TYPES AND IMPACTS OF MARITIME HYDRAULIC STRUCTURES ON THE ROMANIAN – BULGARIAN BLACK SEA COAST: SETTING-UP A COMMON CATALOGUE FOR GIS-BASED COASTLINE CLASSIFICATION

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Abstract: The present study is a basic part of developing a joint GIS-based coastline typology to determine various geomorphic types of landforms (natural/anthropogenic) along the Western Black Sea coast. The main purpose is to develop a web geomorphic classification for this part of the Black Sea coast, covering both Bulgaria and Romania. The research is focused on inventory the multipurpose maritime hydraulic constructions (harbour and coast-protection types) built along the Bulgarian-Romanian coast and to point out on their functions and effects. Setting-up of a common catalogue to all types of maritime structures for the Bulgarian-Romanian part of the Western Black Sea coast will help the establishment of unified technical terminology. The results are an important step to create a common classification criteria based on geomorphologic and engineering research approaches for identifying natural landforms and technogenous objects along the both coastlines.

Key words: western Black Sea coast, coastal erosion, coastal defence works

INTRODUCTION

The Bulgarian and Romanian shorelines are both along the Western Black Sea coast. The Bulgarian coastline is 412 km long, between cape Sivriburun on the north and Rezovska River on the south; the Romanian coast has a length of 243 km from Vama Veche (the Bulgarian border) to Danube Delta on the north (Fig. 1). Despite these administratively divided coasts, they are both part of the one and only shoreline. Differences are thought to be observed at different sections in what regards the geomorphology and geology, thus comprising various types of coastal landforms (beaches, cliffs, firths, lagoons, mudflats, deltas etc.). At the same time various human activities have altered the natural evolution of coastlines to considerable extent and have been recognized as a prevalent modifier of the coastal zone dynamic in recent decades. Many research teams worldwide have coped with this topic, including the western Black Sea coast. Human interventions and related impacts along this part of the Black Sea littoral has been dealt with, among others, by Panin, 1996, 1999, Giosan *et al*., 1999, Ungureanu & Stănică, 2000, Constantinescu, 2005, Kuroki *et al*., 2007, Stănică *et al*., 2007 and Stancheva *et al*., 2011. Both the Bulgarian and Romanian coasts have been highly developed and urbanised in particular over the last century, mainly int the past 50 years, which has lead to the increasing technogenous occupation. A large number of dif-

Fig. 1 The Romanian-Bulgarian Black Sea Coast

ferent types of "hard" coast-protection structures as well as port/harbour developments have been installed along the two coastlines, applying various standards and methods for coastal defence, and using different terminologies for coastal structures. In addition, the nomenclature is not standardized, and the same structures used in Bulgaria and Romania have been described with different names.

The main purpose of the study is to perform an inventory and analyse the multipurpose maritime constructions built along the Bulgarian-Romanian coast according to a common specialized technical terminology. The main result would be a generation of common catalogue of all port and coast-protection structures and unified technical terminology for the Western Black Sea coast.

TYPES OF PORT/COASTAL-DEFENCE STRUCTURES ALONG THE BULGARIAN BLACK SEA COAST

In an attempt to cope with erosion and landslide processes along the Bulgarian Black Sea coast hard stabilisation structures have been widely used since 1980s, such as solid groins, coastal dikes and seawalls. As a result, over 10% of the 412 km long coastline has been armoured and this practice is still ongoing: rubble-mound dikes have been constructed as a common solution to protect coast and infrastructures (Stancheva and Marinski, 2007; Stancheva *et al*., 2010).

A number of 217 port and coast-protection structures (both long-and cross-shore) have been identified along the Bulgarian coast with a total length of 71 km. The port and hard stabilisation structures are not regularly built and distributed along the coast. As a result, there are some parts with largest proportions of armoured coastline. Such segments are located at the northern part of the Bulgarian coast, between cape Ekrene and cape Galata, where 73 various types of maritime structures were identified and also at the southern part, between Nessebar town and cape Foros (Fig. 1). These most built-up areas include the largest Bulgarian Black Sea bays of Bourgas and Varna, where significant parts of urban/land activities (transport logistics, industries, trades, etc.), coastal infrastructures and tourism development are concentrated (Stancheva *et al*., 2007; Stancheva, 2009).

