Gibraltar Harbour

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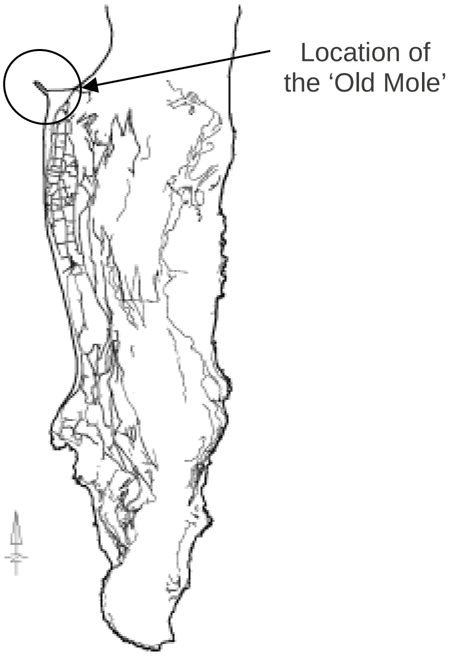
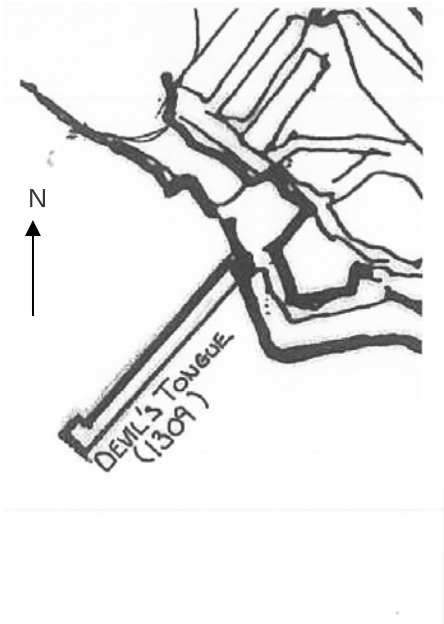
Introduction

The Port of Gibraltar lies on a narrow five kilometer long peninsula on Spain's south eastern Mediterranean coast. Gibraltar became British in 1704 and is a self-governing territory of the United Kingdom which covers 6.5 square kilometers, including the port and harbour.

It is believed that Gibraltar has been used as a harbour by seafarers for thousands of years with evidence dating back at least three millennia to Phoenician times; however up until the late 19th Century it provided little shelter for vessels. Refer to Figure 1 which shows the coast line along the western side of Gibraltar with the first structure known as the 'Old Mole' on the northern end of the town. Refer to figure 1 below.





The Old Mole as 1770

Figure 1 Showing the harbour with the first harbour structure, the 'Old Mole' and the structure in detail as in 1770. The Old Mole image has been kindly reproduced with permission from the Gibraltar Museum.

The modern Port of Gibraltar occupies a uniquely important strategic location, demonstrated by the many naval battles fought at and for the peninsula. Today it sits at the intersection of Atlantic and Mediterranean shipping lanes.

This paper presents a factual record of the history of Gibraltar Harbour and how it has developed since the first harbour structure was constructed in the early 14th Century. The paper will also show how breakwater and reclamation works have reshaped Gibraltar's footprint and will draw upon hydraulic model results to show how developments within the harbour basin and in the Bay of Gibraltar have significantly affected the wave climate in the harbour and the resulting impact on the existing harbour structures and sea defences.

Development of the harbour

The oldest structure of the harbour was the Old Mole, believed to have been constructed circa 1309 at the north end of the town and on it was later constructed the famous battery known as "The Devils Tongue". A later addition "the New Mole", situated on the southern of the harbour, was begun in 1620 and completed in 1660. Refer to figure 2 below.

