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Geometric Detached Breakwater Indicators on the Spanish Northeast Coastline

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ABSTRACT

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Many beaches have been eroded and the obvious environmental and landscape degradation of many coastal stretches are problems that coastal engineers are spending time solving. With this in mind, different protection methods have been used over time, most on the basis of the artificial nourishment of beaches and the building structures such as groynes and detached breakwaters. Detached breakwaters are artificial structures, generally parallel to the coastline, inspired by the working of natural formations, protecting a certain stretch from wave action and being able to create accretion areas. This is why these structures have been in general use, with different results, since the 1970s in countries such as Japan, the United States, Israel, Spain, Italy, and Australia.

The study undertaken for this research focuses precisely on this type of structure, with the purpose of providing an overall view of the state of the art in this field. In addition, the effects of a detached breakwater on the shoreline for a series of real cases on the Spanish coastline were analysed to check whether the empirical relations given by different researchers for classifying the shoreline's type of response were fulfilled for them all or not. This study only takes formulas on the basis of the geometrical characteristics of breakwaters into consideration as being the most used by design engineers for predesigning a construction. All the formulas studied are based on the nondimensional B/X monomial, which is a ratio between the two most important geometric breakwater parameters (the length of the detached breakwater, B, and its distance to the initial coastline, X), so the result of this work led us to propose the following geometric model for the case of the Catalonian coastline: tombolo formation if $B/X \geq 1.3$; salient formation if $1.3 > B/X > 0.5$; limited shore response if $0.5 \geq B/X$.

ADDITIONAL INDEX WORDS: *Detached breakwater, tombolo, salient, limited response.*

INTRODUCTION

The coast is a narrow strip subjected to large imbalances; at many points, it is in a profound state of regression as a consequence of many, varied causes: wave action, tides, and currents; massive mining of aggregate and maritime constructions interrupting sediment transportation; mean sea level rise; development of coastal areas and massive housing developments in the active area of beaches; river regulation constructions; *etc.* All these reasons lead to the erosion of a large number of beaches and environmental and landscape degradation.

This precarious coastline situation today constitutes a serious problem of great concern to which coastal engineers, aware of the generalised beach erosion problem, are devoting their work seeking solutions to guarantee coastal stability.

Different methods of protection have been used throughout time, mostly on the basis of artificial beach nourishment and the building of structures, amongst which detached breakwaters play a major role as being able to create areas of accretion on the coast (Diez, 2003).

Although detached breakwaters are not as popular as groynes, their effectiveness in controlling coastal erosion became manifest from the successful results obtained after their construction in various parts of the world. More than 2100 detached breakwaters were built in Japan between 1962 and 1981 (an average of about 105 a year), which indicates the major trend in that country toward the use of this type of structure for beach protection and stabilisation. Detached breakwaters have also been built in other countries, *i.e.,* Australia, Denmark, the United States, Spain, Israel, Italy, and the Ukraine (Herbich, 2000). However, the results obtained after building a detached breakwater have not always been as desired, and, therefore, they have been studied as coastal defence works on multiple occasions by various engineers. Despite this, the state of knowledge with respect to these constructions is not as clear as might be expected since many different particular cases have been studied and information is multiple, confusing, and sometimes even contradictory.

This is the framework into which the research work presented here fits. This work forms part of a wider study on detached breakwaters being undertaken in the Ports Laboratory of the Escuela de Ingenieros de Caminos, Canales y Puertos, Universidad Politécnica de Madrid. The aims pursued in this research were, first, to provide an overview of

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the state of the art in detached breakwater issues, and second, to analyse the response induced in the coast by several cases of breakwaters and detached breakwater systems selected as prototypes from amongst those on the Spanish coastline, and to check whether the empirical relations given by different authors for classifying the type of coastal response to a breakwater are fulfilled in these prototype cases or not.

REVIEW OF THE STATE OF THE ART

General

Detached breakwaters are noticeably coast-parallel structures built a certain distance from the shore and totally unconnected to it, protecting a certain shoreline area from wave action whilst reducing the amount of energy entering into it. They are artificial structures inspired by the working of natural formations such as reefs, bars, or islands close to the coast, which constitute unique dynamic effects. Reducing wave action in the detached breakwater protected area leads to major alterations in the coastline transportation of sediments and leads to materials being deposited and accumulating in that area in the lee of the structure. If enough material is deposited, it will form a sandy point or a salient that might develop to the extent whereby it reaches the structure, in which case it is called a tombolo (SUÁREZ BORES, 1978).

This ability to create accretion areas on the coast whilst seeking not to completely interrupt the continuity of longitudinal sediment flow is, from the point of view of littoral dynamics, what makes building detached breakwaters more advantageous for protecting and stabilising beaches than other types of structures such as seawalls, which can only guarantee that the coastline will remain in a certain position but do not protect the beach facing them from erosion, or groynes, which can create areas of accretion but form barriers to littoral transport, causing major impacts on the beaches located in stretches downstream of the groyne through reducing sediment supply.

The time required for the coast to regain equilibrium after building a detached breakwater depends on the construction's characteristics and local conditions as far as the marine climate and sediment availability are concerned, although, in 1982, on the basis of the observation of actual cases, NIR (1982) pointed out that most tombolos accumulate half their final volume in a period of 1 to 2 years, whereas the final state of equilibrium is reached about 5 to 6 years after building a detached breakwater and that the salient or tombolo formed may occupy 25% to 75% of the protected area. Hence it can be seen that the rate of sand accumulation is much higher in the first few years after building the structure than in a second stage. Once the time required to reach equilibrium has elapsed, the system remains relatively stable and is not affected, or only moderately so, by seasonal variations or occasional changes due to storms or other nonhabitual events. These results were corroborated by HERBICH (1989).

It should be added that detached breakwaters can be built isolated or forming series structure systems depending on the length of coastline to be protected. A single detached breakwater is used to protect a highly localised area with relatively small dimensions, whereas a system of detached breakwaters is necessary when the length of the coastal stretch to be protected is extensive.

Design Objectives: Advantages and Disadvantages

The main aim of a detached breakwater is to protect a certain stretch of coastline from wave action. Such protection may enable the tendency toward erosion of a beach to be reduced or even totally suppressed, not only preventing a loss of sand but favouring the accumulation of sedimentary material. This is why detached breakwaters are used as a coastal protection means with different goals:

- To reduce incident wave energy in a certain stretch of coast, allowing it to be used and enjoyed.
- To safeguard a beach from the action of storms whilst guaranteeing its width and sheltering all back beach facilities from water.
- To prevent, contain, or retard beach erosion.
- To aid natural sand sedimentation with the purpose of inducing an existing beach to develop by increasing its width, or forming a new one.
- To increase the ability of artificial sand supplies to last in beach regeneration projects.