Groins

The groins are a widely used method for shoreline/cliff retaining (Stancheva and Marinski, 2007) and they have been assumed as a common tool to solve both the erosion and landslide problems. The construction of groins has increased in particular over the 1980s and presently there is a large number of groins installed along the coast. One typical feature of Bulgarian method for groins design is their construction in system of three or more structures, moreover in combination with dikes and seawalls. Groins are with different lengths between 120-130 m offshore and they are made by concrete armour units or with rubble-mound (rock-fill) construction, or are of composite type.

However, application of groins and its further interpretation in Bulgarian expertise has proved to be completely unknown in worldwide coastal engineering practice, despite these constructions have been referred as "groins" (Marinski, 2006). Indeed, they were implemented as structures with both harbour and protection functions: typically there are quay walls for small ships with sheltered water-side area for vessels berthing (Fig. 2). As a result, most of the groins have not functioned properly and they are ineffective in regard to accumulation of sand in the groin fields (Stancheva *et al*., 2011).

Coastal dikes

An "ad-hock" defence method in Bulgarian coastal engineering is a combination of coastal dikes and groins systems furthermore the dikes serve also as road connections. The coastal dikes are onshore structures with the principal function of protecting low-lying coastal territories against flooding, and they are another widely used defence method in Bulgaria. Typically, the dikes are built as a mound of fine materials like sand or clay with a gentle seaward slope in order to reduce the wave run-up and the erodible effect of the waves. The surface of the dikes is armoured with grass, asphalt, stones, or concrete slabs, (Burcharth and Hughes, 2006). In Bulgaria dikes are asphalt-armoured and supported by rubble stones (concrete armour units, tetrapods etc.) on their seaward side or being of composite type (Fig. 3). The longest dike has a length of 10 km and has been recently constructed between Balchik and Albena resort, northern part of the Bul-

Fig. 2 "Groin" with port and coast-protection functions

Fig. 3 Coastal dike

garian coast (Fig.1). As a result of dike building the natural coastline was replaced seaward by almost 30 m thus being covered in concrete and irretrievably modified. Consecutively, the studied section has been identified as one of the most armoured and occupied along the Bulgarian coast. This way a 10 km long natural coast between town of Balchik and Albena Sea resort was armoured and the coastal ecosystem was forever destroyed (Stancheva *et al*., 2010).

Negative effects commonly associated with the "hard" defence methods and particularly with coastal dikes, may include (Lees and Duncan, 1997; Griggs, 2005; Stancheva *et al*., 2011):

1. loss or damage of the natural landforms; destruction of habitats and disturbance of wildlife during works;
2. interruption or reduction of sediment input from the eroding cliff to the adjacent beaches or near coastal sites, which may aggravate the erosion downdrift;
3. loss of valued sand material from the beach and shallow water-area covered in during dike construction;
4. negative visual impacts (such structures can affect exactly those qualities of the coast which people mostly enjoy: the naturalness and openness of the seashore);
5. lost public access to water-area (even more such structures create potential risks for health and safety).

Seawalls

These are less popular structures, but also widely applied protection methods along the Bulgarian coast. Seawalls are used to protect backshore areas from heavy wave action, and in lower wave energy environments, to separate land from water. They range from vertical face structures such as massive gravity concrete walls, tied walls using steel or concrete piling, and stone-filled cribwork to sloping structures with typical surfaces being reinforced concrete slabs, concrete armour units, or stone rubble (Burcharth and Hughes, 2006). Revetments and bulkheads are similar onshore structures. Revetments have the principal function of protecting shoreline from erosion and they consist of a cladding of stone, concrete, or asphalt to armour sloping natural shoreline profiles. Bulkheads is the term for structures primarily intended to retain or prevent sliding of the land, whereas protecting the hinterland against flooding and wave action is of secondary importance (Burcharth and Hughes, 2006). In Bulgaria there is no distinction between revetments, bulkheads and seawalls (Stancheva and Marinski, 2007).