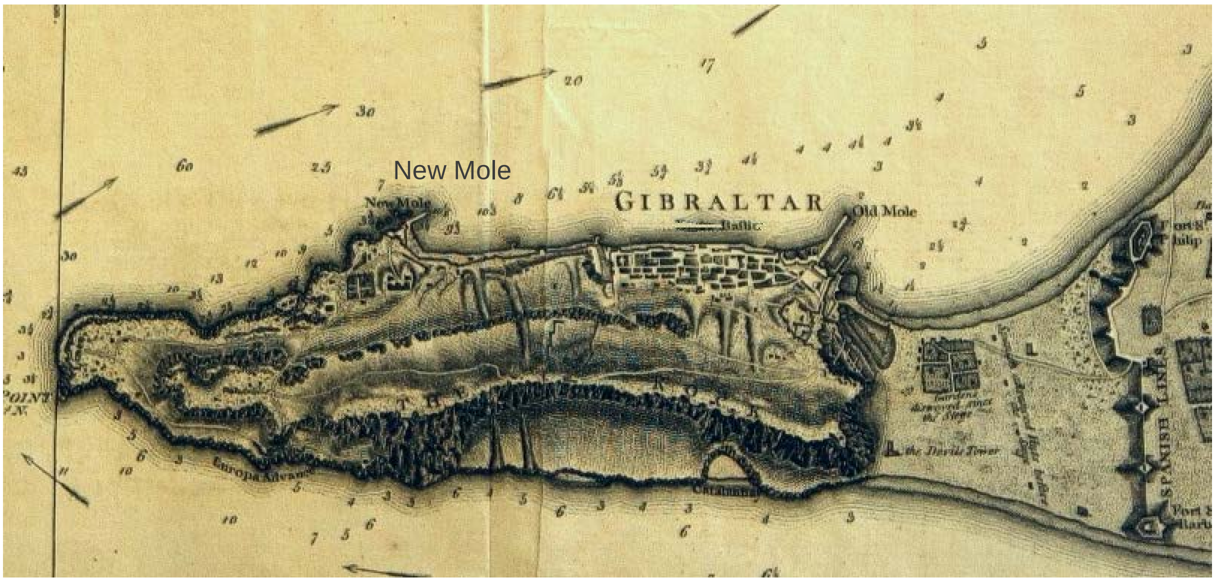


Figure 2 Shows a general plan of Gibraltar showing the 'Old Mole' and New Mole' during the Great Siege 1779 - 1782. The image has been kindly reproduced with permission from the Gibraltar Museum.

An extension to the existing "New Mole" structure of 1620 did not commence until 1851 and a further extension was undertaken much later in 1893. However, despite the extension works the need for more shelter, accommodation and facilities was becoming pressing and it was not until 1895 that significant works funded by the Admiralty made way for a modern harbour and dockyard. These works were completed in 1905 (Scott 1914). Refer to Figure 3.

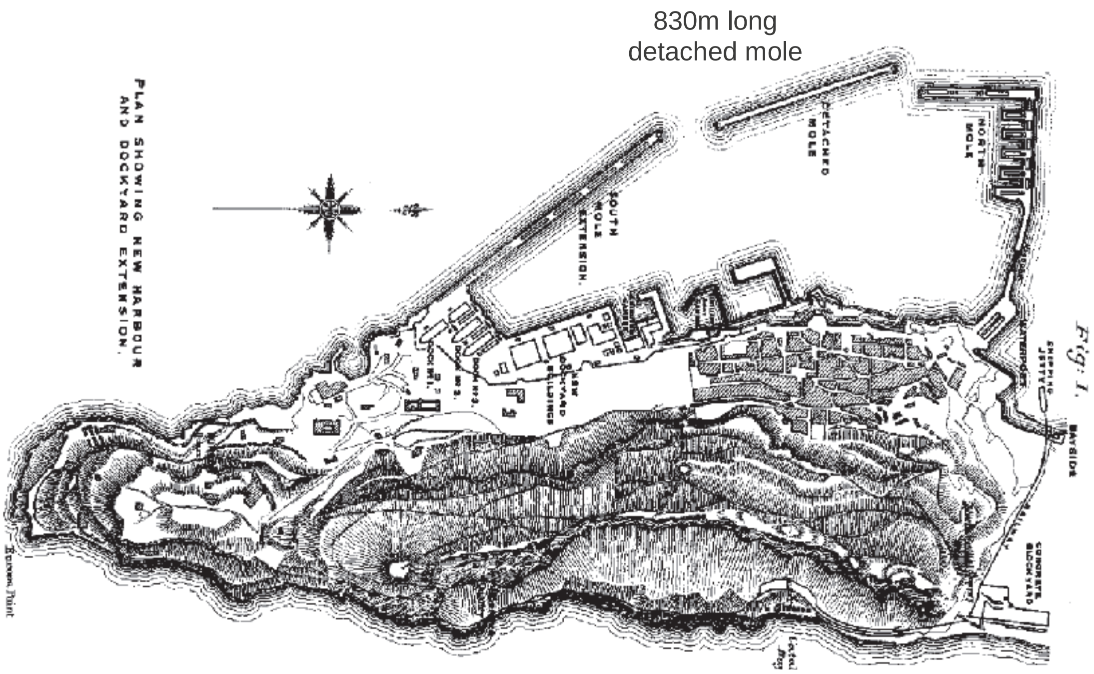


Figure 3 Shows a general plan of Gibraltar showing the new harbour and dockyard extension as at 1914 (Scott 1914). For scaling purposes the detached mole is approximately 830m long or 2,720 feet.

