Effect of geosynthetic reinforcement pull-out on the surface characteristics of facing blocks

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Abstract. The friction coefficient between the facing blocks and the geosynthetic reinforcement is one of the parameters in MSE design. To obtain this parameter, specific tests are foreseen in the standards. However the pull-out process of the geosynthetic reinforcement has an effect on the facing block surfaces. In this study the roughness of the precast concrete block elements was determined before and after the pull-out test to see the effect of the pull-out process, since the frictional behavior is a function of surface roughness. For this purpose 3D scanning was performed on block surfaces and a special macro program was coded to get a surface reading for every 0.5 mm. Since the concrete blocks used in the experiments are produced using the dry-cast method, the surfaces are not smooth and many small sized aggregate particles stick out of the average surface. As a result these extrusions break during the pull-out test. Hence, in conclusion, the roughness values have always increased after pull-out tests for both geotextile and geogrid reinforcement.

1 Introduction

The rise of the usage of geosynthetic reinforced earth walls with precast concrete block facing elements are remarkable for the last 40 years. One of the greatest advantages of MSE walls is their flexibility and ability to absorb deformations due to poor subsoil conditions in the foundation. Also, based on observations in seismically active zones, these structures have demonstrated a higher resistance to seismic loading than have rigid concrete structures [1]

The design of reinforced earth walls has many steps, parameters and design criteria such as internal stability, external stability, global stability, facing stability and such. During these design steps, the major inputs are the properties of reinforcement materials and the soil parameters based on the geotechnical literature. The wall geometry and loads are also other parameters that can be identified by the designer.

However, the facing stability of geosynthetic reinforced earth walls utilizing modular blocks are more difficult to be assessed as an input for the designer. This is mainly because the facing stability is a function of many variables such as block type, connection type (mechanical versus frictional), block geometry, reinforcement type, filling material etc. To assess the frictional properties for a frictional connection, a laboratory test can be conducted

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using the specific materials. In this context, he pullout test defined by ASTM D6638 is widely used to determine the connection strength of segmental (modular block) reinforced earth walls.

In this research, the frictional properties of dry pre-cast concrete blocks were investigated to understand the facing connection strength more in detail. In order to do that the surface roughness of the concrete blocks were determined before and after pulling out a geosynthetic reinforcement from in-between the blocks. Since the most common type of reinforcements used in the industry are woven geotextiles and PVC coated polyester geogrids, these two reinforcement types were used in the tests. Segmental concrete building blocks were used as facing elements.

The connection strength is sometimes provided by the manufacturer, mainly because this parameter can be specific to a certain block, and this certain block type can be a trademarked block of a certain manufacturer. To omit this type of problem, the block type used in this study was chosen as a standard building block which is also used widely as a facing element in segmental retaining walls.

2 Pull-out test procedure and materials

The tests to determine connection strength require a specially designed apparatus. A test apparatus that is similar to the one defined in ASTM D6638 was built to conduct the pull-out tests from between concrete blocks under static tensile loading conditions. The test apparatus has two hydraulic loading mechanisms; vertical loading represents the surcharge load above the modular blocks while tensile (pull-out) load is directly applied on reinforcement. Effective capacities of surcharge and pull-out loads of the apparatus are 7000kgf and 3500kgf, respectively. The pressure due to surcharge load is equivalent to approximately 30 m of wall height. The reinforcement sample is confined between two concrete modular blocks. The modular blocks are laterally restrained and surcharged vertically according to depth of the reinforcement layer with respect to the crest of the wall. Schematic views of test apparatus are shown in Figure 1.

