Preliminary results of soil - geosynthetic strip interaction in pullout

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ABSTRACT: The pull-out resistance of polyester strip reinforcement in crushed stone aggregate was studied with a large-scale pull-out box developed at the Faculty of Civil Engineering in Osijek. Several laboratory pull-out tests of polyester strips in crushed stone aggregate with different grain size distribution and coefficient of uniformity were carried out. The material was classified as poorly-graded and well-graded crushed stone aggregate. The soil/reinforcement interaction parameters deduced from these tests show that grain size distribution of material has a very big influence on the friction coefficient. The results of these tests were compared with similar tests reported by Lo (1998) and Abdelouhab et al. (2009) but for different types of soil. The test results show that the friction coefficient of well-graded crushed stone aggregate and polyester strip is significantly higher than soil-strip interaction parameters deduced from pull-out tests with sand and/or gravel soil type.

Keywords: pull-out test, geosynthetic reinforcement, soil-strip interaction, crushed stone aggregate

1 INTRODUCTION

Mechanically stabilized earth (MSE) structure is a composite structure consisting of granular soil mass (soil fill, backfill) set up in successive horizontal layers between reinforcing elements. This structure can be built with steeper face angles and withstands higher loads than soil alone can take. The improvement of shear strength and bearing capacity of MSE comes from the interaction of soil fill and reinforcement which acts as a tensile element. The reinforcing elements can be made of inextensible or extensible materials (metallic strips, bars and mats, or geosynthetic strips, grids or fabrics). The stress-strain behaviour of MSE structures depends not only on the properties of the soil fill, reinforcement type and properties, but also on the nature of their interaction (Schlosser and Bastick 1991, Sobhi and Wu 1996, Sierra et al. 2009, Khendkar and Mandal 2009, Palmeira 2009, Moraci and Cardile 2009, 2012, Abdelouhab et al., 2009, 2010., Moraci et al. 2014). There are various types of MSE structures with a wide area of application (retaining walls, embankments, steep slopes, bridge abutments, etc.). A common use of MSE is in the construction of gravity walls, where the wall is made as a combination of compacted soil and a relatively large number of closely spaced reinforcing elements. In the design of tall gravity walls, a high tensile strength of reinforcement is required and this can be achieved by using strip reinforcements.

In the past few years in Croatia, two tall MSE walls were built, Strikići (2006) and Sveta Trojica (2012) as part of a major highway construction project connecting the coastal and continental part of the country. These walls were constructed in the coastal region in very difficult site conditions and in a seismically active area. The Strikići wall is 26.8 m high and 500 m long and the Sveta Trojica wall is 34 m high and 430 m long. As reinforcement, strips made of polyester fibres coated with high density polyethylene were used. Polyester strips as opposed to metal strips were selected to avoid the use of metal in the facing near the sea so that oxidation would not cause problems due to the coastal climate. The backfill material was made of crushed limestone rock from a neighbouring site. Wall facings were made of precast T-shaped reinforced concrete panels and connected with the reinforcing strips which were laid in a zigzag pattern.

The design methods commonly used for MSE structures are based on soil-reinforcement anchorage models which require knowledge of the soil-reinforcement friction coefficient.

In order to determine this friction interaction coefficient, both large direct shear and large pullout tests must be performed.

The pull-out resistance of geosynthetic sheets or grids has been studied by a number of researchers (Alfaro et al. 1995., Ochia et al., 1996, Morraci and Gioffrè, 2006, Moraci and Cardile, 2008., Palmeira 2009, Miyata and Bathurst, 2012), however experimental studies on pull-out resistance of geosynthetic reinforcing strips are very limited. Relatively recent studies were published by Lo (1998) and Abdelouhab et al. (2009, 2010).

