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Coarse-grained beach response after storms in three Italian sites

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Abstract:
The storm response of three Italian mixed beaches is investigated. Two sites are located on the eastern side of the country (Portonovo and Sirolo) and one on the western side (Marina di Pisa). Portonovo and Sirolo are two mixed sand and gravel beaches (MSG) where the storms approach from two main directions (SE and NE). Marina di Pisa is a composite mixed beach subject to storms driven by SW. Gravel nourishments were undertaken in recent years on the three sites. Beach evolution was monitored measuring the same network of topographic profiles at a monthly to seasonal frequency. Beach orientation and the presence of protecting structures are the main reasons for the displacement and the accumulation of significant amount of sediments. In Marina di Pisa storm wave tend to pile material towards the upper part of the beach with no rotation of the shoreline. Sirolo and Portonovo act like pocket beaches with shoreline rotation that occurs after each storm in a clockwise or counter-clockwise direction. The wider and longer beach in Sirolo allows sediment to accumulate moderately during storms rather in Portonovo, given its longshore boundaries, the material tend to pile up in greater thickness. Periods of fair weather tend to decrease beach slope in Marina di Pisa and to increase beach width in Sirolo. After a big storm, in Sirolo and even more in Portonovo, the original beach configuration can be reached only after another storm of similar energy approaches by the opposite direction of the previous one.
Keywords: Storm, Beach response, Mixed beach, Mixed sand and gravel beach, Composite beach, Pebble, Microtidal beach, Gravel beach, Beach rotation.

1. Study area

The first beach is located in Marina di Pisa on the western side of the Italian coast (Ligurian Sea), 11 Km southwest of the city of Pisa (see Figure 1). The beach is named Barbarossa, is 180 m long and 15-30 m wide and is approximately oriented N-S. The beach is bounded on both sides by groins that prevent coarse sediments from leaving the system and a seawall made of large boulders separates the backshore from the littoral promenade. Given the net separation at the step line between sand and gravel, Barbarossa beach can be classified as a composite gravel beach according to the classification of JENNINGS & SHULMEISTER (2002). Marble pebbles and cobbles (60-100 mm in diameter), brought by during a nourishment project in 2008, cover the

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original sandy surface. The tide regime is semidiurnal and the maximum tidal range measured at spring tide is 0.4 m. Waves mainly approach the coastline from SW with wave heights between 0.25 and 2 m for more than 60% of the time, <0.25 m for only about 5% and >2 m for the rest of the time (BERTONI *et al.*, 2013). Storms are commonly driven by south-westerly winds. The other two beaches, Portonovo and Sirolo, are respectively located on the northern and central edge of the Conero Headland, in the central sector of the Adriatic Sea (see Figure 1). The beach in Portonovo is approximately 500 m long and 20 to 60 m wide and is bounded by two boulder seawalls protecting historical buildings. The main sediment fraction here is made of pebbles (2-64 mm in diameter). The beach in Sirolo, known as San Michel-Sassi Neri, is a naturally embayed pocket beach approximately 1.2 km long and 20 to 60 m wide, mainly comprised of pebbles (2-32 mm in diameter). According to the JENNINGS & SHULMEISTER (2002) classification, Portonovo and Sirolo are two mixed sand and gravel beaches (MSG) given the full intermixing between sand and gravel. Sediments are mainly made of limestone and marl originated by cliff erosion which is the only sediment source of the two beaches. The average tidal range at spring tide is 0.4 m. The dominant winds come from NE and SE, which correspond also to the main directions of storms. The wave heights are between 0.25 m and 2 m for the 80% of the time, <0.25 m for the 10% and > 2 m for the rest of the time.

2. Materials and methods

The morphological evolution of the three beaches was monitored by means of an RTK-DGPS (Trimble R6) which has an accuracy of ±2 cm. For each site a profile network was measured in three different surveys covering a period of few months (see Table 1).

Table 1. Monitoring methods for beach morphology of each site.