However, detached breakwaters have a series of disadvantages to be borne in mind when assessing the advisability of building them, such as:

- The relatively high construction cost and high costs involved in their maintenance, which are greater the greater the structure's depth and distance from the shore.
- Danger to beach users from strong currents forming in the bathing area and, in themselves, by users accessing the structure either on foot if a tombolo has formed, or because the structure's closeness to the shore allows them to easily swim to it.
- The inconvenience for some beach users caused by losing a stretch of coast for practicing water sports such as surfing or small boat sailing.
- The impact on adjacent beaches, mainly those downstream from the breakwater in the direction of the longitudinal flow of littoral transport, through a reduction in the rate of sedimentary material supply.
- Aesthetic problems due to the view of the horizon being interrupted if the structure's crown level is high.
- The uncertainties existing, even today, in designing a detached breakwater or breakwater system, mainly as regards guaranteeing a certain coastal response.

To improve the functionality of detached breakwaters and their use as coastal protection structures, whilst overcoming their disadvantages, different research fronts are open and orientated toward studying the processes and phenomena associated with building a detached breakwater, the influence of the different parameters determining them, and the effects that this type of marine construction has on the coastline.

Hydrodynamics around a Detached Breakwater

Detached breakwaters cause complex changes in coastal hydrodynamics that directly affect littoral currents and sediment transport. Many processes occur in their surroundings that interact and give rise to large flows of water and sediments, constituting the prevailing mechanism from the coast's morphological response point of view in the presence of this type of structure.

An area protected from direct wave action is generated after a detached breakwater is built; this is an area where wave action is transformed, mainly by diffraction at the tips of the detached breakwater and by transmission through and over the structure, in which the wave heights and current velocities are significantly reduced and in which, therefore, part of the sedimentary material transported is deposited.

If a detached breakwater is far from the shore, it may result that the shelter provided by the structure as to wave action is not enough and, therefore, the effect achieved on the shore is practically negligible. This depends on the greater or lesser effect the detached breakwater has on littoral sediment transport, both directly, for its very presence, and for the phenomena of diffraction and transmission the structure causes.

A detached breakwater undoubtedly constitutes a barrier to cross-sediment transport, both in the onshore direction, interrupting the entry of sand from the front in the protected area, and in the offshore direction, by preventing sedimentary material from being dragged away by rip currents.

As far as the direct influence on longitudinal sediment transport is concerned, what a detached breakwater reduces is sediment transport capability in the protected area, where wave heights are lower.

A detached breakwater's siting with respect to the breaking wave area is important because if the structure is located in the surf zone (nearer to the shore than the breaker line), part of the longitudinal sediment transport passes offshore, behind it; this might be desirable if what is required is for the sediment to reach stretches of coast downstream from the area to be protected. Moreover, with waves impacting on a detached breakwater, they diffract on the tips of the structure and part of the energy is transmitted behind it (SUÁREZ BORES, 1978, 1980).

Diffraction involves a change in wave propagation direction since the wave fronts turn around the ends of the structure, taking up a curved shape that may be likened to circles with a centre at each of the breakwater's tips. When running up the foreshore, waves follow the direction of wave propagation, but they always run down along the maximum slope line; the wave's littoral and rip currents on the beach profile inside the area protected by a detached breakwater clearly move in a zigzag fashion, causing a net dragging of sedimentary particles to the centre of the sheltered area. Little by little, this movement changes the shoreline in plan shape, which tends to become parallel to the diffracted wave fronts (MING and CHIEW, 2000).

Diffraction also reduces wave heights along the diffracted wave fronts. This means there are dynamic sea-level setup gradients inside the protected area, directed from each end thereof to the centre area, causing confronting longitudinal currents to form (called Iribarren's currents in SUÁREZ BORES, 1978), dragging sediments toward the lee of the protected area and depositing them when their speeds drop. These currents in fact form part of two closed systems of non-uniform currents rotating in the opposite direction, located in the strip between the detached breakwater and the shore (GOURLAY, 1981).

These current systems contribute toward moulding the plan shape of the beach in the shelter of a detached breakwater, since they carry material from the outer to the inner area of the area protected on both sides, causing sedimentary material to accumulate in the area where both rotating currents meet.

If the amount of sand transported and deposited inside the protected area is enough, the shore's response to a detached breakwater will become increasingly more evident when the sediment accumulates to form a salient, which will be more or less symmetrical to the detached breakwater's symmetry centre line depending on the symmetry of the current systems formed; this in turn depends on the incident wave diffraction patterns and, in a first incidence, on the deviation of the local waves' predominant direction from the said detached breakwater's perpendicular.

Apart from the currents described, the intersection of the wave fronts diffracted at each of the detached breakwater's tips at the centre of the protected area gives rise to a resulting current directed perpendicularly to the coast and opposite to the salient's growth, which plays an important role in its development (MING and CHIEW, 2000).

Finally, energy transmission in a detached breakwater occurring both over the structure (due to run-up and overtopping phenomena) and through it (due to its permeability) is one of the main factors responsible for coastline changes behind a detached breakwater mainly due to its influence on the diffraction effect, which reduces (HANSON and KRAUS, 1991). Thus, the higher the amount of energy transmitted, the less the difference between wave heights outside and inside the protected area, and, therefore, the effect of diffraction, setup gradient transport, and the amount of sand transported inward of the sheltered area all reduce. Moreover, waves overtopping the structure will give rise to divergent flows outward of the structure's sheltered area to preserve the mass of water inside, which will lead to sediment being transported outward of the protected area. These two effects act jointly and tend to prevent sand accumulating behind the detached breakwater. Thus, the higher the energy transmission in a detached breakwater, the less the effect on the coast.

Also, as wave transmission may significantly vary depending on the structure's configuration (geometry) and composition (permeability), and may change in different timescales depending on the tide and variations in the characteristics of incident waves, it may be asserted that the coast's response behind a detached breakwater is highly sensitive to variations in the acting agents (waves and tides) in time (WAMSLEY, KRAUS, and HANSON, 2003).

The Shore's Response

Morphological changes occurring in a stretch of coastline after building a detached breakwater are its response to altering the surrounding conditions, the local hydrodynamics, and transport patterns.

Part of the sedimentary material transported by littoral flow tends to accumulate in the area protected from wave action by a detached breakwater or breakwater system. Changes in the shoreline are more or less marked, depending on the amount of sediment captured and deposited in that area; thus, the coast's response may be classed into tombolo, salient, and limited response (if changes in the shore are negligible). The type of response depends on the amount of energy entering the sheltered area.

Research previously undertaken has demonstrated that morphological changes occurring in the shoreline are not always accumulative (as happens with emerging breakwaters) in the cases of submerged detached breakwaters, but that the coast's response may also be erosion, depending on the detached breakwater's distance from the shore (Ranasinghe and Turner, 2004; Sánchez-Arcilla *et al.,* 2004). The effects a detached breakwater has on the shoreline are determined by many factors that may be classified according to their nature: parameters relating to the local marine climate or wave action (acting agent), parameters related to the breakwater (its configuration and structural characteristics), and aspects concerning sedimentary material.

Parameters Shaping the Local Marine Climate

The most important are those defining the sea state under average conditions, *i.e.*:

- Wave height (H): Influences the diffraction pattern in the sheltered area, the velocity of closed current systems formed, and the transport capability. A greater wave height causes a greater amount of sediment to accumulate in the protected area and a more pronounced salient to form (Johnson *et al.,* 1995).
- The wave period (T): The greater the period, the greater the amount of energy entering the protected area.
- The wave propagation direction (θ): Its effect depends on the degree of obliqueness. The salient formed when transport inward of the sheltered area grows on one of its sides may well undergo a major increase for small deviations in the waves' angle of incidence from the perpendicular to the coast.