The principal works for what was to become a modern dockyard in the period 1895 to 1905 included the following (Scott 1914) (Coad Jonathan G 1989):

- A southern breakwater extension to the New Mole having a total length of 2,700 feet (including the 1,000 feet begun in 1893). This structure is known as the modern day South Mole. The original structure and the extension comprise rubble mound construction with a quay wall on the harbour side. Refer to Figure 4.

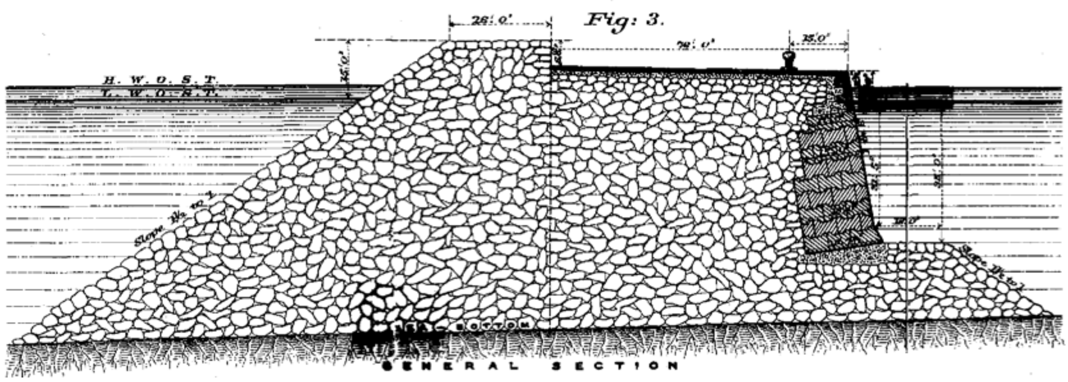


Figure 4 Shows a typical section through the south mole (Scott 1914).

- A detached breakwater 2,720 feet in length and situated between the north and south breakwaters. This structure is known as the modern day Detached Mole and is believed to have been originally constructed for the berthing of Naval Vessels. The structure comprises a concrete filled mild steel caisson with concrete block work for the vertical wall superstructure. The blocks and the top face are lined with limestone blocks (Scott 1914). Refer to Figure 5.

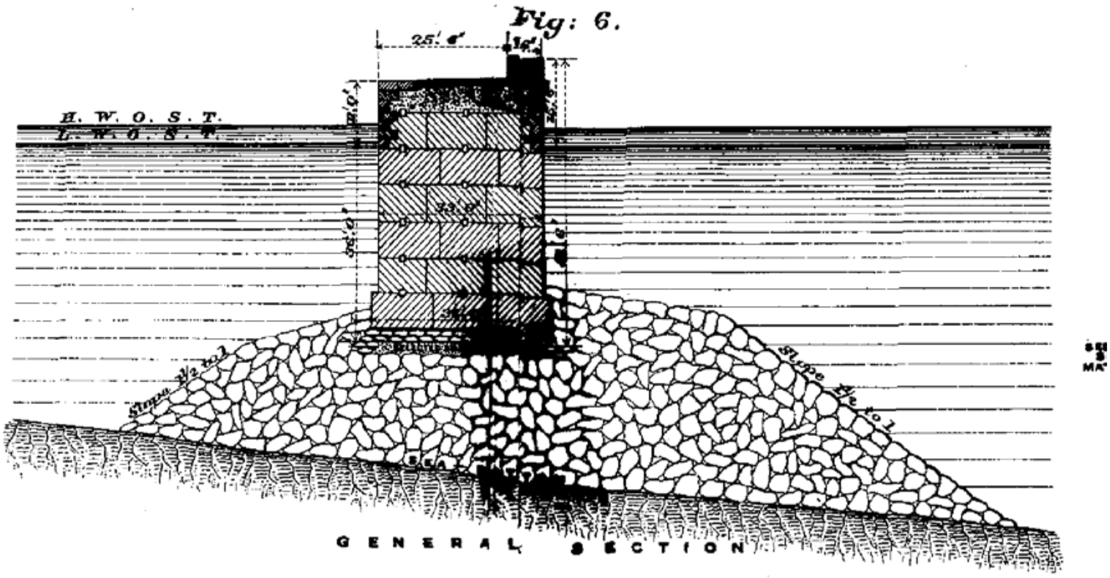


Figure 5 Shows a typical section through the detached mole (Scott 1914)

- A large north mole, with coaling jetties and a viaduct. This structure is known as the modern day North Mole or Western Arm and was originally constructed for the berthing of Naval Vessels. It comprises two vertical sides created by the placing of large limestone blocks founded on a concrete base, which has been in-filled with stone rubble. Refer to Figure 6.

