CENTRIFUGE MODELLING OF MODULAR BLOCK FACING REINFORCED SOIL RETAINING WALL

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Abstract: The purpose of the study is to analyse the behaviour of modular block reinforced soil retaining walls under static 2-D conditions. Centrifuge tests were conducted at Columbia University to study the failure mechanism and the influence of parameters such as the length of reinforcements and their spacing on the structure behaviour.

Clean Nevada sand was used as the backfill, fabric material was used to simulate the geosynthetic reinforcement, and aluminium blocks to simulate the modular concrete blocks. Two different methodologies have been used for the tests: increasing gravity until failure of the structure in order to study the failure mechanism and increasing gravity until 20 g to investigate facial deformation and settlement. In both cases, different lengths of reinforcements were used to analyse the effects of layout on behaviour of the structure. In the deformation tests (gravity increased to 20 g), the effect of spacing was also studied.

In order to measure the facial and vertical displacements, a laser transducer and an LVDT has been used respectively. To monitor the behaviour of the slope during centrifuge tests, two cameras were used. At the end of each test, one of the lateral sides of the box was removed in order to obtain the configuration of the failure surface.

To compare results obtained from the tests in the centrifuge with the behaviour of a full scale structure under static 2-D conditions, finite element models representing the centrifuge models were implemented. The results obtained by the centrifuge tests and by the finite element models were used to define the influence of the design parameters and the role of facing in the overall stability. The implementation of results to current specification guidelines for this kind of structures was discussed.

Keywords: centrifuge, modular block wall, reinforced earth retaining wall, deformation, failure mechanism, failure surface

INTRODUCTION

In this paper, the behaviour of reinforced modular block facing retaining wall using centrifuge scaled model is studied. The attention has been focused on the two-dimensional static condition. The failure of the structure has been simulated using centrifuge scaled model and the influence of some design parameters, such as the length and the spacing of the reinforcement on the performance of the structure has been studied. The role of facing in the overall stability has also been considered, e.g. Tatsuoka (1992).

The procedure and the material used to build a scaled model of a reinforced modular block facing retaining wall in a centrifuge environment are described. The results obtained by the centrifuge tests have been analyzed and compared with a finite element model of the full scale prototype to evaluate the reliability of the results.

The results obtained by the centrifuge test and by the finite element models have been used to discuss about the current design specifications or guidelines from a critical point of view.

CENTRIFUGE

A wide range of geotechnical problems can be investigated using centrifuge physical modelling techniques and the evaluation of the behaviour of reinforced modular blocks retaining wall is not an exception. Small scale physical modelling of engineered earth structures has been used in the past to provide insight into failure mechanism in reinforced soil structures, e.g. Lee *et al.* (1973). The centrifuge provides a tool for geotechnical modelling where prototype structures can be studied using scaled-down models while preserving the stress states using appropriate soil properties. The principle of centrifuge testing is to raise the gravity acceleration of the scaled model to obtain prototype stress levels in the model. In the centrifuge modelling technique, a reduced-scale model N times smaller than the full-scale is used, whereas the acceleration is increased by N times to preserve the stress and strain behaviour [Taylor (1995)]. Scaling laws can be derived by making use of dimensional analysis, e.g. Langhaar, (1951), or from a consideration of the governing differential equations. Note that several individuals have applied centrifuge modelling technique to reinforced slopes(e.g. Zornberg *et al.*, (1997); Takemura and Takahashi, (2003); Gooding and Santamarina (1989) ; Jaber *et al*. 1990). In this study for the first time the centrifuge modelling technique was applied to modular block facing retaining walls.

MODEL TEST

In order to reproduce the behaviour of modular block facing reinforced retaining walls various scaled models were built and centrifuge tests were performed. The materials used to build the model are described as below.

Soil. Nevada #120 sand was used to build the model, this soil has been extensively used in VELACS project thus its properties have been widely investigated. Some of the important soil properties have been investigated by Earth Technology Corporation, e.g. Alurmoli et al (1992). For all the tests in this report clean Nevada sand was used with a unit volume weight of 16 kN/m^3 and a water content of 11.2%. To allow the slip surface to be traced more easily a thin layer of coloured sand was placed between each layer.

Reinforcements. Several materials were tested using the tensile device to find their tensile strength. The shear box was used to analyze the interface friction angle between the sand and the reinforcements. In order to choose a suitable reinforcement the ultimate tensile strength, the initial stiffness and the interface friction angle were considered. Following these criteria, a material which simulates the behaviour of a geosynthetic under 20 g was found. In the centrifuge field, the ultimate strength has to be multiplied by the scale factor (N) to obtain the tensile strength that the reinforcement will experience during the test. The stiffness of the reinforcement plays an important role in controlling wall face deformation and stress distribution inside the backfill and the displacement decreases when a stiffer reinforcement is used. The effect of failure strength is assumed to be small as most reinforced soil structures would have attained failure prior to breakage of reinforcement. A more important feature of the reinforcement is its initial stiffness that for the selected reinforcement is 520 kN/m (also this value has to be multiplied for the scale factor).