  The coast's response will be limited for large deviations with strong currents forming between the shore and the detached breakwater in the direction of the longitudinal wave component, which will tend to drag sediments outside the protected area.

  Also, wave obliqueness has an obvious effect on the symmetry of the salient formed.
- Average sea-level setup (S): Influences the different hydrodynamic phenomena that determine the coast's response.

Detached Breakwater-Related Parameters

These are the only parameters liable to be monitored by the structure's designer to obtain some kind of response from the shore. The way the structure impacts the shore's incident waves and the extent of such impact depend on those parameters, as does the amount of energy in the protected area.

Distinction must be made between characteristics relating to the detached breakwater's geometry as an individual element, those related to its structure, and the geometries of the system should it be formed by a group of detached breakwaters.

A detached breakwater's geometrical characteristics:

- The structure's distance from the shore (X): The amount of sediment retained increases with X, with the shelter effect on the shore growing and the impact on sediment transport and littoral hydrodynamics increasing. Once a critical distance of the breakwater from the shore has been reached (depending on waves, sediment, and beach profile), the amount of energy entering the protected area commences to increase and, therefore, the volume of sand accumulated reduces with X continuing to grow (Zyserman and Johnson, 2002).

  The influence of a detached breakwater's distance from the coastline is determined by the location of the wave-breaking area. The structure's relative position with respect to the area where transport occurs (depending on the marine climate and characteristics of the sediment) determines whether the breakwater is close to or far from the coast. When the breakwater is outside the surf area, the structure has little influence.
- The breakwater's length (B): This is important when a detached breakwater is located sufficiently close to the coast for its presence to cause some effect. The influence of B depends on the relation between this figure and the breakwater's distance from the shoreline (X).

  The volume of accumulated sand progressively increases for growing lengths of the structure, up to a maximum as from which transport flows on each side of the structure are isolated and become a maximum and separate from each other. The maximum amount of sediment trapped occurs when the structure's length is approximately twice the width of the surf area (taking such to be the area where approximately 80% of the sediment transport takes place) (Zyserman and Johnson, 2002).
- The crown elevation (C): The lower the structure's height, the greater the wave overtopping, the greater the amount of energy transmitted to the protected area, and, therefore, the less the amount of accumulated sediment.
- The crown width (A): The greater the crown width, the greater the dampening of the energy transmitted, whether through the structure's body or over it should there be overtopping.
- The breakwater's orientation to the coast (θ_s): Influences the incident wave's diffraction pattern and the shape and size of the salient formed.

  Detached breakwaters are usually built parallel to the coast even though the prevailing waves show a certain obliqueness to the latter's perpendicular; however, when obliqueness is highly marked, it is advisable to orientate them perpendicular to the direction of the wave fronts' advance with the purpose of increasing the stretch of coast protected whilst keeping the structure's length.

A detached breakwater's structural characteristics:

- The structure's permeability (P): The greater the structure's permeability, the greater the amount of energy transmitted to the protected area and disturbance in this area, and the less the coast responds.

Geometric characteristics of the detached breakwater system:

- The distance between structures (G): Wave diffraction is determined by the ratio of the distance between breakwaters to the wave length (G/L). The greater the G/L ratio, the more the diffraction phenomenon is attenuated and the greater the amount of energy entering the protected area. DALLY and POPE (1986) recommend that the value for G should be at least twice the wave's length, so that the shoreline's response is more or less continuous and uniform.

Sedimentary Material-Related Parameters

- The actual transport of sediment in the area (Q_R) is one of the major factors on which the coast's response behind a detached breakwater depends since it could result that the coast's response was negligible through not having enough sediment.
- The sedimentary material's characteristics, *i.e.,* its density (ρ_s) and average nominal diameter ($D_{50,s}$). The transport of the sedimentary material depends on these parameters, *i.e.,* whether the material may or may not be incorporated into the littoral flow for a certain amount of wave energy and whether it may or may not be deposited when that energy diminishes, as well as its sedimentation rate.

Study and Design of Detached Breakwaters

Studying the influence of a detached breakwater or system of detached breakwaters is based on observing and understanding the phenomena taking place after it has been built. The major, basic research route is to analyse cases existing in different places in the world that become a prototype for subsequent structure designs. This analysis can also be performed using tests with physical or numerical models. Models are the tools enabling actual or hypothetical cases to be simulated and the influence of each of the parameters determining the coast's response to a detached breakwater to be studied separately. Several research works have been focused over the last few years on seeking empirical relations between parameters that will determine the coast's response to a detached breakwater, with the aim of developing analytical models enabling this type of structure to be designed. Analytical models allow for simple, rapid analyses, but quantitative results are only approximate; they are therefore valid as a structure presizing method. It is advisable to use numerical models to obtain more precise results. Table 1 lists some of the most outstanding papers in the field of analytical models developed for studying the relation between the characteristics of a detached breakwater and the effects caused on the shore.

Before thinking of designing a detached breakwater, it is fundamental to have deep knowledge of the characteristics of the stretch involved: geomorphology, marine climate (state of the sea under average conditions and in a storm situation), distribution and rates (gross and net) of sediment transport, seasonal climate variations, historical evolution of the coastline, rates of erosion or accretion, sand sources and sinks, beach characteristics (type of sediment and shape of beach profile), and problems existing.

Likewise, the length of the coastal stretch to be acted on has to be defined, and a decision made about what the final state required is, *i.e.,* the degree of protection to be achieved for the beach, the type of response to be induced (tombolo, salient, or limited response), and the geometrical characteristics of the beach.

Knowing the amount of sand that has to necessarily accumulate for the shore to reach the final state of equilibrium is fundamental to know whether there is sufficient availability of sand in the stretch to be supplied by littoral transport without seriously damaging the adjacent beaches or, on the contrary, whether it is of interest to provide an artificial supply.

METHODS

Reason behind the Research Work Carried Out

After reviewing the state of the art, the conclusion reached is that there are no clear design guidelines enabling designers to relate the characteristics of the detached breakwaters they design to the effect they wish to produce on the coast because of the still-limited knowledge of the phenomena taking place, even today, and the many factors coming into play. In this scenario, it would seem logical for many coastal engineers to feel reluctant to use detached breakwaters as a solution to beach protection or stabilisation. However, this contrasts with the theoretical functional advantages of this type of construction.

This is why one of the lines of research in the Ports Laboratory of the Escuela de Ingenieros de Caminos, Canales y Puertos of the Universidad Politécnica de Madrid is to study the functional design of detached breakwaters, apart from considering that suitable sizing of the latter could be the answer to the erosion problems of many beaches, so as to lay down a presizing methodology with a simple design that will enable the characteristics of a detached breakwater to be linked to the response it is required to induce from the coast.

The study being presented here constitutes the first stage of the foregoing research work. Its purpose was to check the veracity of the multiple empirical geometric relations, given by different authors, classifying the type of coastline response to a detached breakwater, by analysing the response of the shore to a group of detached breakwaters selected from those existing on the Spanish coastline.