In order to define the actual behaviour model of the geosynthetic strips used in reinforced soil structures Abdelouhab et al. (2009) several pull-out tests have been carried out in coarse soil (gravel) and fine sand. They have concluded that friction at the soil-reinforcement interface is higher in the coarse soil, and that this difference is related to the high density and uniformity coefficient (C_u) in the coarse soil. In his research, Abdelouhab et al. (2010) showed that friction coefficients at the soil-reinforcement are significantly higher than those used in practice for reinforced soil structures design.

Most published studies of soil-reinforcement interaction were made using geosynthetic strips and sand or coarse soil (gravel), despite the fact that in real MSE structures the crushed stone aggregate is commonly (or very often) used as a filling material.

In order to give better insight about factors affecting friction interaction coefficient, a series of the pullout tests has been carried out in the present study. The tests were carried out in a large pull-out testing device developed at the Civil Engineering Faculty of University of Osijek. In this paper, the results of pull-out tests carried out on three compositions of crushed stone aggregate with grain size distributions from 30 – 60 mm (soil A 30/60), 4 – 60 mm (soil B 4/60) and 0 – 60 mm (soil C 0/60) are presented. The test results are compared with other test results from literature.

2 TESTING EQUIPMENT

A large pull-out test device (the GFOS pull-out device) has been developed at the Faculty of Civil Engineering in Osijek (see Fig. 1). The GFOS pullout device was used for the study of interaction mechanisms between compacted soil and geosynthetic strip reinforcement. The size of the pull-out box is LxBxH=1.9x0.9x1.2 m. It consists of four 20 cm high horizontally set rectangular steel elements, put one over another and firmly framed, enabling work with specimens of different height, the maximum height being 110 cm. Normal stresses are applied using airbags placed under the top cover compressed by steel beams connected to the vertical frames fixing the horizontal elements. The impact of the front wall is reduced by a sleeve 30 cm wide at the front wall. The tests are carried out at constant rate of displacement (2 mm/min), and pullout force (max, 80 kN) is measured by a load cell. A specially equipped fixing system was developed for pull out of the geosynthetic strips from the soil. The fixing system consists of five fastening plates around which the strip is wrapped. Displacements are measured at five positions by the extensometers which can measure the maximum displacement of 200 mm with a precision of 0.01 mm.

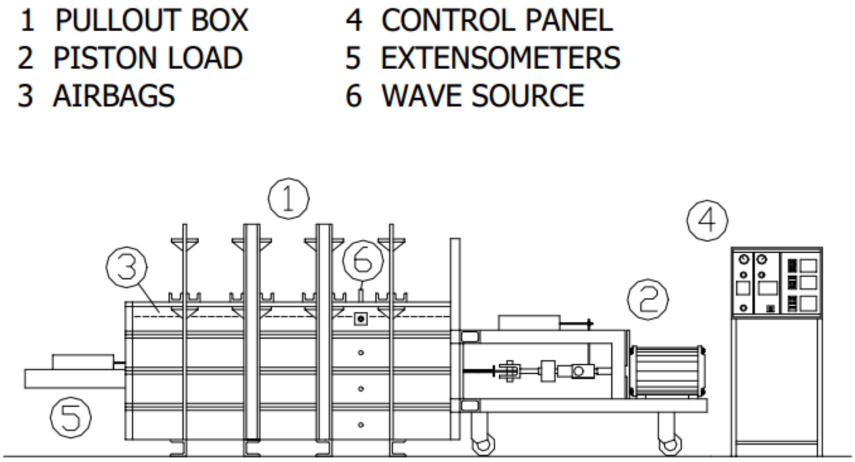

Figure 1. GFOS big pull-out test device

3 TESTING PROGRAM AND MATERIALS

The pull-out tests were carried out on the geosynthetic strip placed on an unbound soil type. The soil is placed in the box in 10 cm thick layers and compacted with a vibro-compactor. In each test, a strip is carefully placed in the soil at the centre of the pull-out box and displacement sensors (extensometers) are connected at different locations along the strip length. The reinforcement displacements are measured by extensometers: on the pull-out cylinder and in four points on the reinforcement. The first point of reinforcement is outside the pull-out box at the entrance of the strip to the box, and the other three are inside the pull-out box. Normal stresses are applied using airbags placed between the top of the fill and the cover plate which allows the simulation of different vertical stresses in a real reinforced-soil structure. The tests were conducted at two different vertical stresses 50 kPa and 150 kPa for A 30/60 and B 4/60 soil, and with three different vertical stresses 50 kPa, 100 kPa and 150 kPa for soil C 0/60. Tests were carried out at controlled displacement rate of 1 mm/min, and a pullout force (max. 80 kN) is measured by load cell.

