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Possibility of artificial beach nourishment using crushed limestone aggregate

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Abstract: Beach feeding has become one of the most popular approaches to coastal engineering over the past decade and many see it as the ultimate saviour, both for increased coastal defence and for tourism. There are two aims of this research: to analyze the change of particle size distribution and grains shape after nourishment and to analyze how shape of crushed limestone aggregate can be improved before beach nourishment to become more comfortable. For this purpose, 13 samples from different parts of an artificial hotel's beach located at Split (Adriatic Sea) were taken and analyzed almost two years after filling the beach with the crushed limestone with coarser grains (16 – 31.5 mm) mixed with the same size river pebbles. The particle size distribution and shape index were analysed for all samples. Also, a few samples of the crushed limestone were taken from the quarry, where the material was taken for beach nourishment. In order to improve grains shape, these samples were subjected to abrasion, by mixing in a laboratory pan mixers or in a ball mill. The particle size distribution and shape index were then analyzed and compared with results obtained on samples from the beach. Shape of crushed aggregate can be improved by the methods of abrasion. For the purpose of beach nourishment this could be too expensive, but the power of the waves to create shape of aggregate before beach filling can be useful for this goal.

Key words: beach renourishment, crushed limestone, shape index, Faury coefficient

1. INTRODUCTION

The term of beach renourishment means that sediment will be placed on the existing beach material and adapt its shape to the changing wave, tidal conditions and other natural conditions. Renourishment is often applied to eroded beaches but it may be useful for the purposes of tourism, so it is important to know reason for renourishment. “Beach renourishment is costly, but may be economically justifiable on sectors of the coastline, such as seaside resorts, where the emplaced beaches will be much used, or where the beach will protect property or infrastructure that is at risk from erosion or flooding” (Bird and Lewis, 2015). The beaches are popular for summer tourism, especially if they are suitable for sunbathing and swimming. Sediment used for renourishment should have similar grain size characteristics to the natural beach and rounded particles are more comfortable and preferable than flat or elongated particles. Badly shaped natural sand usually comes from glacially formed pit deposits and rounded particles like pebbles come from rivers or beaches. Good sources of sediment for beach renourishment are sometimes too far from the beach. In order to minimise transportation costs, suitable material should be sought as close as possible to the beach (Bird and Lewis, 2015; Day et al., 2014; Evangelista et al., 1992).

An artificial hotel's beach located at Split on Adriatic Sea is observed. In the earlier period this part of the coast was quite unsightly with a very narrow walking trail and unattractive beach, Figure 1 (left). In the last 15 years, the beach has been built into the shape as shown in Figure 1 (right). During this time, the beach was several times nourished mainly with crushed limestone coarse gravel. In the experimental part of the work, 13 samples from different part of beach were taken and analysed after 1.5 year of renourishment.

Figure 1. An artificial hotel's beach at 1966 (left) and 2010 (right)

2. EXPERIMENTAL PART

2.1 Testing on the samples taken from beach after renourishment

The artificial hotel's beach was renourished in the summer 2010. with crushed limestone from the nearby quarry mixed with the river pebbles, which were added to improve roundness of borrow material. The marks and location of the taken samples are shown in Figure 2.