Characteristics of the Empirical Relationships Analyzed

The empirical relationships analyzed in this study are those classifying the shore's response by considering the ratio between the two basic geometric breakwater parameters: the length of the detached breakwater (B) and the structure's distance from the initial coastline (X). These are very simple relations, of the type B/X greater than, less than, or equal to a certain figure.

The study is centred on this type of ratio because after the state of the art was reviewed, several models of this type

Table 1. *Summary of the most significant analytical models developed for studying the relationship between the characteristics of a detached breakwater and the effects on the shoreline.*

Authors	Year	Aim	Comments
Inman and Frautschy	1966	Geometrical criterion for classifying the type of shoreline response (basic empirical relation)	Real case data (United States)
Toyoshima	1974	Geometrical detached breakwater design criterion using analytical relations for determining the breakwater's length, distance from the shore, distance between structures, and crown level	Real case data (Japan) Takes into account the type of beach and wave characteristics (wave length and wave height)
Noble	1978	Geometrical criterion for classifying the type of shore response (basic empirical relation)	Real case data (United States)
Suárez Bores	1978	Conceptual criterion for classifying the type of shore response (shore classification)	Real case data (Spain)
Walker, Clark, and Pope	1980	Geometrical criterion for classifying the type of shore response ("Diffraction Energy Method")	Real case data (United States) The amount of energy penetrating into the inside of the protected area as from diffraction isolines is considered
Gourlay	1981	Geometrical criterion for classifying the type of shore response (basic empirical relation)	Data from physical models Points out the importance of locating the breakwater with respect to the surf area
Nir	1982	Geometrical criterion for classifying the type of shore response (basic empirical relation) Determining the average thickness of the sand deposit	Real case data (Israel)
Rosen and Vajda	1982	Geometrical design criterion for detached breakwaters on the basis of graphic relations for determining the length and the distance of the detached breakwater from the shore depending on the response expected (salient or tombolo) Characteristics of accumulation should a tombolo form (width, area, and volume)	Data from physical models, numerical models, and real cases The relative location of the detached breakwater to the breaker line is taken into account
Hallermeier	1983	Criterion for classifying the shore's response	Data from physical models and real cases Takes the littoral area's limit depth into account
Noda	1984	General description of the shore's response	Physical model data Considers the relative location of the detached breakwater with respect to the breaker line
Japanese Ministry of Construction (in Coastal Engineering Research Center, 1995)	1986	Geometrical criterion for classifying the type of shore response (basic empirical relation)	Real case data (United States)
Dally and Pope	1986	Geometrical criterion for classifying the type of shore response (basic empirical relation) for single detached breakwaters and detached breakwater systems	Real case data (United States)
Harris and Herbich	1986	Geometrical criterion for classifying the type of shore response (basic empirical relation) Determining the volume of accretion	Data from physical models and real cases
Coastal Engineering Research Center*	1995	Iterative method for the geometric design of detached breakwaters or systems	Real case data (Japan) The method takes into consideration the type of beach, wave characteristics, depth of breakers, results expected
Pope and Dean	1986	General description of the shore's response behind a detached breakwater system	Real case data (United States) Takes into consideration the depth at which the structure is located
Seiji, Uda, and Tanaka	1987	Geometrical criterion for determining whether there is erosion or not as to the spaces between consecutive breakwaters in a system of series structures Basic empirical relation for a maximum area tombolo to form	Real case data (Japan)
Sonu and Warwar	1987	Law of temporary evolution of the volume of sand accumulated in a detached breakwater's sheltered area	Real case data (United States)
Suh and Dalrymple	1987	Geometrical criterion for classifying the type of shore response (basic empirical relation) Assessment of the salient formed Determining the volume of accretion	Data from a physical model and real cases The relative location of the detached breakwater to the breaker line is taken into account for assessing the salient formed

Table 1. *Continued.*

Authors	Year	Aim	Comments
Sunamura and Mizuno (in Horikawa, 1988)	1987	Geometrical criterion for classifying the type of shore response (basic empirical relation) behind reefs and islands Determining the stretch of coast affected by the obstacle	Natural formation data
Berenguer and Enríquez	1988	General description of the shore's response in the case of pocket beaches	Data from real cases of the Spanish Mediterranean littoral
Kraft and Herbich (in Herbich, 1989)	1988	Geometrical criterion for classifying the type of shore response (basic empirical relation) Determining the volume of accretion	Data from numerical models and real cases
Ahrens and Cox	1990	Geometrical criterion for classifying the type of shore response (response index as a function of a basic empirical relation)	Real case data
Hanson and Kraus	1990	Geometrical criterion for classifying the type of shore response (basic empirical relation)	Data from a numerical model The following are taken into consideration: The breakwater's transmission coefficient Wave characteristics Breakwater's depth
Hsu and Silvester	1990	Geometrical criterion for classifying the type of shore response Definition of the plan shape of beaches associated with the salient behind a detached breakwater (parabolas)	Data from physical models, numerical models, and real cases
Mangor *et al.* (in Pilarzyck and Zeidler, 1996)	1992	Determining the volume of accretion	Data from physical models Cross-distribution of solid littoral transport in the beach profile is taken into account
Rosati, Gravens, and Chasten	1992	Geometrical criterion for classifying the type of shore response	Data from a numerical model and real cases The breakwater's transmission coefficient, wave characteristics, and breakwater's depth are taken into consideration
McCormick	1993	Definition of the plan shape of beaches associated with the salient behind a detached breakwater (ellipses)	Data from physical models, numerical models, and real cases Model modified by Hsu, Jan, and Wen in 2003
Chen and Kuo	1995	Geometrical criterion for classifying the type of shore response (basic empirical relation) Determining the volume of accretion Determining the area of accretion	Data from physical models The formula proposed for determining the volume of accretion is similar to that of Harris and Herbich (1986)
Johnson *et al.*	1995	Geometrical criterion for classifying the type of shore response (basic empirical relation)	Data from a numerical model
Zyserman *et al.*	1998	Geometrical criterion for classifying the type of shore response (basic empirical relation) Determining the volume of accretion	Data from a numerical model The accretion model is qualitatively valid. It takes into account the relation between the breakwater's geometrical parameters and width of the surf area
Ming and Chiew	2000	Geometrical criterion for classifying the type of shore response (basic empirical relation) Determining the area of accretion	Data from physical models
Black and Andrews	2001	Geometrical criterion for classifying the type of shore response (basic empirical relation) behind reefs and islands Assessment of the salient formed Determining the coastal stretch affected by the obstacle Definition of the plan shape of beaches associated to the salient formed (asymmetric sigmoids)	Data from natural formations
González and Medina	2001	Geometrical criterion for classifying the type of shore response (basic empirical relation) Assessment of salient formed Determining the stretch of coast affected by the obstacle Definition of the plan shape of beaches associated with the salient formed (parabolas)	Data from physical models, numerical models, and real cases Their model is based on Hsu and Silvester's parabolic model (1990)
Zyserman and Johnson	2002	Geometrical design criterion for detached breakwaters under crown level: Graphic relations of qualitative validity	Data from numerical models Takes into consideration the relationship between the breakwater's geometric parameters and width of surf area
Ranasinghe and Turner	2004	Classification of the shore's response (accretion/erosion) in the case of submerged breakwaters	Data from physical models and numerical models