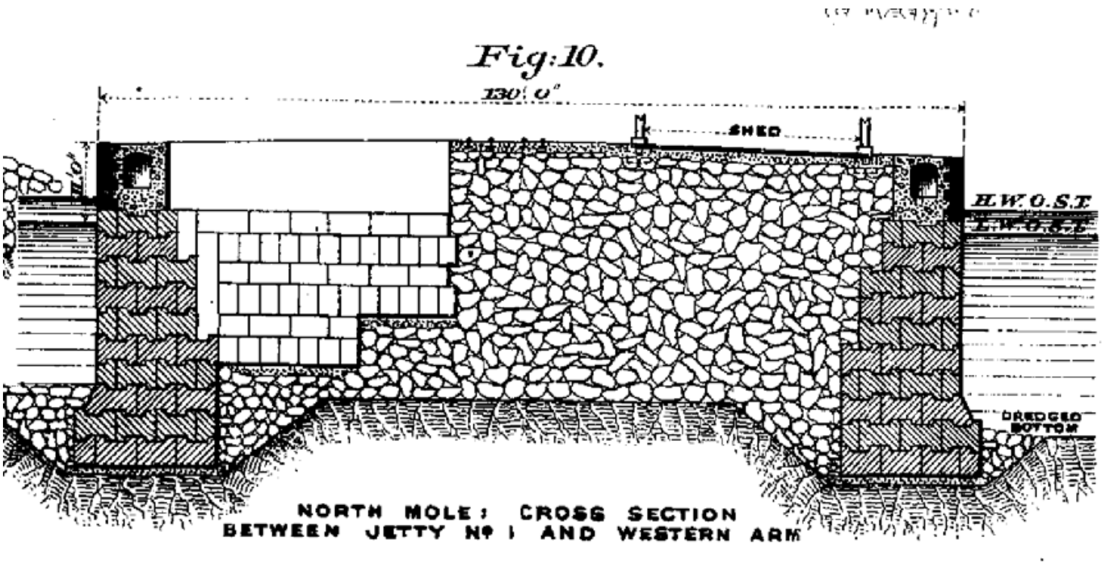


Figure 6 Shows a typical section through the north mole (Scott 1914)

- An extended naval yard, including three large graving docks, wharf walls, slipways for destroyers and other facilities. The dry docks are currently occupied by GibDock a commercial ship repair yard. Refer to Figure 7.

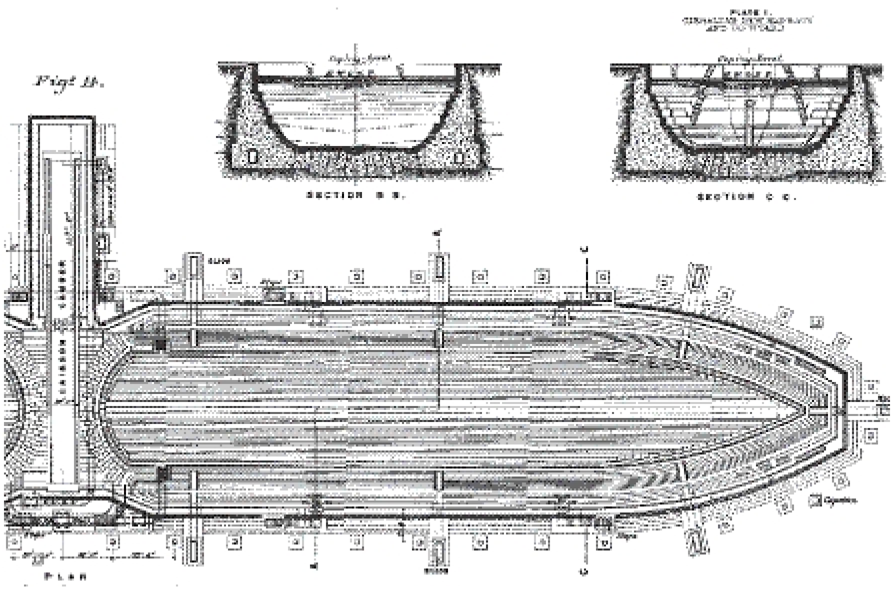


Figure 7 Shows a typical plan and sections through the graving docks (Scott 1914). For scaling purposes the level of the dock floor on the centre line is approximately 15.5m or 51 feet below the coping.

