequate shelter and extra berthing facilities. DELFT HYDRAULICS was commissioned to evaluate nautical and hydraulic aspects for various upgrading and lay-out concepts.
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Introduction

General

Cyprus lies in the eastern Mediterranean and Paphos is situated on the western coast of Cyprus. The harbour of Paphos (Figure 1) dates back to ancient times to which remaining structures of that age bear witness. The location of the harbour site exposes the harbour to waves arriving from directions between east-south-east and west-north-west. The harbour of Paphos provides shelter and berthing facilities for local fishing boats and pleasure craft including yachts and small cruise vessels. Unfortunately the degree of shelter is not always considered sufficient.

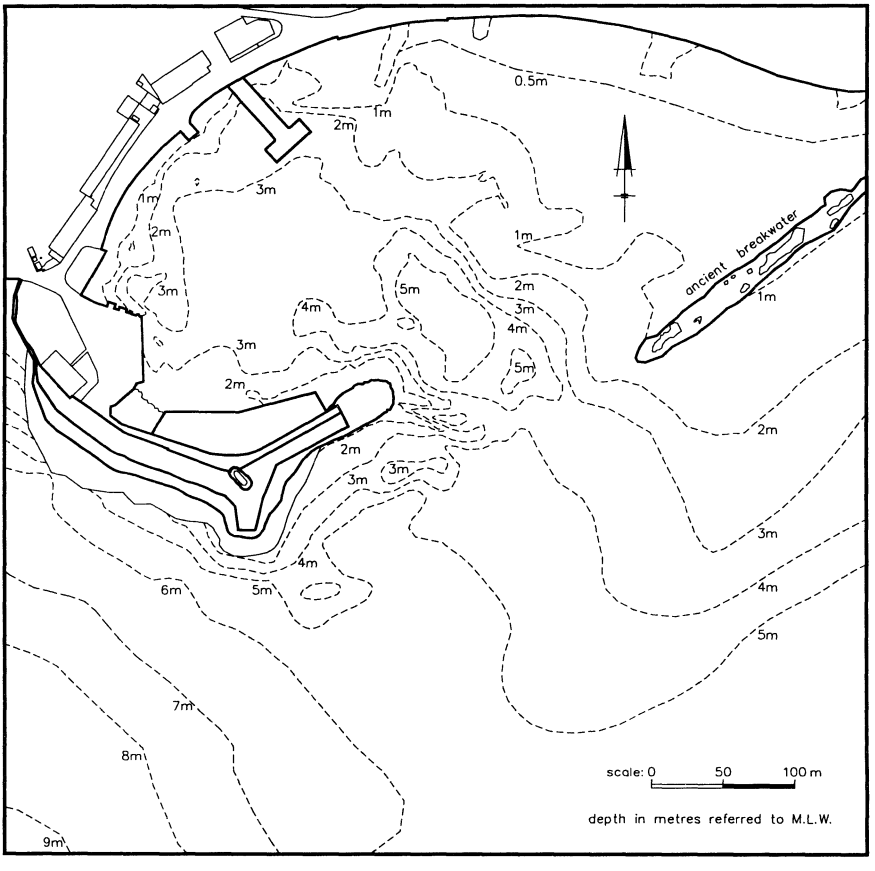

Figure 1 *Paphos - existing situation*

Another issue is the damage the harbour works themselves have sustained in recent years due to wave action. Penetrating waves caused a moored vessel to slam into a jetty resulting in a cracked concrete surface of the jetty and damage to the bow of the vessel. Naturally often no damage is caused during periods of less extreme wave heights, however, the crews and passengers of yachts do experience discomfort due to motions of the vessels and increased alertness of the crews is required during periods with elevated wave heights. For a harbour such as Paphos, where yachts come to allow passengers and crews to relax and enjoy the setting this is an undesirable situation.

The number of pleasure craft putting into Paphos is gradually increasing and a further increase would be welcomed as a boost to the local economy. This necessitates a larger and better protected area in order to provide a greater number of berths. Improved shore facilities and measures to protect the environment are also required.

When reflecting on the solutions to problems experienced during periods of high waves and on a suitable design to increase the number of berths, criteria must be established with regard to acceptable conditions in the harbour under given conditions outside the harbour.

Purpose of the study

The purpose of the study was to solve two problems: the high level of wave agitation within the harbour and the inadequate functioning of the harbour interior. The study required the establishment of the environmental conditions near Paphos.

Local conditions

Environmental conditions

The design of a breakwater requires data on wind and wave conditions near the site. The assessment of conditions for navigation and mooring within the harbour requires data on normal wind and wave conditions. The design of structures requires data on extreme wave conditions with a return period of for example 50 years.