Currently, there are a number of inefficient or partially broken seawalls along the Bulgarian coast without any beach in front of them. Modern concrete seawalls tend to be curved to reflect the wave energy back out to sea or made by separate units (Burcharth and Hughes, 2006). There are also seawalls with wave-breaking cells, like this built at one of the most hazard-prone coastal sections (Fig. 4) at the northern Bulgarian coast, where the rate of cliff retreat is 1.2-1.6 m/y (Peychev and Stancheva, 2009).

Port/harbour structures and navigation channels

These types of structures mostly include maritime constructions with port functions, such as various types of port/harbour breakwaters and moles, jetties, spurs and navigational channels to the protected harbour water-areas. Key features of all harbours include shelter from both long and short period open ocean waves, easy safe access to the sea, adequate depth and manoeuvring room within the harbour, shelter from storm winds and minimal navigation channel dredging (http://chl.erdc.usace.army.mil/coastalstructures). Along with these principal functions such structures may also impact adversely on the coastal processes and sustainability of the surrounding onshore and offshore areas.

Harbour breakwaters include both the protective structures with connection to the coastline and the detached ones. Similar structures are harbour (or port) moles which are used to protect harbours and inlets and to stabilize navigational channels. Such types of structures are shore-connected, may have different configuration and are located at a certain distance into the sea. Typically between mole and coastline reentrant angle is being formed, which filling with sediments on the windward side could continue the decay and even more, depending on the amounts of sediments transported along the coast. Such typical examples of harbour structures at the Bulgarian coast are the main mole (or breakwater) of Varna harbour built in 1906, and the mole of Burgas harbour constructed in 1903 (Fig. 1). Namely in result of installed harbour structures the large Varna and Burgas sand beaches have been formed and they are presently valuable recreational resources of the two largest sea towns. On the other hand the long structures have interrupted the sediment movement along the coast and caused a deficit for new sediment supply to the adjacent coastal sections (Stancheva *et al*., 2008).

Jetties are shore-connected structures generally built on either one or both sides of the navigation channel perpendicular to the shore and extending into the ocean. By confining the stream or tidal flow, it is possible to reduce channel shoaling and decrease dredging requirements. Moreover, on coastlines with alongshore currents and littoral drift, another function of the jetties is also to arrest the crosscurrent and direct it across the entrance in deeper waters. Typically jetties are constructed similar to breakwaters (Burcharth and Hughes, 2006).

Navigation channels and permanent dredging activities for their maintenance are other types of human activities in the coastal zone that have adverse impacts on processes similar to those arisen from the effects of defence structures. Dredging, the removal of sediments shoals from navigation channels is the primary activity that assures safe and efficient navigation. Typically, such works remove the sediments as their effects are similar to sand mining (Magoon and Treadwell, 2009; http://chl.erdc.usace.army.mil/coastalstructures). The two navigational channels (the old one –built in 1907 and the new deepwater – in 1976) in the bay of Varna that connect the Varna Lake with the sea are a typical example for such types of structures

Fig. 4 Seawall

Fig. 5 The deep-water navigational channel (Varna Bay)

(Fig. 5). For maintenance of the deepwater navigation channel to a required depth of 15 m, constant dredging activities are performed. Usually this includes placement of dredged sand just on the coast along the channel and its using then as inert material by the building companies (Marinski, 1998). Also, the harbour structures and particularly the navigational channel obstruct the sediment delivery to the underwater coastal slope north and south from the bay (Stancheva *et al*., 2008).

TYPES OF PORT/COASTAL-DEFENCE STRUCTURES ALONG THE ROMANIAN BLACK SEA COAST

Most coastal structures of the Romanian littoral are concentrated in the southern sector of the coast, *i.e.* 80 kilometres southwards of Cape Midia (Fig. 1), which is mainly human-controlled. Here, there are many works designed as defence structures to protect harbours, touristic beaches and urban settlements. Extensive works were developed mainly in the second half of the XXth Century, technical details and philosophy being given as an example by Spataru, 1984. Structures related to harbours and navigation channels have a strong impact on the coastal evolution. Main types of structures are further presented:

Groins

Generally groins are present along the touristic beaches in various combinations (T-shaped, hockey-cross shaped, etc.) – mainly as part of the coastal defence system in front of the cities of Constanța (Fig. 6) and Mangalia, as well as in front of the touristic resorts of Eforie North and South and in the summer resorts connected to the northern part of Mangalia town (Saturn – Olimp). Another such groin is present (in an advanced state of decay) in the village of 2 Mai, located immediately south of the Mangalia Harbour (Fig. 1). Generally, these groins consist of piles of rocks and tetrapods. Two systems of groins represent the only hard coastal defence structures in front of the Danube Delta (at Portita and another one at Edighiol). The oldest such structure was built back in the 1930s though – on the beach of Mamaia (Fig. 1). Most of these structures were built in the period 1960 – 1980.