- The dredging of the harbour.

It is worth noting that despite there being no significant harbour structures in the intervening period between 1309 and 1905, ever since Gibraltar became of strategic military importance to the British in 1704 walled defences erected along the original sea line have provided protection to the town from attacks by sea. These structures would have also inevitably provided protection from storms.

In the period from 1905 to 2011 many other major changes have occurred within the harbour waters and also in the Bay of Gibraltar as a result of reclamations and developments.

Significant reclamation works were undertaken within Gibraltar harbour between the latter part of the 20th century and the first decade of the 21st century to meet the needs of a growing population. Refer to Figure 8 below.

The shape of the reclamation works was largely governed by the location of a desalination plant water intake on the northern part of the harbour. In addition to this the width of the reclamation was at the time also restricted by the Ministry of Defence ammunition barges that were moored on the detached mole. In fact anecdotal evidence suggests that the area that the MoD gave for dredging actually turned out to be an unofficial munitions dump, which meant that bomb disposal experts were required on the dredger to deal with all the ordnance that was brought up, some dating back to the 18th century.

During this period major harbour works were also being undertaken in the Port of Algeciras and a breakwater was completed by 2011. Refer to Figure 9 below.

By 1990, the Algeciras port, in the south of Spain, overlooking the Straits of Gibraltar, was finding it difficult to cope with the amount of traffic. To overcome this, a decision was taken to carry out the biggest enlargement plan in the port's history (Gutierrez-Serret, R., Grassa, J.M. and Grau, J. 2009).

This enlargement consisted of a 2,060m long vertical detached breakwater, which provides shelter for two wharves: the North Wharf (680m long with a draught of 17.5 m) and the East Wharf (1,540m long with a draught of 18.5m). There is also a rubble mound breakwater on the south side, 890m long, which has a 100 Ha esplanade (Gutierrez-Serret, R., Grassa, J.M. and Grau, J. 2009).

The detached breakwater is a vertical structure comprising 43 anti-reflective caissons with one single alignment. A return period of 275 years was taken into account when designing the breakwater, which yielded a significant wave height of 4.8m and a peak period of 9s in a SSE direction. As can be seen in the geometry illustrated in Figure 9, there is potential for waves to reflect from the Algeciras breakwaters into Gibraltar Harbour. This may have been the motivation to install anti-reflective caissons, and the impact on Gibraltar might be expected to depend on the effectiveness of the anti-reflective mechanism.