The wind climate near Paphos was derived from ship's observations obtained from the Royal Netherlands Meteorological Office (KNMI) and wind measurements at the Paphos International Airport. The wave climate was derived from the ship's observations and buoy measurements near Paphos.

In order to arrive at normal wind condition statistics both the ship's observations and the wind measurements were utilized. The ship's observations were statistically analyzed to determine the offshore wind climate. The resulting wind speed exceedance curve was then compared with the results from the wind speed measurements at Paphos International Airport.

To arrive at the normal wave condition statistics both the ship's observations and the wave buoy measurements were used. The ship's observations were statistically analyzed to determine the offshore wave climate. However, most ships sail at a considerable distance from the shore. Therefore the analysis of the ship's data is representative for the open sea wave climate. Paphos is situated on the west coast of Cyprus and the site is well protected against waves from northerly and easterly directions. Only waves in the sector between 120 and 300 degrees could reach the site of the measurement buoy directly from open sea. Therefore, to arrive at the offshore wave climate at the position of the buoy a correction had to be applied to the open sea wave climate to account for the local fetch restrictions. Furthermore, a correction including the effects of refraction and dissipation had to be applied. The resulting total wave height exceedance curve was then compared to the analysis results from the wave measurements.

To assess the extreme wind and wave conditions at open sea Weibull-distributions were fitted to the probabilities of exceedance of the wind speed and wave height for the relevant directions. The values with a return period of 1, 5, 10, 25 and 50 years were determined using the well established Weibull-relation. The extreme wave conditions at the breakwater were obtained by the application of a correction for refraction, dissipation and shoaling effects on the extreme wave height at open sea.

Water level

The expected water level during storm conditions is an essential factor for designing the breakwater. The water level not only affects the free board height of the breakwater but it also affects the wave height and wave breaking in shallow water.

The water level is influenced by the astronomical tide, the wind set-up/ storm surge, barometric pressure variation, and wave set-up. For Paphos harbour the design water level is equal to the mean sea level plus half a metre for the mentioned influences.

The wave climate within the harbour was determined for four lay-outs by means of numerical wave agitation computations. These computations were done using the PHAROS package which computes the wave heights in the modelled area using a finite element method. The model accounts for, refraction and shoaling, diffraction, reflection, transmission, wave breaking and directional spreading.

Various data

Other data which were indispensable and required various degrees of effort to obtain were the bathymetry, the dimensions of ships visiting Paphos and the manner in which harbour space is utilized. Many of these data were obtained through discussions and observations during site visits. This provided valuable input during the design process of a suitable lay-out for the harbour interior. The site visits were instrumental in identifying local possibilities and restrictions.

Design and operational criteria

1. the future lay-out of the Port of Paphos must allow the vessels presently calling at Paphos to enter safely under prevailing conditions,
2. the future harbour basin must provide safe and secure berthing under the severest environmental conditions,
3. the aesthetics of the future harbour must remain appealing,
4. the piers within the future harbour should be situated and constructed such that unexplored underwater archelogical sites will not be damaged,
5. the ancient Roman breakwater must not be affected in any way.

Operational criteria

The following criteria were established with regard to the limiting operational significant wave heights:

Location/season	Fishing vessels approximately 10 m long	Pleasure craft and mini cruisers up to 25 m long
at sea in deep water conditions/all year	2.00 m	2.50 m
approach channel and harbour entrance	1.50 m	2.00 m
mooring locations within the harbour/summer	0.25 m	0.25 m
mooring locations within the harbour/winter	0.40 m	0.40 m

Limiting wave heights

The anticipated wave agitation for the various lay-outs was calculated to determine the degree of compliance with these criteria.

The channel depth criterium for the various types and sizes of vessels calling at Paphos can be summarized as follows:

Vessel type	Maximum length [m]	Maximum breadth [m]	Draught range [m]	Required channel depth [m]
fishing vessel	10	3.8	1.2 - 1.5	3.3
motor yacht	25	6.9	2.5 - 3.7	5.7
seagoing sailing yacht	25	6.5	3.2 - 3.7	5.7

Required channel depth

The design of the harbour basin interior should take the static wind loads of wind force Bft 10 into account.

During summer the motions of a moored ship should not exceed 0.25 m. During winter this value can be increased to 0.4 m.

The water depth of basins in the harbour of Paphos should exceed the draught of the vessels they are intended for by at least 0.65 m.