	Marina di Pisa	***Portonovo***	***Sirolo***
N. profiles	*11*	*50*	*18*
Profile spacing	*15 m*	*10 m*	*70 m*
Surveys	*Nov 2013 (pre-storm)*	*Oct 2012 (pre-storm)*	*Mar 2012 (pre-storm)*
	Dec 2013 (post-storm)	*Nov 2012 (post-storm)*	*Apr 2012 (post-storm)*
	Feb 2014 (recovery)	*Dec 2012 (recovery)*	*Oct 2012 (recovery)*

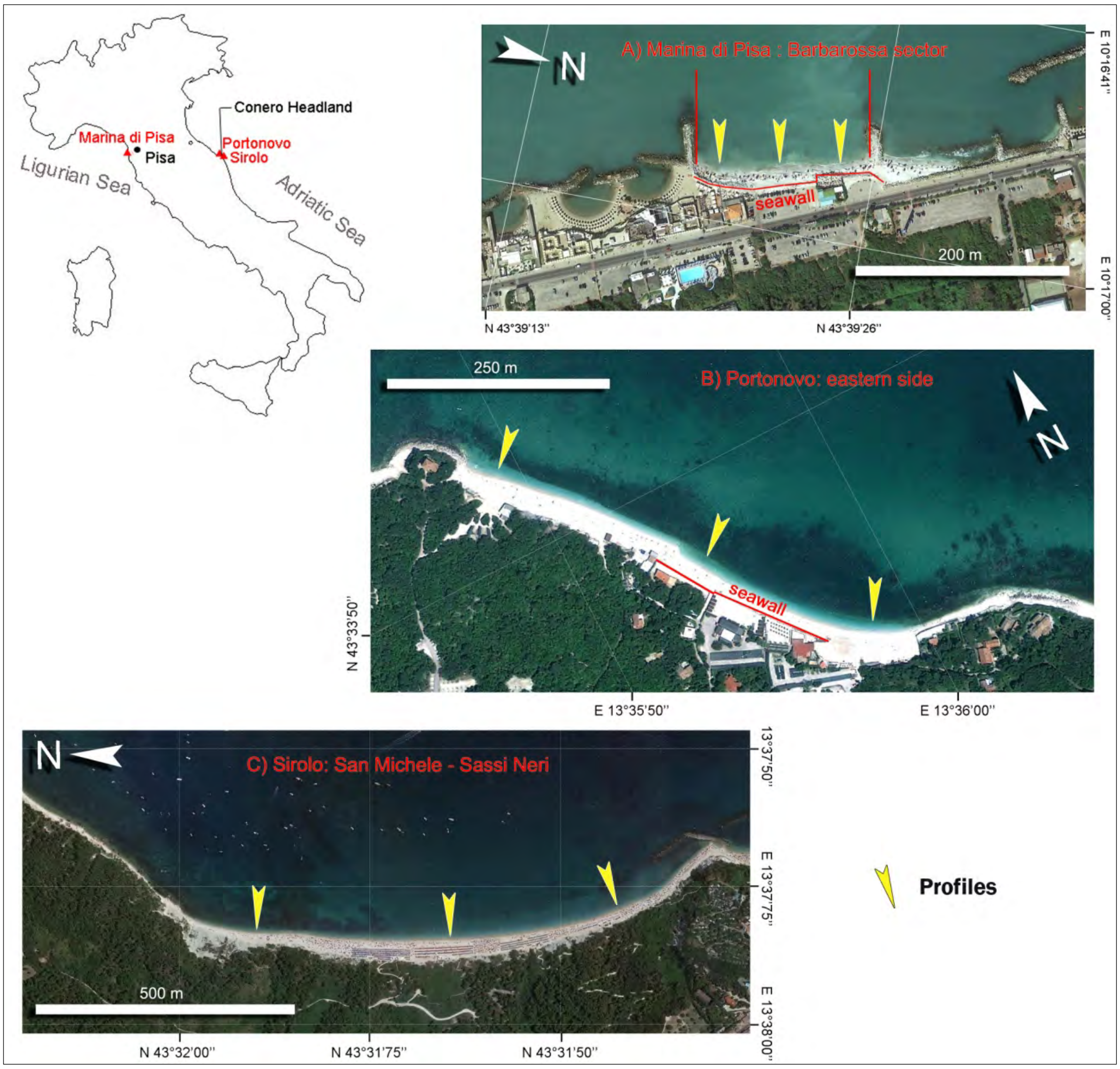

Figure 1. Study site.