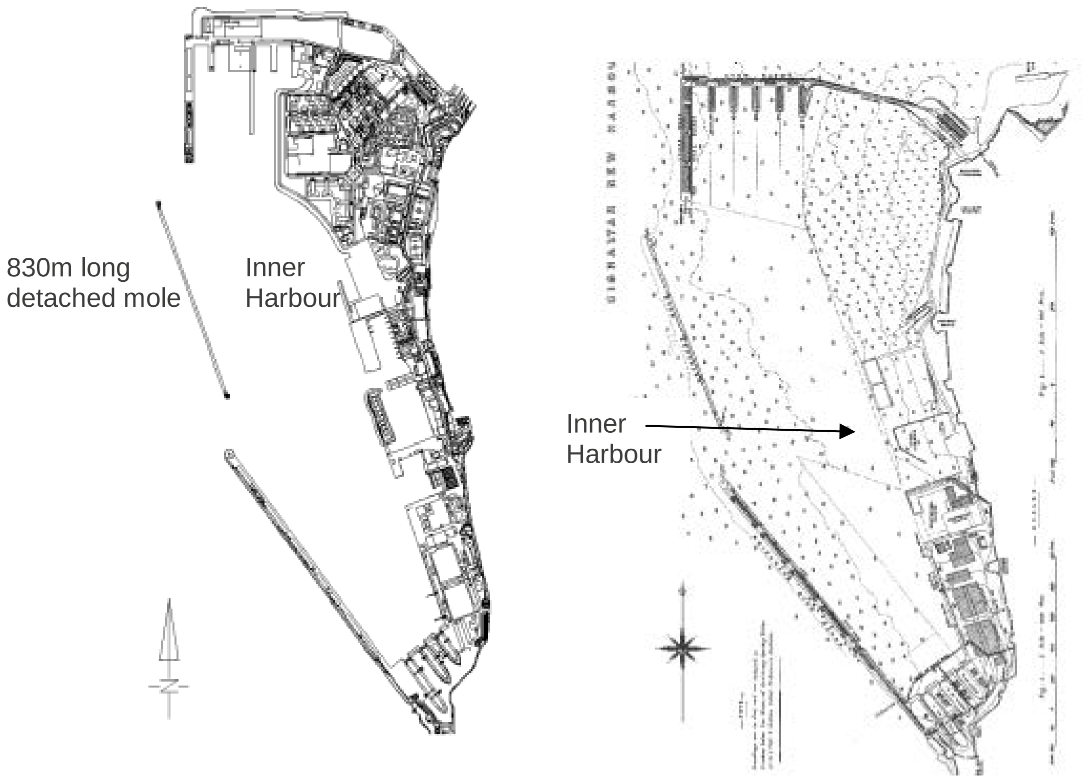


Figure 8 shows the extent of the reclamation works within the harbour area in 2008 in comparison to that at the end of 1905 (Scott 1914). For scaling purposes the detached mole is approximately 830m long or 2,720 feet.

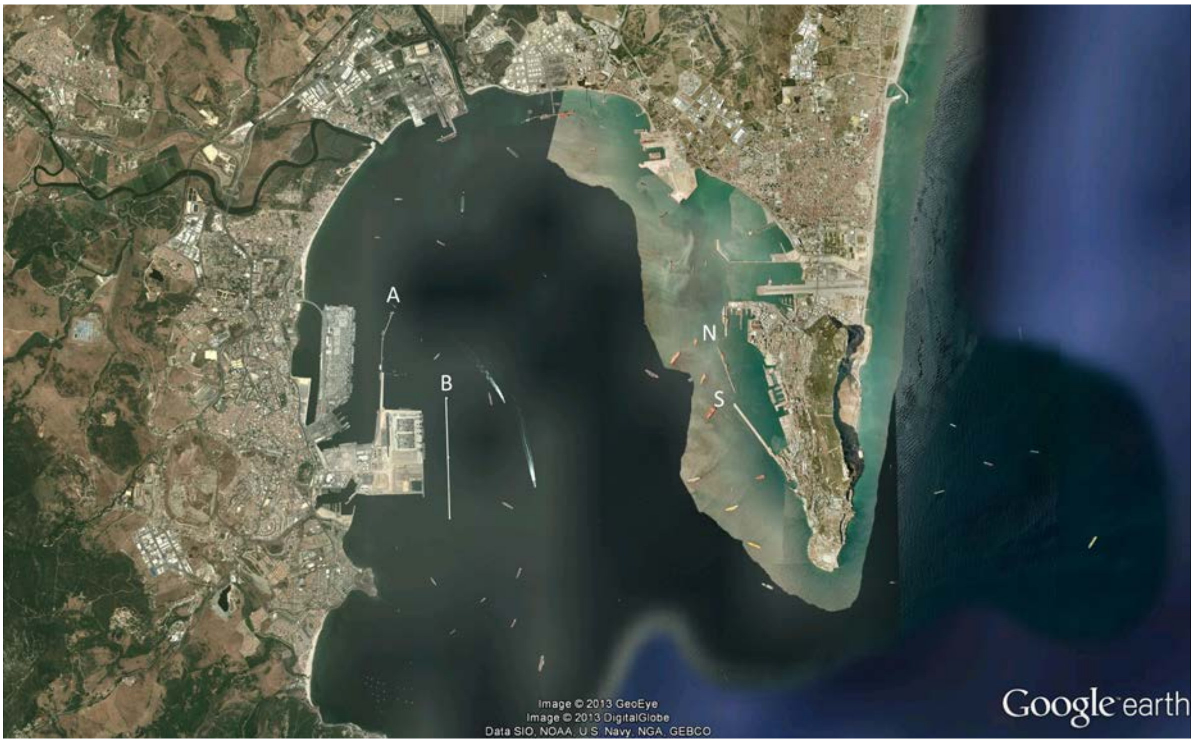


Figure 9 Gibraltar Bay showing breakwaters at Algeciras, with vertical wall frontage (A) and wave screen frontage (B) and Northern (N) and Southern (S) entrances to Gibraltar Harbour

Harbour use

A significant amount of reclamation works have occurred over the last 300 years. More recently in the late 20th Century the harbour basin has been considerably reshaped to allow the construction of much needed housing for the local community.