3.1 *Material*

3.1.1 *Fill materials*

The pullout tests were carried out with a crushed stone aggregate with various grain size distributions and coefficients of uniformity (Fig. 2). The crushed stone aggregate was classified according to ASTM D 2487 – 00 as poorly graded for a material with grain size distribution 30 – 60 mm (soil A) and as well-graded crushed stone (gravel) for material with a grain size distribution 4 – 60 mm and 0 – 60 mm (soil B and C). The first poorly graded material was referred to as material A 30/60 and well-graded material was referred to as material B 4/60 and C 0/60. The coefficient of uniformity *Cu* for material A 30/60 was around 1.5, for material B 4/60 around 5 and for material C around 7.

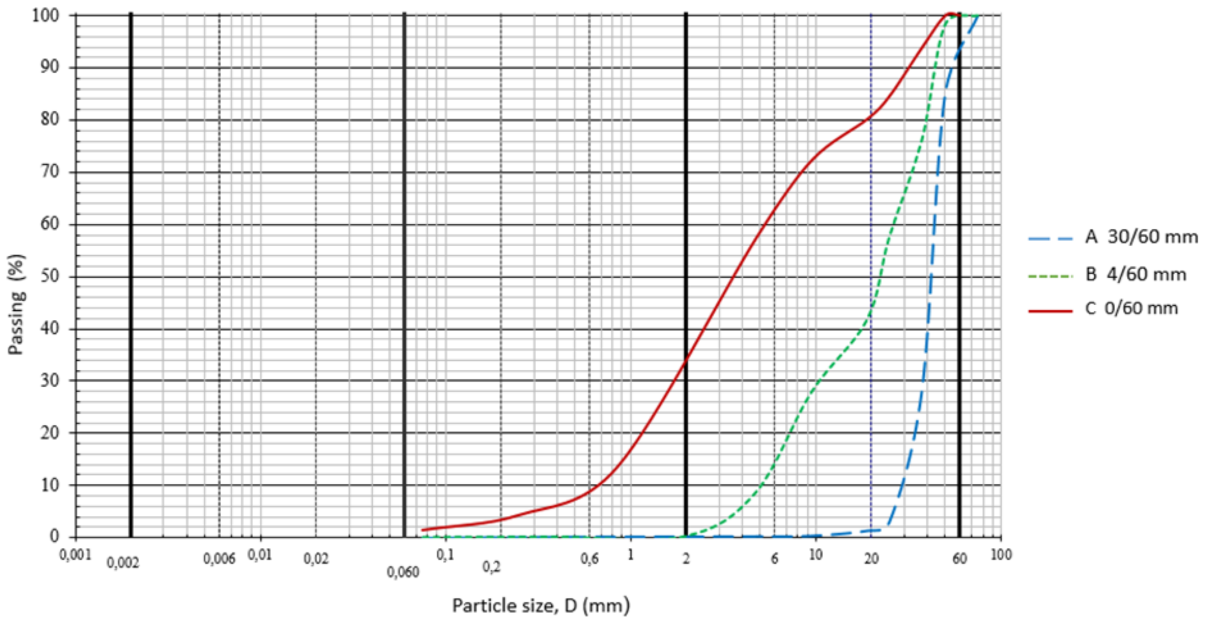

Figure 2. Gradation of the materials used in the tests

3.1.2 *Reinforcement*

The reinforcement element used in this study was an extensible geosynthetic strip, made of discrete channels of closely packed high tenacity polyester fibres encased in a polyethylene sheath. The polyester fibres are the load carrying elements and the polyethylene sheath is the protection of fibres during construction. The dimensions of the strips used in the study were: 90 mm width and about 6 mm thick. The length of strip in the pullout box was 1.6 m (the sleeve on the front of the box is 30 cm) and the total length of strip was more than 1.9 m. The typical polyester strip cross section is shown on Fig. 3.