Table 2. *Limit conditions for classifying the shore's type of response behind a detached breakwater.*

Author (year)	Tombolo $B/X > \ldots$	Salient $B/X < \ldots$	Limited Response $B/X < \ldots$
Inman and Frautschy (1966)	—	—	0.33
Noble (1978)	—	—	0.17
Gourlay (1981)	0.8	0.5	—
Nir (1982)	—	—	0.5
Coastal Engineering Research Center (1984)	2	1	—
Dally and Pope (1986)	1.5	1.5	0.5
Suh and Dalrymple (1987)*	1	1	—
Sunamura and Mizuno (1987) (in Horikawa, 1988)	0.67	0.67	0.28
Herbich (1989)	1	1	0.5
Hsu and Silvester (1990)	1.33	1.33	—
Ahrens and Cox (1990)	2.5	2.5	0.76

* Formulation not applicable to detached breakwater systems.

proposed by different authors giving different values for classifying the type of coastal response were seen to exist. Their simplicity leads engineers to use them a great deal in practice to make a first geometrical sizing of breakwaters depending on the effect wanted to be produced on the coast. However, the choice of one model or another leads to different results since each one gives different values to the B/X ratio for classifying the type of response.

The basic empirical relations studied were those of AHRENS and COX (1990), COASTAL ENGINEERING RESEARCH CENTER (1984), DALLY and POPE (1986), GOURLAY (1981), HERBICH (1989), HSU and SILVESTER (1990), INMAN and FRAUTSCHY (1966), NIR (1982), NOBLE (1978), SUH and DALRYMPLE (1987), and SUNAMURA and MIZUNO (1987; in HORIKAWA, 1988). They are all shown in Table 2, where the limit conditions separating one type of response from another (tombolo, salient, and limited response), which were used for checking fulfilment of the classification criteria of the studied prototypes, are given in simplified form for each author.

Detached Breakwaters Researched

Structures on the northeast Mediterranean coastline (Catalonia) were chosen as prototypes (totalling 27 units) to compare the shore's response as induced by them with those expected according to the relationships analysed. The choice of the Catalonian coast as a study area responded to an attempt to eliminate, as much as possible, dispersion in results because of different mean sea states, since the marine climate's characteristics influence the shoreline's response, but are not taken into consideration in the empirical relations analysed.

The average climate conditions to which the breakwaters used in the research work are subjected are relatively homogeneous. The average flow of energy on the Catalonian coastline has a predominant NE-E component. However, the set of directions characterising the average directional flow are formed by the range of sectors between the NE and the SSW. The sectorial wave distribution noticeably varies throughout the year and shows peculiarities in each season: in autumn, ENE and SSW waves are the most intense; in winter, those of the SSW are the most important; and in spring and summer, E and ESE predominate.

Table 3. *List of aerial photographs consulted.*

Official Body	Month	Year	Flight Scale
Directorate General of Coasts	July	1990	1/5000
Directorate General of Coasts	May	2001	1/5000

Solid littoral transport is basically due to wave action and takes place in the direction of the coastline's alignment direction and in a NE-SW direction. The average rate of net sediment transport is about 70,000 m^3/y.

Another important piece of data for this research is the number and volume of artificial sand nourishments made on the stretches of coastline under study, if they existed. However, no information is available on the projects for renourishing beaches carried out by the Ministry of the Environment on those beaches.

The detached breakwaters chosen for the research are listed below, running from north to south along the Catalonian coastline (see Figure 1).

Characteristics of the Data Used

The values of the two geometric parameters appearing in the basic empirical relationships (B and X) need to be known for each of the prototypes considered to check fulfillment thereof. The best source for obtaining these data was the design drawings of the different detached breakwaters where, it was assumed, the coastline at the time of designing the constructions as well as the dimensions of the breakwaters designed would appear. However, as it was not possible to consult those sources, the methodology used to obtain the B and X parameters of each detached breakwater was to directly measure both parameters on aerial photographs of the stretches of coast where the selected detached breakwaters were located.

It was assumed that direct measuring on scale photographs would lead to an accumulation of errors, making it unadvisable for quantifying parameters in a strict research way unless no other source of reliable data was available. There are two types of such errors: first, those linked to aerial photogrammetry, since they are not georeferenced photos (orthophotos) and, therefore, bring scale errors. The objects photographed seem deformed because conical projections are captured in the photogrammes and not parallel vertical projections of the earth's surface. Furthermore, the centre line of the camera, which is mounted on apparatus in flight, is not perfectly vertical, and the exact relative position of the camera to the items photographed is not known. Aerial photographs therefore represent a scale distortioned reality, in which the scale is not accurately known.

Nevertheless, scale errors that could have accumulated in the data-obtaining process can be considered as offset to a certain extent when calculating the B/X ratios of the overall breakwaters studied, which is the really necessary parameter in this research. The nondimensional B/X monomial is obtained from dividing two variables with a length dimension,

Figure 1. Catalonian coastline beaches where the detached breakwaters chosen for this research work are located. (a, b) Location maps. (c) System of three detached breakwaters off San Antonio Beach (Calonge, Gerona). (d) Detached breakwater off Terramar Beach (Sitges, Barcelona). (e) Detached breakwater off San Gervasio Beach (Vilanova i la Geltrú, Barcelona). (f) System of two detached breakwaters off Cubelles Beach (Cubelles, Barcelona). (g) System of three detached breakwaters off Mota de Sant Pere Beach (Cubelles, Barcelona). (h) System of seven detached breakwaters off Cunit Beach (Cunit, Tarragona). (i) Detached breakwater off Altafulla Beach (Altafulla, Tarragona). (j) System of nine detached breakwaters off L'Ardiaca beach (Cambrils, Tarragona). **For a color version of this figure, see page 1222.**