Present day harbour use is split between a commercial dockyard and military berths on the south and leisure and commercial port facilities towards the central and northern sections.

The infrastructure on the North Mole northern end of the harbour includes the liner terminal and other port related facilities. On the southern side, the present day South Mole provides berthing for Navy vessels whilst the dry docks are part of GibDock, a commercial ship repair yard. The Detached Mole also provides berthing facilities for commercial port operations.

The principal changes in harbour use are reflected in the changes in use of the harbour:

- Largely commercial use in the years preceding the major works completed in 1905
- Largely Naval (MoD) with commercial use from 1905 until the mid 20th century
- Largely commercial with Naval use from the mid 20th century to the present day

Clearly harbour use has shifted dramatically from military and naval operations to commercial use.

This trend is likely to continue especially given likely developments in cruise liner and bunkering activities.

Wave climate in the Bay of Gibraltar

Gibraltar Bay is situated at the eastern end of the Straits of Gibraltar and receives waves generated in the Atlantic, across the Straits and in the Mediterranean to the east. Situated on the east of Gibraltar Bay, the natural coastline shelters Gibraltar Harbour from Mediterranean waves, the residual of which are incident from the south. Atlantic and Straits generated waves are incident from the south west.

[MAKE MORE OF 3 SOURCES OF WAVES, ADD DISCUSSION OF NORTHERLIES AND OLD MOLE. DISCUSS THE PERSISTENCE OF EASTERLIES, AND THEIR UNUSUALLY LONG PERIOD]

[EXAMPLE STORM]

Rock revetments provide the sea defences around the recent areas of reclaimed land within the harbour basin. Otherwise the South Mole, Detached Mole and North Mole act as the first line of primary structures which protect the harbour from waves generated in the open sea. The Moles were designed to protect the harbour from southerly and south-westerly waves with entrances (labeled S and N in Figure 9) oriented to face west and north-west to minimize wave transmission. The rock revetments have had to be upgraded in works lasting over a period of two years between 2009 and 2011 as a result changes in wave climate.

Developments at Algeciras described above, and completed in 2009, include wave screens on the outer breakwater (labeled B in Figure 9), to limit wave reflection. Gutiérrez-Serret et al quote a predicted reduction in wave height after reflection of 60% (for periods <8s and Hs <1m) and 20-40% for other conditions, based on physical model tests.

The effect of reflections from the Algeciras breakwater on wave conditions at the entrances of Gibraltar Harbour have been investigated using the numerical model SWAN. A SWAN model of the approaches to Gibraltar Bay and the Bay itself has been run with a historic coastline prior to any port development at Algeciras and with the present day coastline. A representative Mediterranean storm wave condition at the entrance to the Bay has been taken as 4m Hs, 9s Tp incident from ESE. Based on analysis of waves observed at the Algeciras Buoy, this condition may be expected to occur approximately 0.1% of the time, or approximately annually dependent on storm duration. Based on Gutiérrez-Serret et al, a reflection coefficient of 0.7 has been assigned to the Algeciras breakwater wave screen for this wave condition.

Modeled directional wave spectra at the entrances to Gibraltar Harbour (Figure 10) have clear components corresponding to refraction and diffraction of the wave (relatively unchanged between historic and present day coastlines), and reflections from the Algeciras breakwaters, incident from between 240 ºN and 290ºN. The reflected components are incident from directions to which the Harbour entrances are relatively open. The increase in incident wave energy is significant, and more marked at the North entrance than at the South entrance.