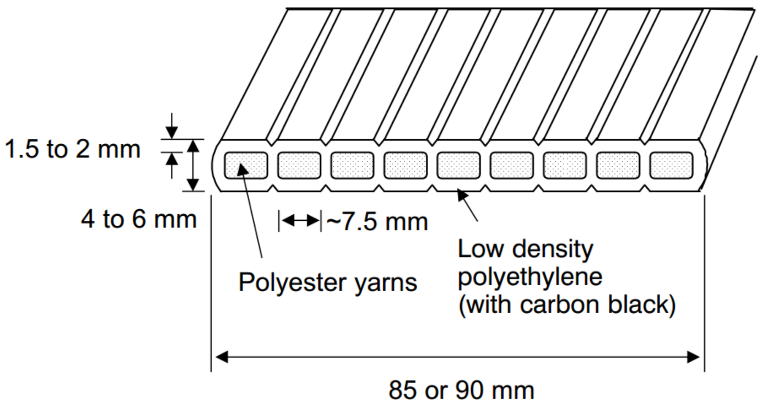

Figure 3. Cross section of typical polyester strip (Lo 1998)

4 TEST RESULTS AND DISCUSSION

A total of twelve tests were performed for three different gradations of crushed stone aggregate. In the tests confinement stresses of 50 kPa and 150 kPa were applied for materials A 30/60 and

B 4/60, and 50, 100 and 150 kPa for material C 0/60. The density values obtained after compaction in the tests varied between 1.72 - 1.96 g/cm^3 for material A 30/60, 2.09 - 2.17 g/cm^3 for material B 4/60 and 2.17 - 2.47 g/cm^3 for material C 0/60. Test records of pull-out force – displacement measurements during pull-out tests for three different gradation of crushed stone aggregate and for 50 kPa confinement stresses are presented in Fig. 4.