Breakwaters

Detached breakwaters are present in front of the touristic resort of Mamaia (fig. 7), as well as in front of the city of Mangalia. Submerged breakwaters are also present in front of Constanța, as well as in front of the Eforie North – Eforie South coastal stripe (Fig. 1). Most of these structures have been built during the 1980s.

Fig. 6 L- shaped groins, Constanța

Fig. 7 Breakwater (Mamaia resort)

Seawalls

Seawalls have been developed to protect the cliffs of Eforie North (Fig. 8) and South, first such works being developed in the first half of the XXth Century (mainly 1930s). These works were consolidated in the 1950s. Other seawalls – built mainly for cliff protection – were developed in the 1960s in the tourist resorts north of Mangalia, including also the town itself, and continued during the early years 2000 at Costinești (Fig. 1).

Port/harbour structures and navigation channels

These structures have drastically altered the water and sediment dynamics along the Romanian Black Sea coast and can be defined as true impermeable boundaries of coastal sedimentary cell (Ungureanu and Stănică, 2000; Kuroki *et al*., 2007, etc.). The middle arm of the Danube Delta, Sulina (Fig. 1), has been developed for navigation starting with the XIXth Century by building two parallel jetties, which have continued seawards the riverbanks. The seaward limits of these jetties are nowadays at about 8 kilometres offshore of the present coastline (fig. 9), with significant changes on coastal circulation of water and sediments (Panin, 1999; Giosan *et al*., 1999, Stănică *et al*., 2007, etc.). Sulina jetties consist mainly of massive blocks of rocks and very few concrete.

The southern boundary of the Danube Delta coast is given by the Midia harbour structures (fig. 10) – jetties and moles extending about 5 kilometres offshore. These structures – which have interupted the longshore drift transporting Danube borne sediments, consist mainly of rocks and concrete tetrapods. From Cape Midia southwards (Fig. 1), two more significant harbour structures have induced major changes to coastal – marine circulation of water and sediments: the Jetties protecting the Port of Constanța (the biggest around the Black Sea – jetties have an offshore length of 11 kilometres) and those protecting the Port of Mangalia (offshore length of less than 2 kilometres). Both structures are made mainly of piles of concrete tetrapods as well as rock blocks. Another 3 small marinas are present along this 80 kilometres stretch of the Black Sea coast – Tomis (in front of Constanța, Fig. 11), Eforie and Costinești, each having marina moles consisting both of rocks and concrete tetrapods. Each of these marina moles plays an important role in changing the local coastal circulation.

A centralized situation of common types of maritime structures (port and coastal protection works) along Bulgarian-Romanian Black Sea coast is presented in Table 1.

Fig. 8 Seawall, Eforie North

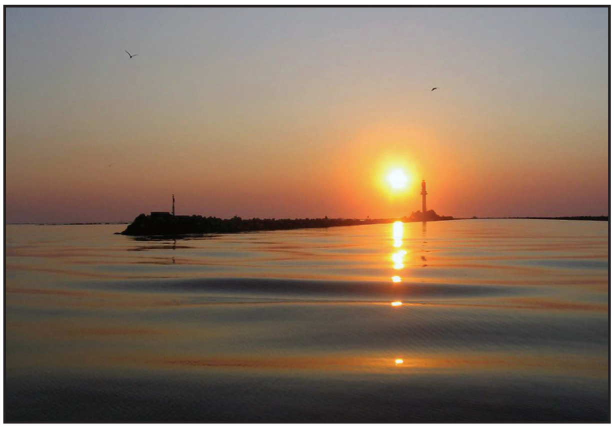

Fig. 9 Sulina jetty

Fig. 10 Midia harbour jetty

Fig. 11 Tomis touristic harbour moles

Table 1 Catalogue of port and coastal-protection structures at the Bulgarian-Romanian coast
(modified from: Burcharth and Hughes, 2006)