There are numerous modular concrete blocks used in the market. Obviously, using different blocks will end up giving different results in terms of connection strength between reinforcing element and block. In order to get the most standardized results, it was preferred to use the most common type of block in this research, namely a building block, which is a rectangular hollow block (Figure 2). The blocks have the outer dimensions of 190 mm (height) x 190 mm (width) x 390 mm (length). Technical specifications of modular block material is shown in Table 1.
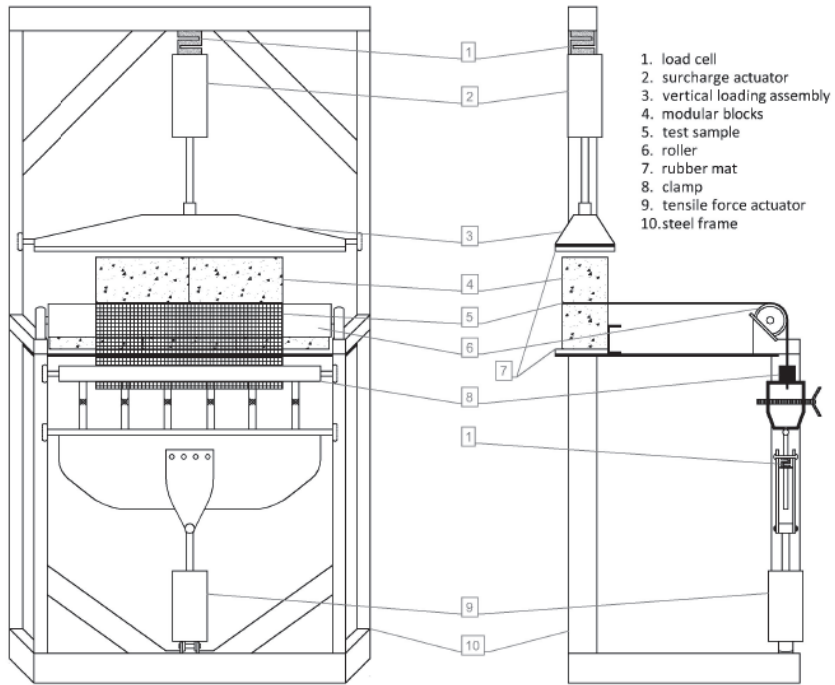
1. load cell
2. surcharge actuator
3. vertical loading assembly
4. modular blocks
5. test sample
6. roller
7. rubber mat
8. clamp
9. tensile force actuator
10. steel frame

Fig. 1. Schematic front view and side views of test apparatus (not to scale)

Table 1: Material properties of concrete modular blocks

Property	Unit	Value
Dimensions	mm	190x190x390
Weight of a Module	kg	17.5
Density	gr/cm^3	2.3
28-day Compressive Strength	MPa	17.5
Max Water Absorption	%	6

Figure 2: Hollow Concrete Modular Blocks

In order to simulate the more critical high walls, two geosynthetic reinforcement types with relatively high tensile strength values were chosen. One geosynthetic reinforcement chosen was a polypropylene woven geotextile with a tensile strength of 120 kN/m tensile strength in both directions. The other geosynthetic reinforcement tested was a woven PVC coated Polyester Geogrid which had a tensile strength of 300 kN/m in the machine direction and a tensile strength of 60 kN/m in the cross-machine direction. The relevant material properties for geotextile and geogrid are listed in Table 2.

Table 2: Material Properties of Reinforcements

Property	Unit	Value	
		Geotextile (120kN/120kN)	Geogrid (300kN/60kN)
Material	-	PP	PET, PVC Coated
Nominal Tensile Strength - MD	kN/m	120	300
Nominal Tensile Strength - CMD	kN/m	120	60
Static Puncture Resistance	kN	15	-
Elongation at Nominal Strength	%	14	12
Strength at 2% Strain	kN/m	26	60
Strength at 3% Strain	kN/m	39	-
Strength at 5% Strain	kN/m	75	120

The test procedure and apparatus is used in this research is similar to the one proposed by Bathurst and Simac [2]. Before beginning the tests, top elevation of bottom row of modular block units is adjusted according to the top level of roller by using rubber mat layers. Rubber mat layers placed below the bottom layer of modular block units is to compensate the potential slight height differences between the blocks. Afterwards, bottom row of modular block units is placed so that the interface elevation is coincident with the top of roller. Following the replacement of bottom row blocks the 780 mm wide reinforcement sample (equal to the width of two blocks) is attached to the clamp and the reinforcement extended to the top of the bottom row of facing blocks. Reinforcement is trimmed by taking the interface width into account. Dowels, pins or similar tools aren't used to fix reinforcement to modular blocks, only friction on interface is utilized. Upper row of the modular blocks is placed over geosynthetic reinforcement laying on the bottom row of blocks. Above the upper layer blocks another rubber mat and steel plate was placed to allow an even load distribution. The surcharge load on modular blocks is applied through the vertical load actuator. A load cell is mounted on vertical load actuator to monitor and control the applied surcharge loads. Likewise the surcharge load, pull-out load is also monitored by using a load cell. Load cell is mounted between clamp and piston of hydraulic pull-out load actuator. The capacity of the lateral actuator was sufficient to facilitate a complete pull-out. The upper limit for normal load in the experiments was set to 3400 kgf corresponding to an equivalent wall height of approximately 15 m.