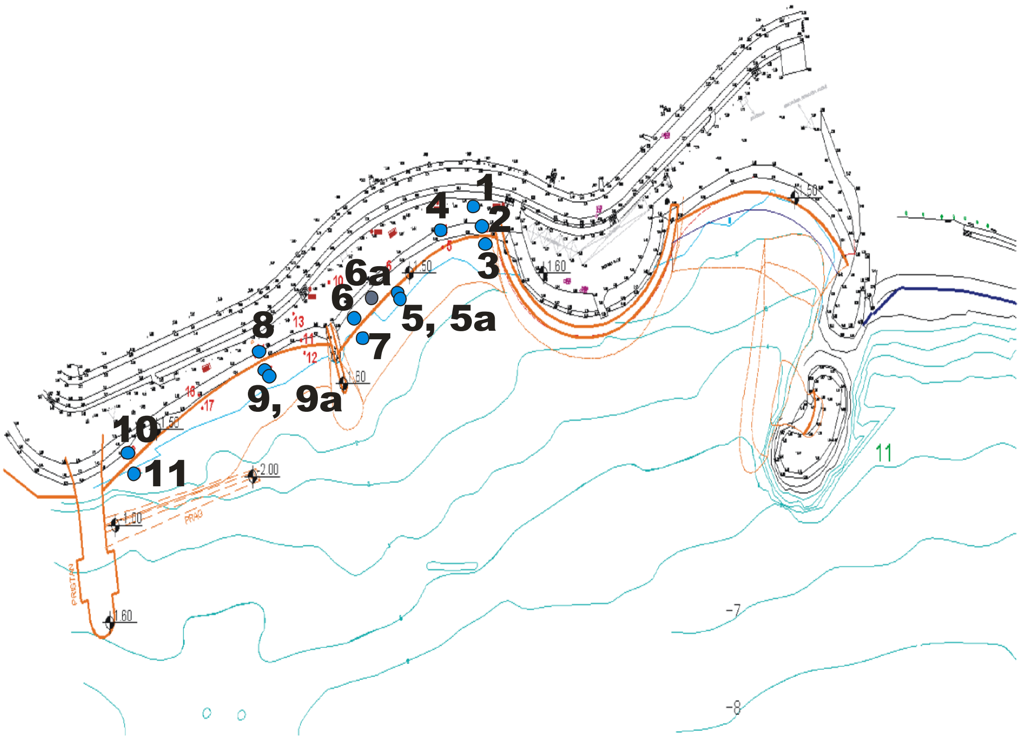

Figure 2. The marks and location of the taken samples

All samples, except 6a, were taken in October or November 2011. and sample marked with 6a was taken in the spring 2013. The purpose of sample 6a was to notice potential changes in the sample 6 through the period of 18 months. Some samples were taken from the beach and some from the shoreline, like samples marked with 5 and 5a. The particle size distribution for all samples is shown in Figure 3.