3. Results

Compared to the two Adriatic sites, the profile at Marina di Pisa resulted less altered. The most energetic storm in this site came in November 2013 from W with a maximum H_s of 4 m. The storm shifted material on the upper part of the beach, especially in the central and southern area (see Figure 2) where a building and a parking area occupy the entire upper backshore (see Figure 1A) and facilitate the sediment accumulation. After this major storm the beach surface was characterised by a more pronounced step. Despite the period from the second and the third survey was characterized by weak storms, the initial beach configuration was not reached again. The beach width remained the same and slope decrease was concentrated only on the upper part of the profile. It was likely the weaker storm waves reached the backshore dragging sediments towards the sea and therefore this process produced a slope decrease. The initial profile configuration could be reached again with stronger storms able to pile sediments into the two groins or backshore seawall (see Figure 1A).

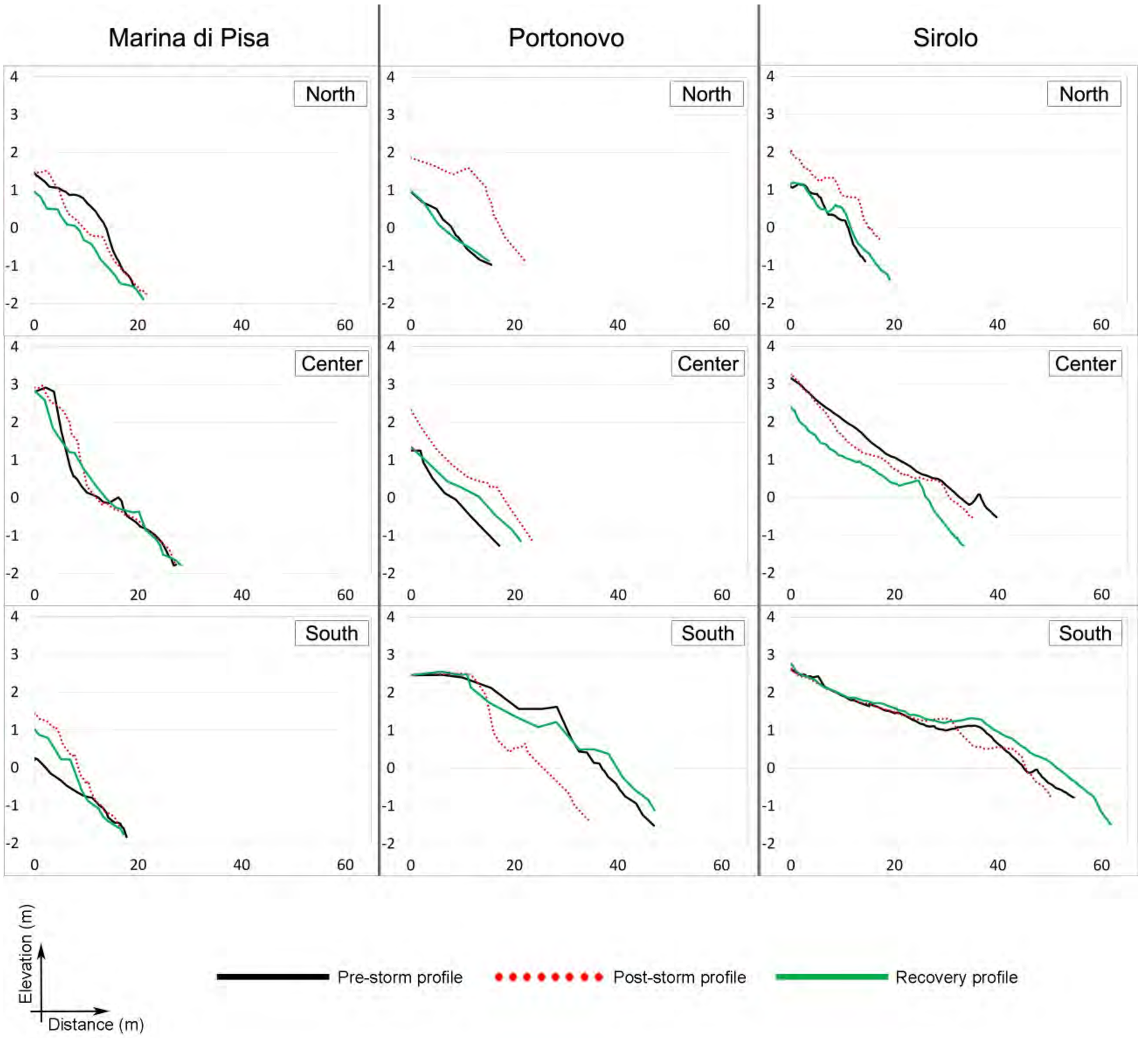

Figure 2. Profile comparison on the three sites. Elevation is meant above sea level.

The largest topographic changes were experienced in Portonovo; here a storm approaching from ESE with an H_s peak of 5.1 m between of October and November 2012 displaced a huge quantity of material towards N. In the southern zone the beach appeared clearly "cut" by an erosive scarp: relative to the pre-storm survey, the central and the lower part of the profile were reduced in elevation of 1 to 1.5 m and retreated approximately 15 m. On the other hand, the central and northern beach areas were interested by a substantial accretion toward sea and increase in elevation. Due to shifted material from S to N the beach surface in the northern zone was from 1 to 2 m higher than previously (see Figure 2). At this stage the beach experienced a clockwise rotation. After that storm the beach profile returned to be quite similar to the pre-storm configuration with the only difference of a milder slope which resulted also in a beach widening. The final beach configuration was created by another storm of similar energy that came from the opposite direction relatively to the previous one (Dir