Table 4. *Characteristics of the prototypes studied and summary of results.*

Name of the Detached Breakwater and Identification Labels	B	X	B/X	Coast's response	Inman and Frautschy (1966)	Noble (1978)	Gourlay (1981)
Gerona Calonge I (G-Cal I)	145	100	1.45	Tombolo	—	—	Fulfils
Gerona Calonge II (G-Cal II)	150	100	1.50	Tombolo	—	—	Fulfils
Gerona Calonge III (G-Cal III)	160	100	1.60	Tombolo	—	—	Fulfils
Barcelona Sitges (B-Sit)	158	117	1.35	Tombolo	—	—	Fulfils
Barcelona Vilanova i la Geltrú (B-ViG)	200	234	0.85	Tombolo	—	—	Fulfils
Barcelona Cubelles I (B-Cub I)	135	81	1.67	Tombolo	—	—	Fulfils
Barcelona Cubelles II (B-Cub II)	135	84	1.61	Tombolo	—	—	Fulfils
Mota de Sant Pere I (B-MSP I)	105	186	0.56	Limited response	Does not fulfil	Does not fulfil	—
Mota de Sant Pere II (B-MSP II)	100	206	0.49	Limited response	Does not fulfil	Does not fulfil	—
Mota de Sant Pere III (B-MSP III)	100	199	0.50	Limited response	Does not fulfil	Does not fulfil	—
Tarragona Cunit I (T-Cun I)	236	198	1.19	Tombolo	—	—	Fulfils
Tarragona Cunit II (T-Cun II)	162	151	1.07	Tombolo	—	—	Fulfils
Tarragona Cunit III (T-Cun III)	115	108	1.06	Tombolo	—	—	Fulfils
Tarragona Cunit IV (T-Cun IV)	131	100	1.31	Tombolo	—	—	Fulfils
Tarragona Cunit V (T-Cun V)	147	133	1.11	Tombolo	—	—	Fulfils
Tarragona Cunit VI (T-Cun VI)	162	122	1.33	Tombolo	—	—	Fulfils
Tarragona Cunit VII (T-Cun VII)	168	113	1.49	Tombolo	—	—	Fulfils
Tarragona Altafulla (T-Alt)	93	204	0.46	Salient	—	—	Fulfils
Tarragona Cambrils I (T-Cam I)	60	115	0.52	Salient	—	—	Undetermined
Tarragona Cambrils II (T-Cam II)	138	97	1.42	Tombolo	—	—	Fulfils
Tarragona Cambrils III (T-Cam III)	82	78	1.05	Salient	—	—	Does not fulfil
Tarragona Cambrils IV (T-Cam IV)	154	96	1.60	Tombolo	—	—	Fulfils
Tarragona Cambrils V (T-Cam V)	57	120	0.48	Limited response	Does not fulfil	Does not fulfil	—
Tarragona Cambrils VI (T-Cam VI)	193	124	1.56	Tombolo	—	—	Fulfils
Tarragona Cambrils VII (T-Cam VII)	72	97	0.74	Salient	—	—	Undetermined
Tarragona Cambrils VIII (T-Cam VIII)	194	120	1.62	Tombolo	—	—	Fulfils
Tarragona Cambrils IX (T-Cam IX)	210	114	1.84	Tombolo	—	—	Fulfils

geometrically contained in one and the same plane and perpendicularly oriented to each other, and therefore the scale errors of each measurement are considered to cancel each other out when calculating the quotient.

Second, those deriving from estimation: their minimisation calls for scrupulous office work and largely depends on the skill of the person performing the work. In this case, the situation was aggravated by the level of uncertainty associated with measuring the two parameters needed as well as determining the shoreline. Measuring the detached breakwater's length (B) means deciding between which two points the measurement was to be made (the ends of the breakwater's crown; the ends of the breakwater taking as such the tip slopes with the seawater level; the ends taking into consideration the intersection with the bottom; . . .). The measurement was made considering the ends of the breakwater at the seawater level.

Measuring the detached breakwater's distance from the initial shoreline (X) involves first determining what that original line is and then deciding up to where the measurement is made: to the breakwater's longitudinal centre line; to the intersection of the water with the slope on the side of the sea. . . . The measurement was made between the first one and the original shoreline.

In determining the shoreline, it must be borne in mind that neither the wave's advance on the beach profile nor what the sea level was when the photographs were taken was known, and, therefore, the "sea's edge" cannot be taken as the shoreline. So, the tide's maximum level or dry beach limit was taken, which is marked by a different sand colour (wet sand takes time to dry and shows a darker colour than dry sand), although it is not always easily discernible. Nevertheless, the error made in this study when the shoreline position was determined is estimated as minimal because the astronomical tidal on the Catalonian coast is small (approximately 30 cm) and the meteorological one is assumed to be negligible on the clear days when these flights are usually carried out.

The foregoing leads to considering that those errors that might have accumulated in the process involved in obtaining the distance (X) and length (B) parameters are small and, therefore, all data on which the study is supported are acceptable and the results obtained and conclusions drawn are suitable.

The aerial photographs used in the study were taken on two different flights along the Spanish coastline because of the availability and high quality of their photos and the manner in which they matched this study's requirements. The features of the two flights selected for this research from amongst the total number of flights made over the Spanish coast are shown in Table 3.

Using photographs from different flights over the coast was due to the need to measure the detached breakwater's distance from the shoreline's initial position just at the time when the breakwater was built, since their construction dates differed in each case. Obviously, to take measurements from an aerial photograph taken just before or immediately after each of the breakwaters had been built was desirable; however, this was impossible because the dates (month and year) of the flights do not coincide with the construction of each breakwater. (In fact, the number of flights over the Spanish

Table 4. *Extended.*

Nir (1982)	SPM (1984)	Dally and Pope (1986)	Suh and Dalrymple (1987)	Sunamura and Mizuno (1987)	Herbich (1989)	Hsu and Silvester (1990)	Ahrens and Cox (1990)
—	Does not fulfil	Does not fulfil	Not applicable	Fulfils	Fulfils	Fulfils	Does not fulfil
—	Does not fulfil	Fulfils	Not applicable	Fulfils	Fulfils	Fulfils	Does not fulfil
—	Does not fulfil	Fulfils	Not applicable	Fulfils	Fulfils	Fulfils	Does not fulfil
—	Does not fulfil	Does not fulfil	Fulfils	Fulfils	Fulfils	Fulfils	Does not fulfil
—	Does not fulfil	Does not fulfil	Does not fulfil	Fulfils	Does not fulfil	Does not fulfil	Does not fulfil
—	Does not fulfil	Fulfils	Not applicable	Fulfils	Fulfils	Fulfils	Does not fulfil
—	Does not fulfil	Fulfils	Not applicable	Fulfils	Fulfils	Fulfils	Does not fulfil
Does not fulfil	—	Does not fulfil	Not applicable	Does not fulfil	Does not fulfil	—	Fulfils
Fulfils	—	Fulfils	Not applicable	Does not fulfil	Fulfils	—	Fulfils
Does not fulfil	—	Does not fulfil	Not applicable	Does not fulfil	Does not fulfil	—	Fulfils
—	Does not fulfil	Does not fulfil	Not applicable	Fulfils	Fulfils	Does not fulfil	Does not fulfil
—	Does not fulfil	Does not fulfil	Not applicable	Fulfils	Fulfils	Does not fulfil	Does not fulfil
—	Does not fulfil	Does not fulfil	Not applicable	Fulfils	Fulfils	Does not fulfil	Does not fulfil
—	Does not fulfil	Does not fulfil	Not applicable	Fulfils	Fulfils	Does not fulfil	Does not fulfil
—	Does not fulfil	Does not fulfil	Not applicable	Fulfils	Fulfils	Does not fulfil	Does not fulfil
—	Does not fulfil	Does not fulfil	Not applicable	Fulfils	Fulfils	Does not fulfil	Does not fulfil
—	Does not fulfil	Does not fulfil	Not applicable	Fulfils	Fulfils	Fulfils	Does not fulfil
—	Fulfils	Does not fulfil	Fulfils	Fulfils	Does not fulfil	Fulfils	Does not fulfil
—	Fulfils	Fulfils	Not applicable	Fulfils	Fulfils	Fulfils	Does not fulfil
—	Does not fulfil	Does not fulfil	Not applicable	Fulfils	Fulfils	Fulfils	Does not fulfil
—	Undetermined	Does not fulfil	Not applicable	Does not fulfil	Does not fulfil	Fulfils	Fulfils
—	Does not fulfil	Does not fulfil	Not applicable	Fulfils	Fulfils	Fulfils	Does not fulfil
Fulfils	—	Does not fulfil	Not applicable	Does not fulfil	Fulfils	—	Fulfils
—	Does not fulfil	Does not fulfil	Not applicable	Fulfils	Fulfils	Fulfils	Does not fulfil
—	Fulfils	Does not fulfil	Not applicable	Does not fulfil	Fulfils	Fulfils	Does not fulfil
—	Does not fulfil	Does not fulfil	Not applicable	Fulfils	Fulfils	Fulfils	Does not fulfil
—	Does not fulfil	Does not fulfil	Not applicable	Fulfils	Fulfils	Fulfils	Does not fulfil

coastline is very limited, and those made bore no type of time frequency between each other.) For this reason, the shoreline existing in 1990 was considered as the initial one in those cases where detached breakwaters are not photographed, as they had not yet been built.