The operational criteria had to be met while leaving the ancient breakwater intact. This meant more than not building on or close to this breakwater. It also meant that any new structure or dredging must not be a threat to it. For this reason the proposed channel had to have a mild slope near the ancient breakwater and maintain a safe distance to it (Figure 2).

Harbour lay-out concepts

Various lay-out concepts were considered with regard to nautical aspects and port planning. One of the considered lay-outs concerned a detached offshore breakwater. During periods with severe wind and wave conditions from south to southeasterly directions shippers of fishing vessels entering Paphos on northerly to northwesterly courses. The offshore breakwater does not allow vessels to enter on these courses. Therefore this lay-out, while offering sufficient protection against waves was unacceptable from a nautical point of view. Considering all criteria the lay-out shown in Figure 2 is the most favourable concept. The optimilisation of the length of the breakwater was performed by increasing the length in two stages during the numerical wave agitation calculations. In addition to fulfilling the criteria the concept also utilizes a shallow area to reduce the amount of construction material needed. The elevation of the crest of the breakwater was under 2.5 m above MLW. This was considered crucial for aesthetical reasons.

Harbour basin planning

Various considerations to arrive at a suitable harbour interior lay-out should be taken into account:

- The size, number and type of the required berths determine the required water surface area. Paphos requires berths for 90 fishing boats ranging from 3 to 10 m in length, 60 recreational vessels ranging from 3 to 25 m in length and for 10 various special purpose vessels ranging from 10 to 25 m in length. So, the total number of required berths is 160.
- The choice of the location of the various berth types and sizes within the harbour is crucial to avoid hindrance between the various vessels. The berths intended for the larger vessels should be located close to the entrance for reasons of acceptable wave action, required manoeuvring space and in order to avoid the passage of large vessels through areas with small craft.
- The manoeuvring space must be adequate. The minimum requirement for turning basins is a diameter equal to twice the maximum length of the vessels for which a turning basin is intended.
- Commercial and recreational craft must be kept separate to avoid conflict of interest.
- Resident and transient customers should have separate berthing areas, if possible.
- The type of berthing system must be suitable for wind force conditions of 10 Bft. It is good practice that vessels need not connect to one another. Also the access to the shore should preferably be direct and not require ferrying of crews to and from their ship.
- The berthing piers must provide suitable facilities and space regarding fishing vessels' unloading activities.