NNE; H_s max 4.4 m). Similar beach behaviour was experienced in Sirolo. Here two consecutive storms from ESE with an H_s max of 2.1 m transported sediments from S to N. The beach surface in the northern compartment resulted 1 m higher and a slight clockwise rotation of the shoreline occurred (see Figure 2). Here the final beach configuration was generated by the combination of a storm occurred in May 2012 (Dir NNE; Hs max 3.1 m) and period of fair weather during the summer that produced a general accretion of the beach especially at its ends. The central portion of the beach resulted 1 m lower after this period and a counter-clockwise rotation of the shoreline occurred. HARLEY *et al.* (2014) already noticed a natural readjustment of the Sirolo embayment after storms driven by ESE winds.

4. Conclusions

In Sirolo, given the greater width and beach length of its natural configuration, the morphological changes are less evident than in Portonovo. In both beaches significant amount of sediments move alongshore according to the storm direction. Beach rotation was already observed in Sirolo by HARLEY *et al.* (2014). Portonovo, nevertheless its stronger urbanization and its longshore limits make it act as a pocket beach even though it is not a natural one like Sirolo. The behaviour of Marina di Pisa beach is different; here shoreline rotation does not occur even after the major storms. In this beach sediments move preferentially cross-shore and mainly deposit on the upper part of the beach. The major factor that allows these two different behaviours is the beach orientation: Marina di Pisa receive storm waves from SW in a clear cross-shore direction, rather the two Adriatic beaches withstand storms from both longshore direction (NE and SE). Furthermore, in Marina di Pisa and Portonovo, the presence of protecting structures allows sediment to pile up a significant thickness of sediments during storms. Furthermore sediment size seems to have also an important role on beach response: the larger diameter of pebbles in Marina di Pisa make the beach system less dynamic if compared to the other two Adriatic sites. In Marina di Pisa is very unlikely that the beach can return to a “normal” configuration after the major storms.

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