CONSEQUENCES OF A DETACHED BREAKWATER ON THE MORPHOLOGICAL RESPONSE TO STORMS OF LA BARCELONETA BEACH (BARCELONA, SPAIN).

Amanda Sancho, Jorge Guillén and Elena Ojeda[1]

Abstract: This study analyzes the morphodynamic behaviour under storm conditions of La Barceloneta, an artificial embayed beach, previous and after the construction of a detached breakwater using video image measurement. In general, the decreases in the emerged beach area due to storm events were higher after the construction of the detached breakwater. So the detached breakwater built in La Barceloneta beach do not seem to be completely effective in preventing beach erosion during the most energetic storms events.

INTRODUCTION

Many coasts are in erosion as a consequence of a variety of causes (e.g., wave action, maritime constructions interrupting sediment transport, decrease of river inputs, development of coastal areas and massive housing constructions, etc.). Nowadays the most common approach to mitigate beach erosion is the protection of the beach using hard engineering solution (e.g., seawalls, detached breakwaters, groins) soft engineering techniques (beach nourishment), or some combination between them. For instance the detached breakwater in conjunction with beach nourishment can provide an attractive engineering solution to solve erosion problems (Ilic et *al,* 2005).

The addition of sand to the emerged beach is used to protect the beach or the region behind it, and also to attain a certain beach width for recreational uses (Hanson et *al,* 2002).

On the other hand, detached or shore-parallel breakwaters are coast-parallel structures built at a certain distance from the shore and totally unconnected to it, protecting a certain shoreline area from wave action (Bricio et *al.,* 2008). Their principal role is the protection of the coast from flooding or erosion although they have also been used to create artificial beaches (Ilic et *al.,* 2005). However, the results obtained after building a detached breakwater have not always been as desired, because it depends on the effect that the detached breakwater has on littoral sediment transport (Bricio et *al.,* 2008).

1 Instituto de Ciencias del Mar, Marine Geology Department, Passeig Maritim de la Barceloneta 37-49, 08003 – Barcelona (Spain) asancho@icm.csic.es

The advantage of detached breakwaters, compared to more traditional shoreline structures, is that they decrease the wave energy in the area immediately behind the breakwater, resulting in the development of depositional forms such as salients and tombolos (Ilic et *al.,* 2007).

The main aim of this study is to analyze the effects of a detached breakwater in the beach morphodynamics during storm conditions. To attain this, we have compared the morphological behaviour of La Barceloneta beach, located in Barcelona (NW Mediterranean), under similar storms conditions before (described by Ojeda and Guillén, 2008) and after the construction of the detached breakwater.

STUDY AREA

The Catalan coast is a micro-tidal zone (range < 20 cm), in which waves are the main stirring mechanism controlling coastal evolution. The most energetic storms approach from the east and they have a typical duration of a few days and are often associated with the cyclonic activity in the Western Mediterranean (Ojeda and Guillén, 2008).

The city of Barcelona is located in the north-western Mediterranean (Fig. 1) and has approximately 13 Km of coastline containing the city harbour in the southernmost part of the city, three marinas and more than 3 km of beaches. These beaches were created as a part of the renewal plan that took place in the zone for the 1992 Olympic Games.

Fig. 1. Localization of La Barceloneta beach. The beach presents the morphological configuration before the construction of the detached breakwater.

La Barceloneta is an artificial embayed beach which shows an orientation of approximately 20º from the north and a length of 1100 m. Between 1992 and 2005, the emerged area of La Barceloneta displayed an erosive trend alleviated by sporadic artificial nourishment and sand relocations (Ojeda and Guillén, 2008). La Barceloneta beach (NW Mediterranean) is an example of an erosive beach where, in order to solve this problem, the beach was nourished and a submerged and a detached breakwaters were built.

To prevent this erosion a number of works were launched on 2006: the beach was nourished with 80000 m^3 and 46000 m^3 of sand in March and June 2006, respectively; a submerged breakwater of 120 m-length and located at 2 m under sea level, was built between December 2006 and March 2007; and, finally, a detached breakwater of 140 m-length, located at 7.5 m and standing out approximately 1 m above sea level, was built during the period November 2006-May 2007 (Fig. 2).