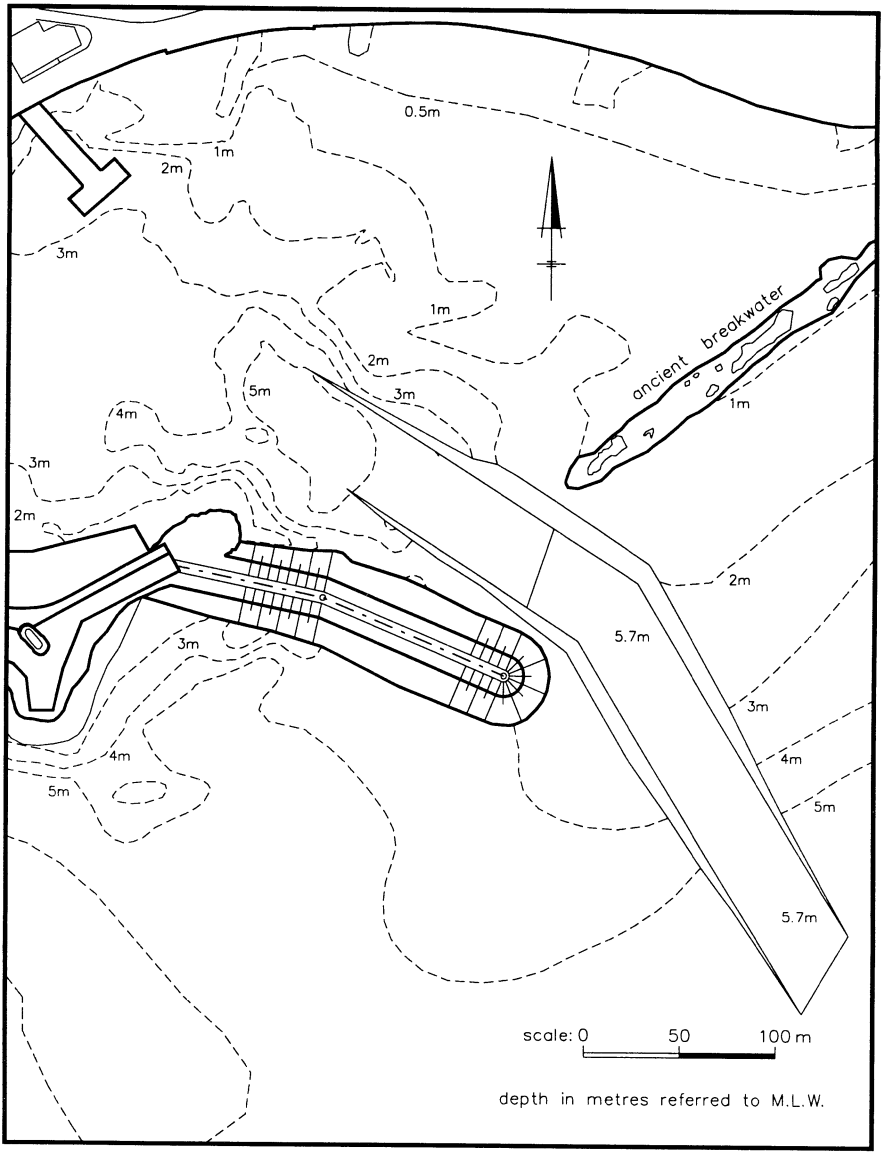

Figure 2 *Paphos - breakwater extension channel (-5.7 m)*

Additional considerations to be taken into account when considering the harbour interior lay-out involve:

- aesthetics;
- availability of fresh water, fuel, electricity, communications, sewage pump-out, garbage reception and waste oil reception;
- suitable lifesaving and fire fighting equipment;
- slipway and repair facilities;
- availability of stores.

The sewage pump-out, the garbage and waste oil reception are particularly important in order to maintain a clean and appealing environment. This is even more pressing when a further narrowing of the harbour entrance is considered as this may cause reduced flushing of the water inside the harbour basin. A floating service station is capable of providing the required services at a location with sufficient distance to recreational activities. An example of a proposed harbour interior is shown in Figure 3.

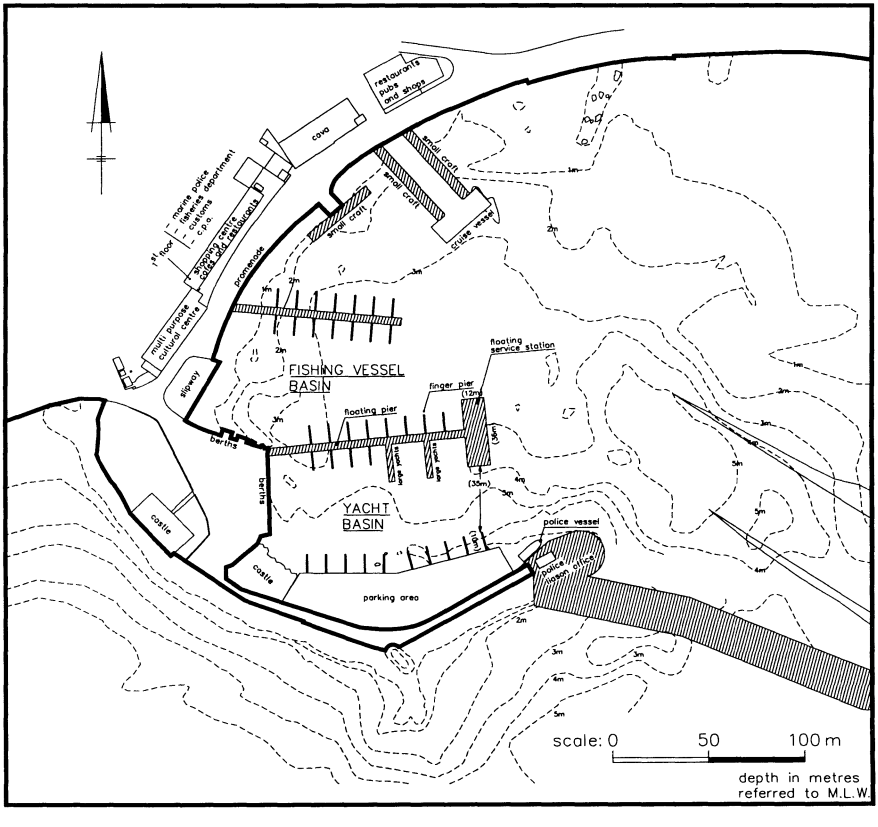

Figure 3 *Paphos - extended breakwater, increased harbour area - channel (-5.7 m)*

Results

Criteria were established with regard to acceptable wave heights in the access channel and at the berths.

An attractive lay-out was designed with regard to nautical aspects and port planning.

The plans for an attractive harbour interior including a floating pier arrangement were drawn up.

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