3 Roughness measurement

Surface roughness, often shortened to roughness, is an expression of surface texture. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations

are large, the surface is rough; if they are small, the surface is smooth. Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces.

Roughness can be measured by manual comparison against a "surface roughness comparator", a sample of known surface roughness's, but more generally a surface profile measurement is made with a profilometer that contacts the surface (typically diamond styles) or with an optical reader (e.g. a white light interferometer). A roughness value can either be calculated on a profile (line) or on a surface (area). The roughness parameter is calculated using a formula for describing the surface. Although these parameters are generally considered to be "well known", a standard reference describing each in detail is given by Whitehouse [3]. There are many different roughness parameters in use, but R_a is by far the most common though this is often for historical reasons rather than for particular merit as the early roughness meters could only measure R_a. The roughness average, R_a, is the most widely used one-dimensional roughness parameter. The formula presented below assumes that the roughness profile has been filtered from the raw profile data and the mean line has been calculated. The roughness profile contains n number, ordered and equally spaced points along the trace, and y is the vertical distance from the mean line to the ith point. Height is assumed to be positive in the up direction, away from the bulk material.

Amplitude parameters characterize the surface based on the vertical deviations of the roughness profile from the mean line and R_a value is calculated using equation (1).

$$R_a = \frac{1}{n}\sum_{i=1}^{n} |y_i| \qquad (1)$$

For the determination of the surface roughness scanning was performed and surface readings were taken for every 0.5 mm along different lines. For each test a new block was utilized to make a proper comparison for the change in the surface characteristics during pull-out. The standard building blocks used have two holes in it resulting in contact between geotextile and block occurring only at the concrete interfaces. The concrete geotextile interfaces can be divided into 5 zones for practical assessment. These are 3 pieces of wall block that connect the panel at the back and front and the two panels that is to say at the front and back. To eliminate local differences, three Cross-Sections were analyzed from each of 5 zones. The output including all the readings every 0.5 mm is identified as a Line (Figure 3). Due to the fabrication of the blocks, there were deep notches in the middle of the short edges so the roughness on these parts was not taken into consideration. The measured roughness value for each line for one block is given as an example in Table 3.
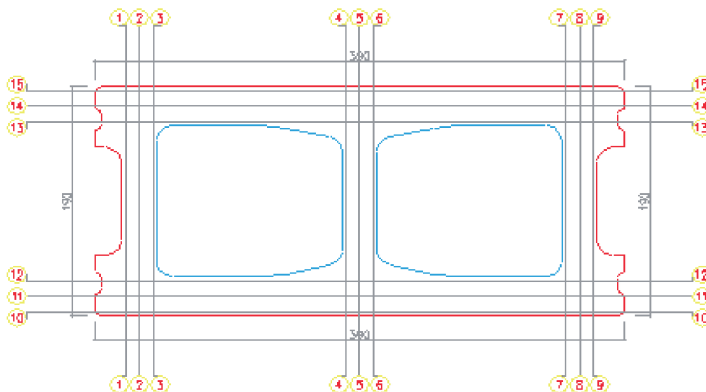

Figure 3 Lines along which roughness measurement were taken

Table 3 Roughness results example of one block with geogrid

		Roughness on block surface R_a		Change in %
		Before test	**After test**	
TENSILE STRESS DIRECTION	LINE-1	0.0730	0.0907	24.2
	LINE-2	0.1704	0.1761	3.34
	LINE-3	0.1203	0.1382	14.91
	LINE-4	0.0885	0.1337	51.1
	LINE-5	0.1390	0.1808	30.1
	LINE-6	0.09703	0.1149	18.09
	LINE-7	0.329	0.351	6.48
	LINE-8	0.1407	0.205	45.7
	LINE-9	0.1861	0.208	11.53
	LINE-10	0.206	0.224	8.48
	LINE-11	0.1113	0.1312	17.88
	LINE-12	0.0987	0.1164	17.95
TRANSVERSE DIRECTION	LINE-13	0.1486	0.1801	21.2
	LINE-14	0.1383	0.1488	7.60