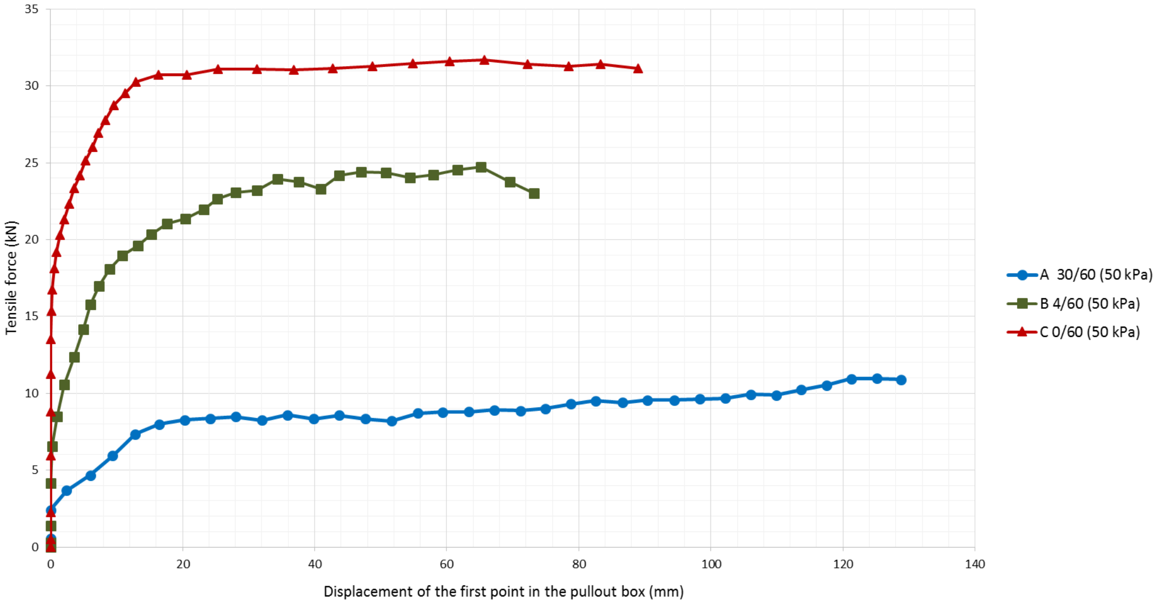

Figure 4. The displacement of the first point in the pullout box s under different confinement stress and for different material gradation

The tests in well graded material B 4/60 and C 0/60 showed a significant increase in pull-out forces in comparison with poorly graded material A 30/60 and these differences are higher for lower confinement pressure. This phenomenon is connected with constrained dilatancy effect. A comparison of average pull-out forces for materials A 30/60, B 4/60 and C 0/60 is shown in Fig. 5.

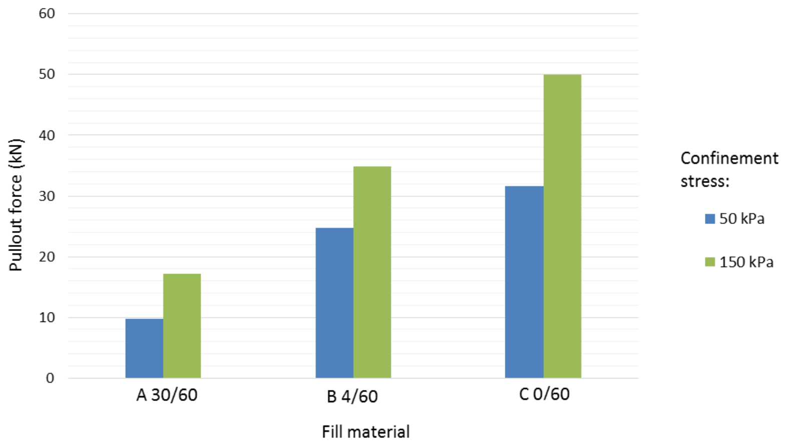

Figure 5. Measured pull-out forces for material A 30/60, B 4/60 and C 0/60

The results of all pull-out tests were used to obtain the value of friction coefficient *f** for the fill (crushed stone aggregate) and geosynthetic strip. The purpose of the tests was to determine the influence of density and uniformity coefficients on crushed stone aggregate -geosynthetic strips friction coefficient. The soil near the interface is subjected to considerable sliding during pullout, leading soil volumetric dilation. The volumetric dilatation of the soil in the vicinity of the strip is constrained by the surrounding soil and this results in an increase ($\Delta\sigma_v$) of the local vertical stress σ_{v0}. This phenomenon is named constrained dilatancy (Abdelouhab et al. 2010) and the real friction coefficient is expressed:

$$f = \frac{\tau_{max}}{\sigma_{vo} + \Delta\sigma_v} \quad (1)$$

To take into account in design this phenomenon and the influence of dilatancy Schlosser and Bastick (1991) defined friction interaction coefficient $f_{S/GSY}$:

$$f_{S/GSY} = f\,\frac{\sigma_{v0} + \Delta\sigma_v}{\sigma_{v0}} \quad (2)$$

Where f is the true coefficient of friction between soil and reinforcement (no dilatancy effect), and $\Delta\sigma_v$ represents the increase of normal stress on the reinforcement due the restrained dilatancy. In this research the $\Delta\sigma_v$ around the linear inclusion were not measured during the pullout tests and therefore friction interaction coefficient is given by:

$$f_{S/GSY} = \frac{P_{max}}{\sigma_v 2lb} \quad (3)$$

Where P_{max} is the maximum tensile force measured at the head of reinforcement (kN),σ'_v is the normal effective stress acting in a vertical direction at the reinforcing strip level, b is the reinforcement width (m) and l is the reinforcement length (m).