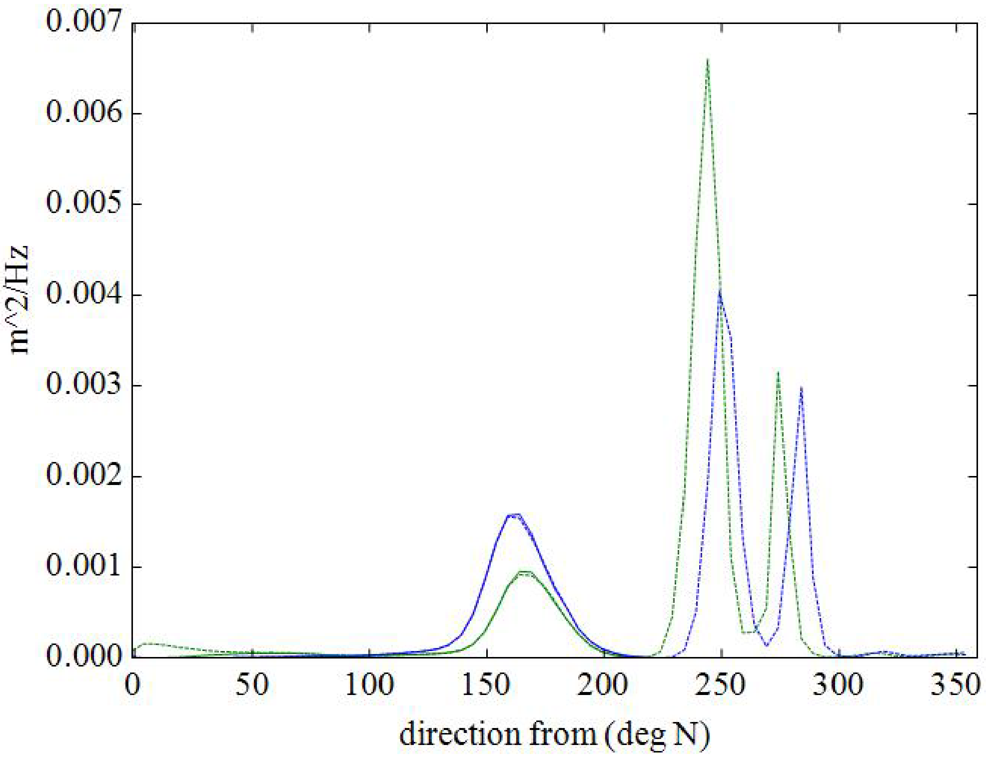


Figure 10 Directional wave spectra modeled at Gibraltar Harbour entrances for a representative easterly Mediterranean storm, North entrance (green), South (blue), historic coastline (solid), present day coastline (dashed).

Discussion on storm intensity in future projections (Donat et al) suggest some relatively mild variations, with a likely overall decrease in extreme wind speed, and therefore also incident wave height, at Gibraltar Bay, of the order of 5% over the 21st century. Predicted sea level rises over the 21st century are relatively minor compared to the 30m water depth at the entrances to the Harbour, and the effect of sea level rise on incident wave conditions at the harbour is expected to be minimal.

This study is limited in that it does not cover the complete wave climate, and changes in reflective properties at Algeciras are not expected to impact on the incident waves at Gibraltar Harbour that originate in the Atlantic or the Straits to the south. However, the representative condition modeled demonstrates an effect that is expected to hold for many of the most extreme waves incident at Gibraltar Bay. For the extreme component of the wave climate incident from the Mediterranean, it would appear that changes in the reflective properties within Gibraltar Bay will have a greater impact in incident wave conditions at Gibraltar Harbour than climate change.

Conclusions

In terms of the evolution and development of the harbour it is clear that for many years Naval needs have been paramount in the development of the harbour up until the early part of the 20th century. In the early years the short quay on the northern end of the town known as the Old Mole was the only place where warships could lie alongside, but its exposed position and in the event of an attack meant that it was not secure, moreover this location had to be shared with the merchant community. It was therefore clear that the Admiralty's first priority in this respect was to improve mooring facilities. Small improvements and extensions took place up until 1895 when the Admiralty began operations of a comprehensive project for the enclosure and defence of the harbour and the extension of the dockyard.

The more recent changes within the harbour have been driven by the needs of a growing population and a desire to expand the existing land mass as a result.

Numerical modelling results suggest that there may now be an additional component of wave energy at the entrances to Gibraltar Harbour corresponding to reflections from the Algeciras breakwaters. The direction of that wave energy limits the effectiveness of the Moles in protecting Gibraltar Harbour. It is therefore believed that future developments within Gibraltar Bay may have more of a significant effect on wave conditions within Gibraltar Harbour than sea level rise or climate change. It is recommended that reflections from the Algeciras breakwaters are taken into account in the design of structures at Gibraltar.

Gibraltar's current sea defences have been effective in protecting Gibraltar Harbour for over 100 years. Recent studies have shown that these structures will need to protect against the effect of increased wave energy.

Acknowledgements

The authors would like to acknowledge with thanks the permission granted from the Gibraltar Museum and HR Wallingford to reproduce valuable historic and current information of key importance, without which the publication of this paper would not have been possible.

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