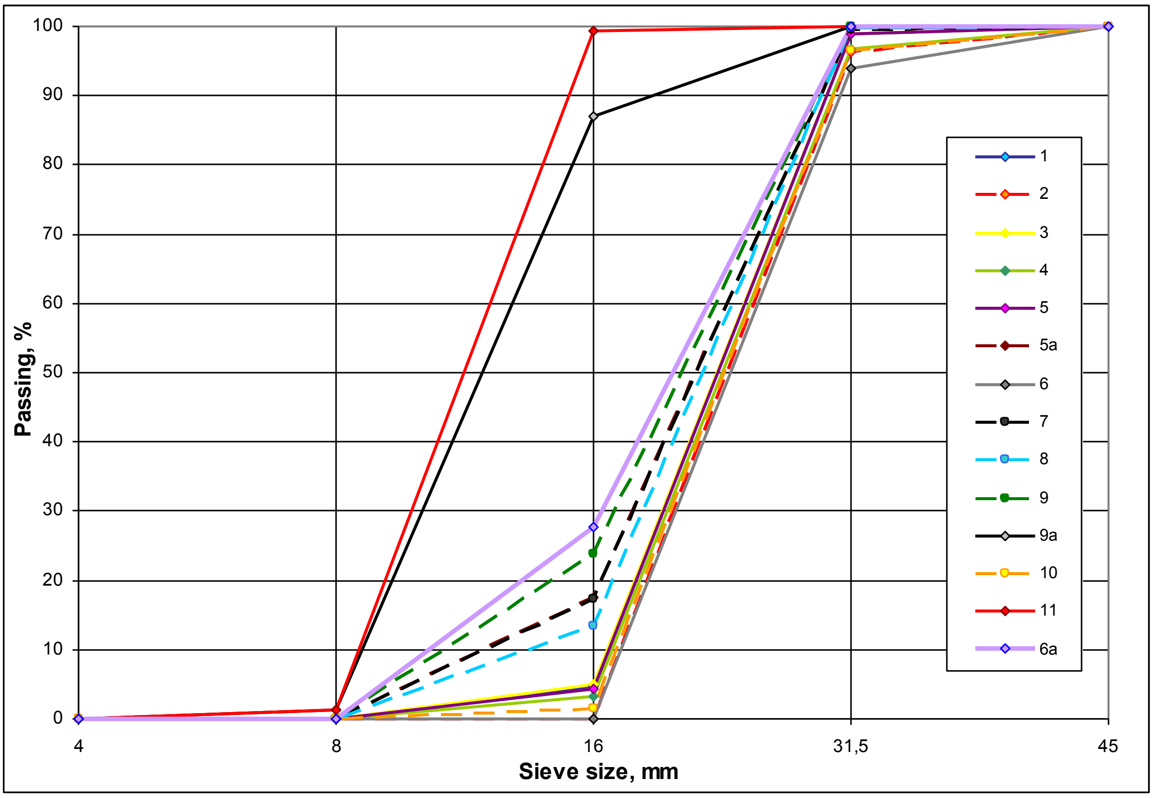

Figure 3. Grading curves of all samples

According to Figure 3, for the samples 9a and 11 the percentage of aggregate passing through 16 mm sieve were 87.1 and 99.3 %, while the samples marked 2 and 6 had no grains smaller than 16 mm. The samples 5a and 7 had the same grading curves and both were taken from the shoreline. The grading curve of the sample labels 6a in regard to the grading curve of the 6 was different. It is obvious that, through a period of 18 months, parts of the grains were crushed.

Volumetric coefficient by Faury and shape index were analyzed for 8-16 and 16-31.5 mm fractions. These methods are based on measurement of the aggregate dimensions giving several shape characteristics as degree of sphericity and elongation.

Volumetric coefficient by Faury is ratio between the total volume of aggregate grains to the volume of spheres with diameter equal to the longest axis of the each grains. This method sets down the amount of measured grains to minimum 100 grains from each size of the coarse aggregate.

The shape index (Uthus et al., 2005; HRN EN 933-4:1999) is a method for determining the elongation of coarse aggregate grains. The length L is defined as the longest axis of the grain and the thickness E is the shortest axis. Shape index SI is defined as a ratio between the weight of particles with L/E > 3 and weight of all measured particles in percents. The obtained results are shown in Table 1.

According to Table 1, the grains from the sample 1 had the highest roundness. This sample had a high percentage of river pebbles in its composition (Figure 4, left). The sample 9a had a lowest value of the volumetric coefficient (Figure 4, right). The grains from the 6a were more round than grains from the sample 6 and there weren't elongated grains in 8-16 mm fraction (SI = 0). According to SI index, the samples 4 and 8 had a large number of elongated and broken grains.

2.2 Laboratory testing

The purpose of this part of the experimental work is to test abrasion of the crushed aggregate and possibility to improve the roundness of grains. Two samples of crushed limestone with coarser gravel (16 – 31.5 mm) were subjected to abrasion, one by mixing in a laboratory pan mixer and other in a ball mill. The crushed limestone was from the same quarry and the same size as the material for renourishment.

Table 1. Faury coefficient and shape index for grain size 16-31.5 and 8-16mm

Sample	Number of grains in the sample	Faury coefficient C	Shape index SI	Number of grains in the sample	Faury coefficient C	Shape index SI
		16-31.5 mm			8-16 mm	
1	105	0.305	7.02	100	0.255	*
2	103	0.255	13.54	-	-	-
3	105	0.272	13.97	105	0.193	21.70
4	104	0.243	20.65	61**	0.166	45.95
5	106	0.281	6.98	108	0.212	23.08
5a	105	0.279	11.92	104	0.226	19.40
6	105	0.244	10.15	-	-	-
7	105	0.279	11.92	105	0.279	16.37
8	104	0.230	25.73	102	0.180	75.38
9	104	0.256	14.21	102	0.219	22.29
9a	105	0.269	19.17	105	0.143	13.25
10	104	0.273	8.63	-	-	-
11	103	0.285	7.92	-	-	-
6a	102	0.311	12.20	103	0.260	0.00
CLA	105	0.179	24.02			
CLPan	104	0.260	7.90			
CLMill	104	0.242	15.70			

** - grains were too small and inconvenient*
*** - insufficiently number of grains in the sample*

Figure 4. The sample 1 with C=0.305 (left) and the sample 9a with C=0.143 (right)

Testing in a pan mixer: The 15 kg of crushed aggregate and 4.5 kg of quartz sand (0.5 - 1 mm) were placed in the pan mixer. Water was added after 3 minutes of dry mixing. The amount of water was determined by visual observation to form dense-graded mix of water and particles of quartz, without water separation. After wet abrasion through 195 minute, aggregate was dried and sieved. Size distribution of the sample taken from the quarry (CLA) and the sample from the pan (CLPan) are shown in the Figure 5. In CLPan grading curve, particles smaller than 1 mm include particles of quartz, but the increase in the passage of particles through the sieve 1- 16 mm is obvious.