Stages in the Methodology Used

The research methodology used in the data-obtaining process for each of the beaches consisted of the following steps:

(1) Obtaining the B and X parameters: Overlapping of photographs of the stretch of coast under study, in the event that it covered more than one photograph, with 1/5000 scale photographs from the 1990 and 2001 flights (the case of the coastal stretches for Cunit and L'Ardiaca beaches in Tarragona).

- Plotting of the initial shoreline: The 1990 initial shoreline was assumed for the case of Mota de Sant Pere and Altafulla beaches, where the currently existing detached breakwaters had still not been built in that year.

  The preconstruction shoreline for the beaches where detached breakwaters had been built by 1990 was estimated on the 1990 photos from its position in the stretches of beach adjacent to that protected by the detached breakwater or system of detached breakwaters, and from the shapes followed by the back beach line (mostly limited by buildings, a road or path, or a promenade). It was assumed in such cases that this line was the beach's natural "dune-line", without artificially altering it, and this is noticeably parallel to the shoreline. Neither hypothesis has to be always true (in fact it is likely they are not strictly true in most cases), but in the absence of further information, they are a good criterion from which to estimate the initial position of the shore, particularly in those cases where the stretch of coastline studied was protected and, therefore, altered by an extensive system of detached breakwaters, as is the case of Cunit Beach (a system of seven detached breakwaters) and L'Ardiaca Beach (nine detached breakwaters).

- Measuring the parameters required in this study (length of structure [B] and structure's distance from initial shoreline [X]): Measurements for all cases except Mota de Sant Pere and Altafulla beaches were made on the 1990 photos since the detached breakwaters appeared in them; data for these two beaches were taken on the 2001 photographic montages, after superimposing the initial shoreline plotted.

  In those cases where the detached breakwaters appeared in the photographs taken in both those years, comparing them enabled the changes undergone by the beaches throughout a decade to be observed; if such changes were not significant (as happens in many of the cases studied in this work), it may be concluded that the beaches were already in a state of equilibrium by 1990.

(2) Calculating the B/X ratio (length/distance) for each case studied.

(3) Comparing the effects actually induced on the shore with those that should have theoretically occurred according

to the classifications as given by different authors depending on the value of the nondimensional B/X monomial: In the event of coinciding, the empirical model would be verified; in the event of not coinciding, it would be considered as not valid for the case of the Catalonian shoreline.

(4) Analysing the results and drawing conclusions.

RESULTS

On the basis of the methodology as described above, and always under the limitations specified and the method's inaccuracies, the fulfilment of all basic empirical relations considered in this work for classifying the type of shoreline response to a detached breakwater or system of detached breakwaters was checked on the Catalonian shoreline.

Likewise, a table was drawn up (see Table 4) that shows the elemental geometric characteristics of these breakwaters (B and X), the ratio between these two parameters (B/X), the effect they have had on the shore, and the specification of whether or not they match the classifying criteria listed in Table 2.

The results obtained after making the pertinent comparison of actual effects observed and those expected in keeping with the foregoing criteria have been summarised in Table 4, using the following terms:

- "Fulfils", if the response given by the shore meets the classification criterion.
- "Does not fulfil", if the B/X ratio for the type of response given by the shore is not within the limits as laid down by the classification criterion considered.
- "—", if the classification criterion does not address the type of response given by the shore.
- "Undetermined", if the B/X ratio is in a range of values for which the classification criterion does not specify the type of shore response.

When the formulation of the classification criterion is not applicable to detached breakwater systems, the term "Not applicable" is used in Table 4.

ANALYSIS AND DISCUSSION

The results obtained have been graphically represented for analysis in accordance with the following procedure (see Figures 2a–d).

The limit conditions as specified by each author for classifying the shore's response to a detached breakwater are represented on a graph (where the abscissa is the distance from the detached breakwater to the initial shoreline [X] and the ordinate is the structure's length [B]) by equal sloping straight lines equal to the monomial B/X set as a classification limit between every two types of response (tombolo–salient and salient–limited response).

The tombolo condition limit straight lines have been drawn with solid lines (above which each author ensures it will form, and below, a salient will form), the limited response limit conditions with dashed lines (below which the shore's response to a detached breakwater is very low), and those conditions ensuring that a salient will form below the limit straight line with dot-and-dash lines, but they do not guarantee that a tombolo will form above it.

This graph also shows all the prototypes considered in this research work, identifying the B/X ratios of the cases where a tombolo has formed with a circle, the cases of well-developed salients with a triangle, and the cases of limited or nil response with crosses. It is thus easier to identify what limit conditions of those given by different authors have been fulfilled for all the prototypes studied here and which have not.

The results show that of the 11 empirical ratios studied, those that best perform on the mainland's northeast coastline are those of Herbich (1989), verified in 81.5% of cases; Sunamura and Mizuno (1987), fulfilled in 78% of cases; Gourlay (1981), in 74% of cases; Hsu and Silvester (1990), valid in 59% of cases; and Dally and Pope (1986), fulfilled in almost 50% of cases (48%). The remaining six models would not be applicable since the number of cases verified does not even reach 20% of the total.

This graph also shows the concentration of tombolo cases between the limit figures 1.00 and 2.00 of the B/X monomial; the confidence band of the B/X figure could even be closed for the tombolo forming between 1.30 and 1.60, with over 50% of the cases of tombolo studied.

These results lead us to propose the following geometric B/X model for the case of the Spanish northeast shoreline:

Tombolo: $B/X \geq 1.3$

Salient: $1.3 > B/X > 0.5$

Limited response: $0.5 \geq B/X$

CONCLUSIONS

The following conclusions are listed after analysing the state of the art and after the study performed on the overall detached breakwaters chosen for this research work on the Spanish northeast Mediterranean coastline: Each and every one of the problems occurring on the coast has its own features (cause, climate conditions, environmental conditions, requirements, *etc.*). This makes indiscriminate use of formulations and the extrapolation of results obtained in studies of specific cases lead to results not desired in practice, which are other than those theoretically expected initially although there are experiments with satisfactory results where the same theories were applied. This is why the aim of this research was to check whether the geometric empirical relations given by different authors for classifying the shore's type of response to a detached breakwater or system of detached breakwaters by considering the cases existing on the Catalonian coastline were fulfilled or not.