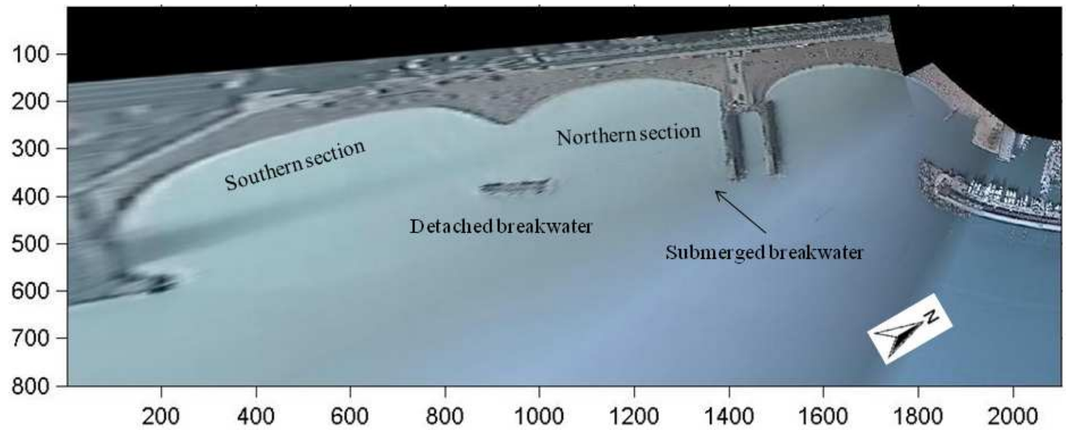

Fig. 2. Morphological configuration of La Barceloneta beach after the construction of the detached breakwater. Coordinates are given in metres measured from a local zero.

METHODOLOGY

Wave data was characterized using information from Llobregat directional buoy (XIOM, http://www.boiescat.org/) and, when this data was not available, from the WANA model data set, node 2066051, (Puertos del Estado, www.puertos.es). The seven significant storms, affecting La Barceloneta beach between May 2007 and January 2009, were analyzed (Table 1) and compared with the results of 16 significant storm events occurring from November 2001 to December 2004, prior to the construction of the detached breakwater. Significant storms were defined by Hs higher than 2.5 m during the peak of the storm and a threshold Hs of 0.5 m for pointing out the beginning and the ending of the storm. A wave energy parameter was defined as the sum of squares of the significant wave height per duration.

Table 1. Characterization of the storm events

Event	Initial Date	Hs_{max} (cm)	Wave direction
1	19/10/2007	292	ESE
2	15/12/2007	337	E
3	08/05/2008	262	SE
4	28/10/2008	280	S
5	22/11/2008	260	SSW
6	25/12/2008	439	E
7	22/01/2009	338	SSW

For each storm event, the shoreline position of La Barceloneta beach was obtained by means of an Argus video system (Holman and Stanley, 2007). The video system is located atop a building close to the Olympic Marina at a height of around 142 m, and it is composed of five cameras pointing at the beaches and offering a 180° view of the coast (images available at: http://elb.cmima.csic.es). The images are in the visible range of light and the sampling is done every daylight hour during a ten-minute period (1 picture per second).

The shorelines before and after each storm event were mapped using the 10-minute time exposure images. In order to minimize errors, three shoreline positions were obtained for each sampled day.

Finally, the emerged beach area of the “two” new beaches was calculated for each storm event using the beach promenade as the back limit of the beach

RESULTS

Before the construction of the detached breakwater the responses to storms were general erosion or accretion, beach rotation and differential erosion alongshore (Table 2, adapted from Ojeda and Guillén, 2008).

Table 2. Variation of the emerged beach area before the construction of the detached breakwater (adapted from Ojeda and Guillén, 2008).

Event	Initial Date	Hs_{max} (cm)	Wave direction	Wave Energy ($\Sigma Hs^2 \cdot, m^2 \cdot h$)	Morphological response	Δarea La Barceloneta (m^2)
A	10/11/2001	403	ESE	747	Beach rotation	6148
B	14/12/2001	303	ENE	334	Beach rotation	1097
C	04/01/2002	329	ESE	136	General accretion	4847
D	11/04/2002	290	E	175	General accretion	3695
E	07/05/2002	380	E	378	Localized erosion (S)	-1311
F	14/11/2002	257	SE	136	Localized erosion (S)	-2726
G	21/11/2002	260	S	81	Beach rotation	-521
H	25/02/2003	275	SSW	290	Beach rotation	1080
J	03/04/2003	270	E	110	General erosion	-3157
K	15/10/2003	396	SSW	718	Localized erosion (N)	-977
L	31/10/2003	380	SSW	298	General accretion	7578
M	04/12/2003	258	E	92	General accretion	6756
N	08/12/2003	285	E	125	General erosion	-4253
O	29/03/2003	280	E	132	Localized erosion (N)	-516
P	16/04/2004	320	ESE	179	General erosion	-2468
J	03/05/2004	260	ENE	130	General erosion	-4404

The detached breakwater caused a new morphological configuration of the beach dividing it into two separated beaches (labelled as northern and southern sections in Fig. 2) with different morphodynamic responses to storms. Table 3 displays the changes in the two beach areas (La Barceloneta North and La Barceloneta South) associated to each storm and the wave energy parameter. The initial area (May 2007) of the northern and southern sections of the beach were about 24300 m^2 and 53800m^2 respectively.