For the geogrid, the contact area of the geogrid and the concrete blocks was even smaller. The contact area between the geogrid and block is shown in Figure 4. As a consequence, the lines along which measurements are taken was chosen as the locations where the geogrid tendons coincide with the block as can be seen in figure 5.
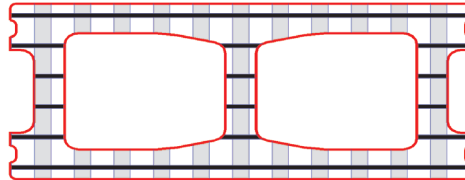

Figure 4 Schematic showing the contact area of geogrid and block (Gray – Longitudinal tendons; black cross tendons; red – boundary of the block
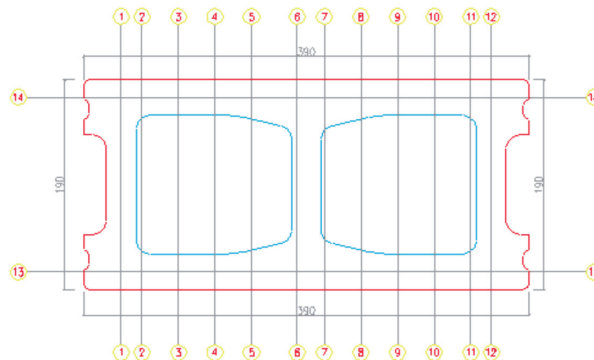

Figure 5 Lines along which roughness was measured on blocks

The measured roughness values along different lines measured along one block is given as an example in Table 4.

Table 4 Roughness results example of one block with geotextile

| | | Roughness on block surface R_a | | Change in % |
		Before test	After test	
TENSILE STRESS DIRECTION	LINE-1	1.445	1.441	-0.28
	LINE-2	1.508	1.525	1.14
	LINE-3	1.469	1.462	-0.52
	LINE-4	1.537	1.530	-0.47
	LINE-5	1.559	1.605	2.88
	LINE-6	1.550	1.526	-1.60
	LINE-7	1.660	1.668	0.44
	LINE-8	1.610	1.603	-0.43
	LINE-9	1.664	1.726	3.58
TRANSVERSE DIRECTION	LINE-10	1.587	1.613	1.60
	LINE-11	1.593	1.603	0.66
	LINE-12	1.538	1.551	0.86
	LINE-13	1.383	1.370	-0.87
	LINE-14	1.408	1.404	-0.24
	LINE-15	1.432	1.435	0.23

4 Conclusions

The roughness values have always increased after pull-out tests for both geotextile and geogrid reinforcement. However, the increase in roughness was much more significant when a geogrid was used as a reinforcement.

The reason for the increase in roughness of the block surface has been considered to take place because of the surface characteristics of the concrete blocks. Since the concrete blocks used in the experiments are produced using the dry-cast method. The surfaces are not smooth and many small sized aggregate particles stick out of the average surface. During the pull-out, it is anticipated that some of these small particles may detach from the rest of concrete.

The average change in surface roughness remained at 0.8% for geotextile where the increase in roughness was on the average 14% for geogrid.

The reason for the geotextile to create less breakage on the surface can be explained by the comparatively much lower normal stress acting on the geotextile ($\sigma_{normal-geotextile} = 446$ kPa) compared to the normal stress acting on the geogrid ($\sigma_{normal-geogrid} = 892$ kPa) for the same total vertical load. Therefore this breaking of particles is much less when geotextile reinforcement is used. This is indicated with the smaller change in surface roughness value when geotextile was used in the pull out test.

However, the increase in roughness does not increase the pull-out capacity as one would expect. The reason for this is that these fractured particles accommodate to the fact as reported by Astarcı [4] to act as rollers and thereby decrease the resistance against pull-out.

References

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