Values of friction interaction coefficient for crushed stone aggregate with different densities are presented in Tab. 1. The test results showed that the friction interaction coefficient increases as the density and uniformity coefficient increases. The friction interaction coefficient decreases as the confinement stress increase (Fig. 6). The difference of friction interaction coefficient is greater for material with higher density and higher uniformity coefficient.

Table 1. The friction interaction coefficient for the crushed stone aggregate with various density and uniformity coefficients

Fill type	Density (t/m^3)	Uniformity coefficient (C_u)	Friction interaction coefficient ($f_{S/GSY}$)
A 30/60	1.72 - 1.96	1.5	0.38 – 0.78
B 4/60	2.09 - 2.17	5.5	0.65 – 1.65
C 0/60	2.28 – 2.49	7.0	1.12 – 2.14

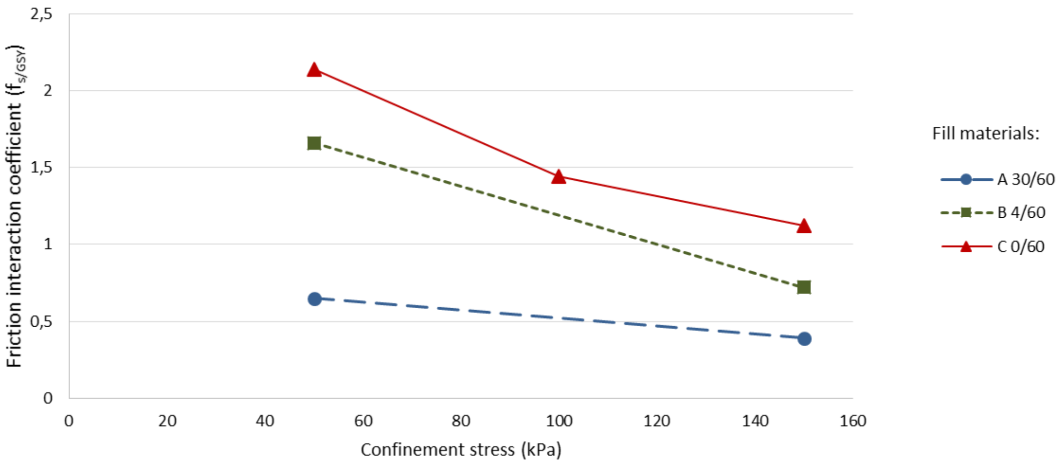

Figure 6. The apparent friction coefficient for various crushed stone aggregate grain size distributions

The friction interaction coefficient values from the current research are compared with friction interaction coefficient for different soil types and polyester strips from literature. In the research published by Lo (1998) of reinforced soil walls in Australia, two soil types were used in the reinforced zone: the first is considered to be a high-quality fill soil (PR) and the second was average fill soil (SW and M). The soil PR was well-graded, sandy gravel with less than 5% fines (i.e. particles passing through a 75 µm sieve). The soil SW was a well-graded, gravelly sand and the soil M was a well-graded sand with some gravels. In the research of Abdelouhab et al. (2009) the fill soil in the pull-out tests was coarse soil with a grain size distribution 0 – 31.5 mm and a sand with a grain size distribution 0.16 – 0.63 mm. Abdelouhab et al. (2009) suggests the use of practice lines of friction interaction coefficient for gravel and sand depending on confinement stress (Fig. 7 - full lines). The friction interaction coefficient obtained by pull-out tests reported by Lo (1998) and Abdelouhab et al. (2009) were compared with results of pull-out test for a crushed stone aggregate from the current study. The results shown also confirm that the grain size distribution and the uniformity coefficient have a significant influence on the soil – reinforcement friction interaction coefficient. For the poorly graded crushed stone aggregate (A 30/60) the friction interaction coefficient is below the practice line for sand in contrast to well graded crushed stone aggregate where the friction interaction coefficient lay above the practice line for gravel (see Fig. 7).