Table 3. Variation of the emerged beach area after the construction of the detached breakwater*.

Event	Initial Date	Hs_{max} (cm)	Wave direction	Wave energy ($m^2 \cdot h$)	Δarea La Barceloneta North (m^2)	Δarea La Barceloneta South (m^2)	Δarea La Barceloneta (m^2)
1	19/10/2007	292	ESE	224	73 (NC)	763 (NC)	836
2	15/12/2007	337	E	348	-2681(E)	-4074 (E)	-6755
3	08/05/2008	262	SE	257	-2929	-4261 (E)	-7190
4	28/10/2008	280	S	365	82 (R)	-1521 (E)	-1439
5	22/11/2008	260	SSW	411	-645 (E)	-2261 (E)	-2906
6	25/12/2008	439	E	563	-9887 (E)	-7296 (E)	-17183
7	22/01/2009	338	SSW	265	1397 (A)	-221 (R)	1176

* The morphological response is showed in brackets: NC, no change; E, erosion; A, accretion; R, beach rotation.

In tables 2 and 3, the last column represents the variation of the total emerged beach area of La Barceloneta.

The results show that most of storms produce general erosion in the emerged beach, with sand losses that are lower in the northern section. However, during Event 6 (the most energetic storm according to the wave energy parameter) the losses at the northern section of the beach were even higher (around 10000 m^2) than at the southern section (around 7000 m^2). This area decrease implied a 60% reduction of the northern emerged beach area (Fig. 3).

Each beach displays a homogeneous morphological response during storm events. In addition to the general erosion, storms coming from the South can produce beach rotation in both beaches and a general accretion in the Barceloneta North (Event 7).

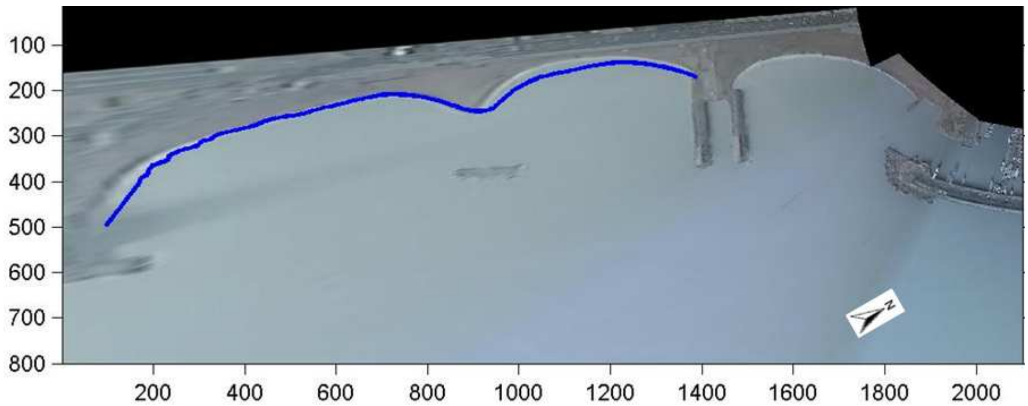

Fig. 3. La Barceloneta beach the day after event 6 (December 2008). The blue line shows the shoreline position before this storm. Coordinates are given in metres measured from a local zero.

CONCLUSIONS

The detached breakwater caused a new morphological configuration of La Barceloneta beach dividing it into two separated beaches and changing its morphodynamic response to storms.

Previous to the construction of the detached breakwater, storms were responsible of changes in the emerged beach area that ranged between +7000 m^2 and -4000 m^2 (Ojeda and Guillén, 2008). After the construction of the detached breakwater most of the storms produced decreases in the emerged beach area in both beach sections. Changes in the emerged beach area ranged between +1400 m^2 and -10000 m^2 and 800 m^2 and -7300 m^2 in the northern and southern sections respectively. While changes in the total emerged beach area varied between +1000 m^2 and -17000 m^2.

These preliminary results suggest that the new protection structures on La Barceloneta beach (detached and submerged breakwaters) are not completely effective to prevent beach erosion during the most energetic storms events.

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