The study of detached breakwater influence on the shoreline was confined to a single descriptive, geometric, and measurable aspect: the ratio between the length of the detached breakwater and the distance from the initial shoreline (nondimensional monomial B/X or length/distance), taking as such the dry beach line just before being affected by a detached breakwater.

It was seen during the review of the state of the art that there is a large range of figures proposed for classifying the type of shoreline response on the basis of the B/X monomial

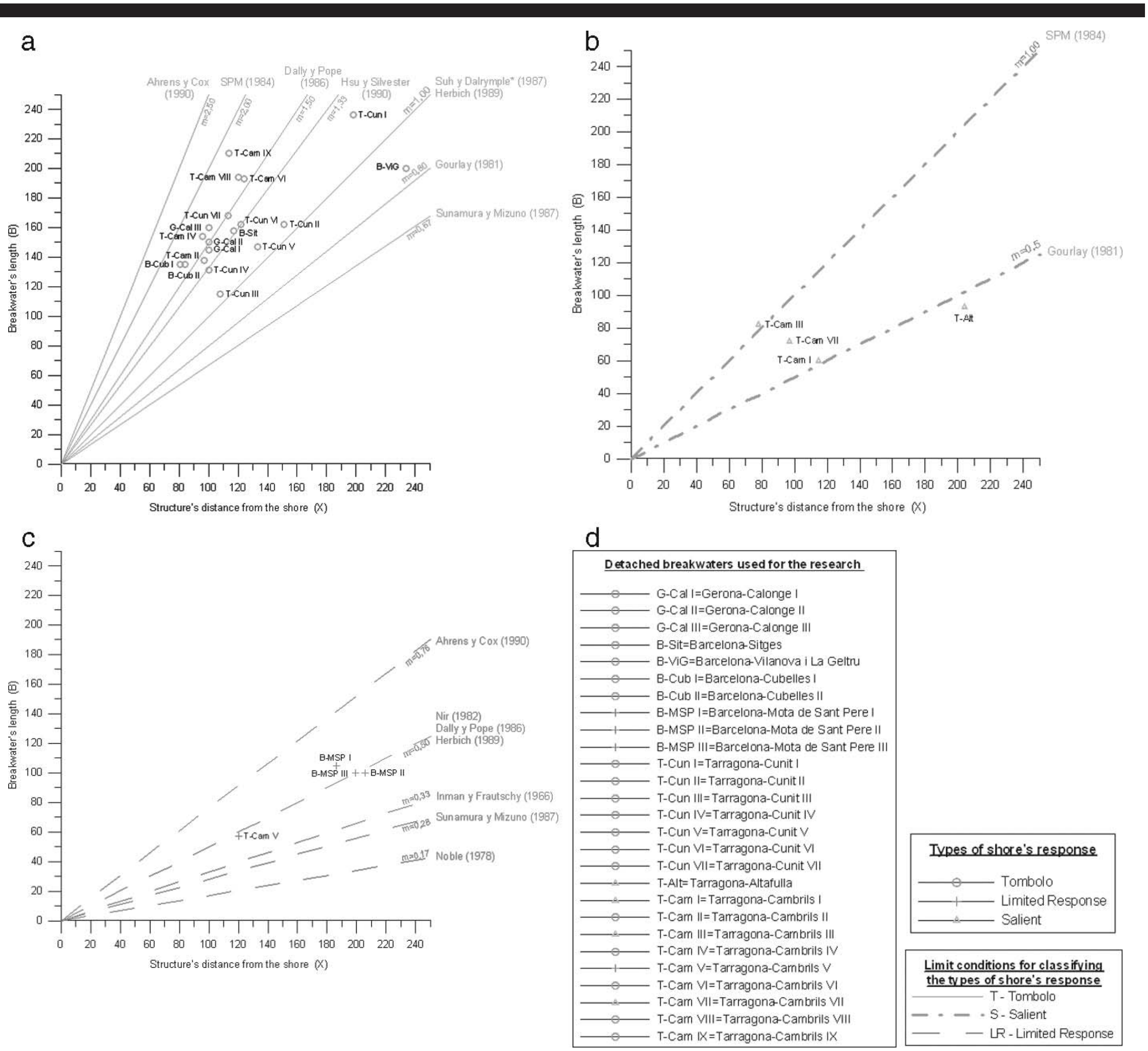

Figure 2. Graphic representation of the research's results: (a) Tombolo. (b) Salient. (c) Limited response. (d) Labels.

that could be basically explained by the importance of surrounding conditions (which are not taken into account in this type of empirical relation), mainly incident wave characteristics because the shore's response to a detached breakwater or system of detached breakwaters is noticeably sensitive to states of the sea and, consequently, the problem of determining such becomes highly complex. This is why a certain littoral area was chosen for the study, in an endeavour to eliminate dispersion through average states of the sea, to the greatest extent possible, as represented by wave height, period, wave direction, and the average reference level.

After checking the geometric empirical relations for classifying the shore's type of response to a detached breakwater or system of detached breakwaters as taken into consideration in this study, the general estimation of the geometric model B/X as proposed for the case of the Catalonian coastline could be:

Tombolo:	$B/X \geq 1.3$
Salient:	$1.3 > B/X > 0.5$
Limited response:	$0.5 \geq B/X$

These conclusions respond to the analyses performed during the drafting of this first phase of the research, which will be specified with *in situ* experiments and numerical models in later stages. Successive phases of the research work's undertaking involves improving the model proposed by considering parameters that influence both the performance of the breakwater (permeability) and of the coast (size of sediment and beach slope). Furthermore, the influence of artificial sand renourishment in the response given by the coast after a detached breakwater's construction will be investigated.

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□ RESUMEN □

La erosión de un gran número de playas y la evidente degradación ambiental de muchos tramos costeros, son problemas a los que los Ingenieros de Costas dedican su actividad en busca de soluciones. Con este fin, se han venido utilizando diferentes métodos de protección, basados la mayoría en la regeneración artificial de playas y en la construcción de estructuras, como espigones y diques exentos. Los diques exentos son estructuras paralelas generalmente a la costa, que protegen de la acción del oleaje un determinado tramo, y que son capaces de crear zonas de acreción en la costa. El estudio llevado a cabo para la realización de la investigación que aquí se presenta, se ha centrado en este tipo de obras, con el fin dar una visión global de estado del arte en este campo. Además, se han investigado los efectos inducidos en la costa por un conjunto de diques existentes en el litoral español, con el fin de comprobar, para todos ellos, el cumplimiento, o no, de las relaciones empíricas dadas por diferentes autores para la clasificación del tipo de respuesta de la costa. En este estudio sólo se han considerado las fórmulas basadas en las características geométricas de los diques, por ser las más empleadas por los ingenieros proyectistas para predimensionar una obra. Todas las formulaciones estudiadas se basan en la relación B/X entre los dos parámetros geométricos básicos de los diques exentos (la longitud de la estructura -B- y la distancia de ésta a la orilla -X-), por lo que el resultado de la investigación condujo a la propuesta del siguiente modelo geométrico aplicable al caso del litoral de Cataluña: formación de tómbolo si $B/X \geq 1{,}3$; formación de saliente si $1{,}3 > B/X > 0{,}5$; respuesta limitada de la costa si $0{,}5 \geq B/X$.