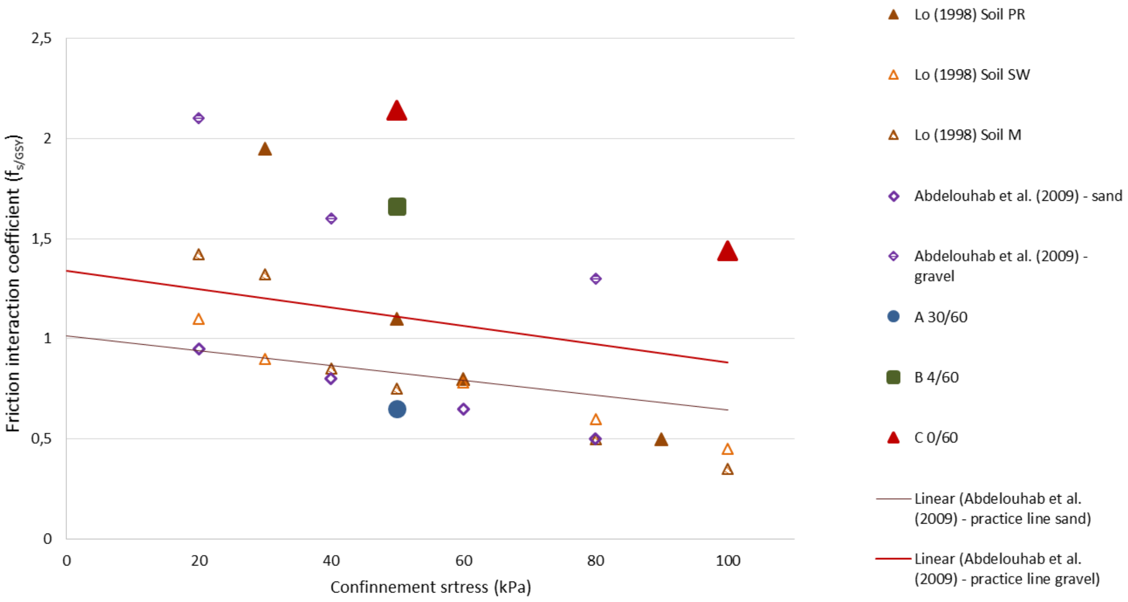

Figure 7. The friction interaction coefficient versus the confinement stress for the pull-out test with sand, gravel, sand-gravel mixtures and crushed stone aggregate

5 CONCLUSION

The pull-out resistance of geosynthetic strips was investigated using the large pull-out testing device developed at the Faculty of Civil Engineering in Osijek, Croatia. The tests were performed for the geosynthetic strips placed on an unbound soil type. These tests were carried out for the purpose of analysing the behaviour of the two tall MSE walls which were built in the coastal region of Croatia. The tests were unfortunately carried out afterwards, so conservative values had to be used in the design of the MSE walls. The walls were built with crushed stone aggregate as the frictional fill material and with the geosynthetic strips as a reinforcement material. The fill material used in the current study was very similar to the material used in the construction of these walls and results from this study therefore could be used for back analysis or for similar projects in the future. The tests in the current study were performed for various confinement stresses and for three different grain size distributions of the fill material. The first material was poorly graded crushed stone aggregate with grain size distribution from 30 – 60 mm and the second was well-graded crushed stone aggregate with grain size distribution from 4 – 60 mm and 0 – 60 mm. The test results confirmed that the maximum friction interaction coefficient at the interface decreases as the confinement stress increases. The results also showed the importance of grain size distribution and uniformity coefficient of a soil fill on the friction interaction coefficient. In the case of poorly graded crushed stone aggregate the friction interaction coefficient at the soil – reinforcement interface are lower than the practice line suggested by Abdelouhab et al. (2009) used for a sand while for a well graded crushed stone, the friction interaction coefficient are significantly higher than those used in practice.

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