Type of Structure	Objective	Principal Functions	Type of Construction
Sea/coastal dikes	Prevent or alleviate flooding by the sea of low-laying land areas	Separation of shoreline from hinterland by a high impermeable structure	Concrete armour units or rubble-mound (rock-fill) and composite type
Similar structures:			
rip-raps	Prevent or alleviate flooding by the sea of low-laying land areas	Covering less tightly specified dumped or placed rock structures	Made from a variety of rock types or concrete rubble from building and paving demolition
Groins (Y, T, Z, I- shape)	Prevent beach erosion	Reduction of alongshore sediment transport	Impermeable, concrete sheet-pile or rubble-mound (rock-fill) design
Seawalls	Protect land and structures from flooding and overtopping	Reinforcement of some part of the beach profile	Formed of concrete/rock blocks or sheet piling
Similar structures:			
i) revetments	Protect the shoreline against erosion	Reinforcement of some part of the beach profile	Consist of a cladding of stone, concrete, or asphalt to armour sloping natural shoreline profiles
ii) bulkheads	Retain soil and prevent sliding of the land behind	Reinforcement of the soil bank	Vertical wall anchored with tie rods
Reef breakwaters	Prevent beach erosion	Reduction of wave heights at the shore	Rubble-mound structures constructed as a homogeneous pile of stone or concrete armour units
Detached breakwaters	Prevent beach erosion	Reduction of wave heights in the lee of the structure and reduction of long-shore sediment movement	Rubble-mound construction
Submerged breakwaters	Prevent beach erosion	Retard offshore movement of sediment	Rock-armoured, rubble-mound structures or made of commercially available prefabricated units
Harbour breakwaters	Shelter harbour areas and harbour entrances, and water intakes against waves and currents	Dissipation of wave energy and/or reflection of wave energy back into the sea	Shore-connected or detached; sloping-front and vertical-front structures: composite or rubble-mound armoured with rock or concrete armour units, with or without wavewall superstructures, or concrete blocks placed on a rubble stone base layer
Similar structures:			
i) jetties	Stabilise navigation channels at river mouths and tidal inlets	Protect against storm water and cross-currents	Shore-connected, construction similar to breakwaters
ii) moles	Protect harbours and inlets that are important commercial and military navigation links and to stabilise navigational channels	Shelter from waves and storm winds, provide adequate depth/ manoeuvring room within the harbour, secure minimal navigation channel dredging	Shore-connected, construction similar to breakwaters
Navigation channels	Provide safe, reliable, and efficient waterway navigation	Maintained by constant dredging activities to a required depth for modern ships	

CONCLUSIONS

This study shows for the first time a common inventory of the variety of harbour and coast-protection structures affecting the coastal dynamics of the entire western Black Sea littoral. Setting-up of a common catalogue is the basis for establishment of unified technical terminology and engineering criteria for indication of different technogenous objects along the both coastlines (Table 1). The study findings clearly figure out that the western part of the Black Sea coast, covering Romanian – Bulgarian section, has been subject to various types of coastal protection activities. This development has started first with few coastal engineering works mainly with navigation purposes (building harbours/ports, jetties) by the end of the XIXth Century. These interventions have been expanded over the entire XXth Century, but in particular in the period 1950s – 1980s, when significant areas of the western Black Sea tourist beaches have been subject to direct human impacts.

The present research shows that the applied by far coastal defence methods along both coasts are mainly of the "hard" type, being made by rock mounds, concrete blocks, etc., and dedicated to control coastal erosion and prevent tourist beaches as well as to harbour and navigation channels protection. All types of traditional "hard" coastal defences are present here, as shown in Table 1. All these works have had in most cases an adverse impact on the natural coastal water and sediment circulation, and costal geomorphology. This has had, at its turn, an overall major influence on the shoreline dynamics. Nevertheless, in spite of the common historical heritage regarding the coastal engineering interventions, it is very difficult to find references to these works in a unitary way.

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