The obtained values for Faury coefficient and shape index are shown in Table 1. According to Table 1, Faury coefficient for CLPan is increased from 0.179 for CLA to 0.260 and became almost equal to average value for the beach (0.267). It should be noted that rounded river pebbles contribute to this average value.

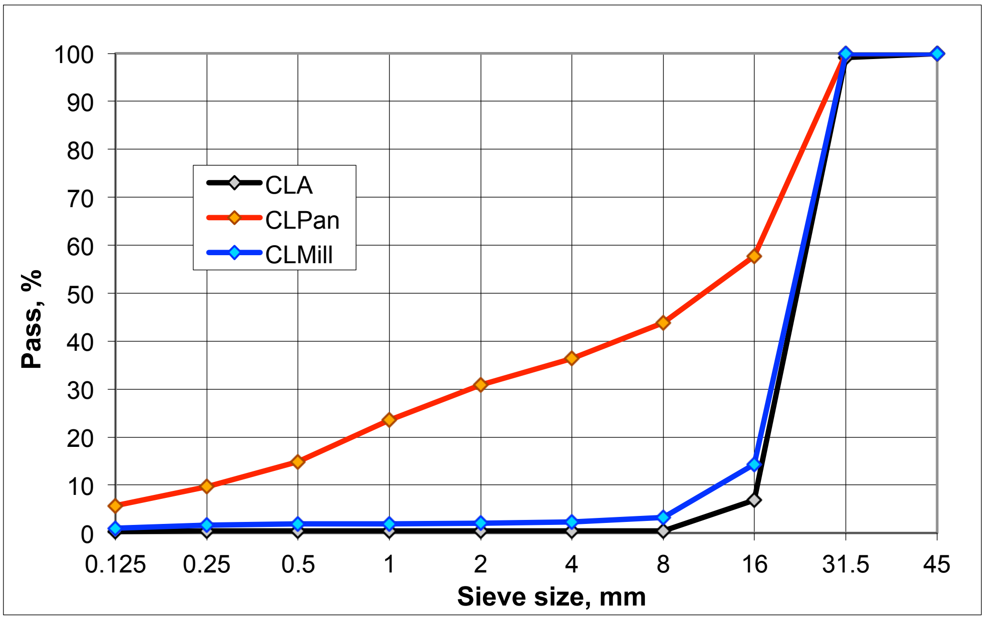

Figure 5. Grading curves of CLA, CLPan and CLMill samples

SI is decreased from 24.02 to 7.90, which means that there are less elongated grains. The difference between the CLA and CLPan grains are shown on the left picture in the Figure 6.

Figure 6. Grains: left - CLA vs CLPan and right - CLA vs CLMill

Testing in a ball mill: The 7 kg of crushed aggregate and 3 kg of steal balls with diameter of 20 mm were placed into a ball mill and put into work as long as pan mixer - 195 minutes. The material was sieved and the grading curve was shown in Figure 5. There was no significant difference between grading curves CLA and CLMill, but Faury coefficient was increased to 0.242 and SI was decreased to 15.70. The grains are shown on the right picture in the Figure 6. The CLMill grading curve is the most similar to the grading curves from the samples 7 and 8. This method provides a satisfy grain shape without additional crushing aggregate.

3. CONCLUSION

The hotel's beach is an artificial beach, which was brought into the present situation with series of activities. In the final phase of the project, the beach was renourishment with crushed limestone from the nearby quarry. The fraction was 16 – 31.5 mm with badly shaped grains, so the river pebbles were added to improve a shape.

- Analysis of the samples taken from the beach after 1.5 year of renourishment showed that crushed aggregate changed grains shape and reduced the grain size in places with a stronger action of the waves.
- Shape of crushed limestone aggregate can be improved by the methods of abrasion by mixing in a laboratory pan mixers or in a ball mill. The method in a ball mill provides a satisfy grain shape without additional crushing aggregate.
- Abrasion of aggregate for beach nourishment would maybe be too expensive, but coastal engineering experts can try to use the power of the waves, tidal conditions and other natural conditions to create shape of aggregate before beach filling.

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