The chosen material was a fabric with a mesh of 2 mm, having the following properties:

- Ultimate strength: 3.8 kN/m
- Interface friction angle: 27°
- Initial stiffness: 520 kN/m

Thus, in a centrifugal field of 20 g, the reinforcement used can be classified as very stiff. In the centrifugal field the reinforcement will have an ultimate strength of around 75 kN/m and an initial stiffness of around 10,000 kN/m. Figures 1 and 2 show the tensile test performed and the result obtained from the test respectively.

Figure 1. Tensile test

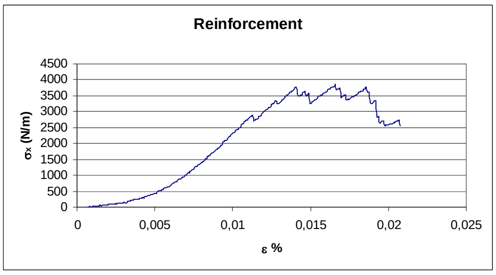


Figure 2. Tensile test

Modular Blocks. Figure 3 shows the shape and features of the blocks used in the test. The blocks were model for the modular blocks used in the full-scale shake table tests (Ling *et al*., 2005). They were 1 cm high, 1.4 cm deep, and 2.2 cm wide. The mass was 5.76 g. The front end lip is a major characteristic of this block system. The lip at the front part of the block (additional 2mm in height and 2 mm in depth), in fact, provided alignment during construction. The lip also prevents direct outward slippage of top block relative to the bottom block. To increase the interblock shear resistance and to improve the reinforcement connection strength to the facing, the hollow portion of the block was filled with compacted sand (with gravels in the practise). The reinforcement was carefully placed in between the blocks in order to obtain the best connection between the reinforcement and the bricks.

Figure 3. Modular blocks

Figure 4: Comparison with a full scale modular block

The aluminum blocks were manufactured with dimensions 20 times smaller than the concrete block used in the construction of modular blocks retaining wall reported in Figure 4 (note: the small scale model used is on the top right corner of the concrete block).The dimension of the bricks used in the model acts as a constraint for the model itself.

Membrane. The side friction between the aluminium side walls of the box and the model was reduced by placing a rubber membrane smeared with grease. The membrane was pre-cut into a number of thin vertical strips in order to reduce the tensile force that may restrain the model movement, e.g. Wu *et al.* (2006)

Instrumentation and data acquisition system

For the current study the centrifuge facility of Columbia University was used. It can reach a maximum speed of 265 R.P.M. and it has a nominal radius of 3 m to the platform. The model was built inside a strong box. The model was built only on the left part with actual box dimensions of the box of 20 cm x 94 cm (width x length).

The laser transducer was used to measure the lateral wall displacement. It was placed within the sensitive measuring range directed to a point at half width of the model and at 0.4 the height of the wall. This height was chosen assuming that it was the point where the maximum deformation will occur, based on a finite element parametric study of the behaviour of segmental block reinforced-soil retaining walls (Ling and Leshchinsky 2003).

The LVDT (Linear Variable Differential Transformer) was placed on the top of the wall in order to measure the vertical displacement as showed in Figure 5. It was used only in the “non failure” test to preserve its integrity (Tests 4,5,6,7).

Two cameras were used in the test. A camera was placed in front of the model in order to visualize the movement of the model during the test (Figure 5). A second camera was recording from the top of the model in order to visualize a possible tension crack that will occur during the test.

After each test, the side of the box was removed and through a transparent panel the position of each soil layer, previously identified with coloured sand strata, was carefully traced. By this procedure it was possible to identify the failure surface, if any. Once determined, the failure surface was traced on a transparency and digitalized.

Model construction

The model was built inside the strong box. Nevada sand with the described water content was placed into the box and compacted to obtain the desired density, using a rectangular steel rammer. A 5 cm thick foundation was placed. After the foundation was compacted and levelled, a frame was secured to the box. The purpose of the frame was to allow the model to be built with compaction of the backfill and with a perfect alignment of the bricks in the face. After the frame was fixed, the bricks were placed and the backfill compacted. The reinforcement was positioned between the bricks when it was required by the design. In each soil layer where the reinforcement was present, the surface was traced with coloured sand. The box with the whole model was placed onto the platform of the centrifuge. The frame was removed, and the laser transducer, the LVDT and the camera were securely fixed to the box. Figure 5 shows the typical cross-section of the model, and Figure 6 shows the front view of the model before the test.

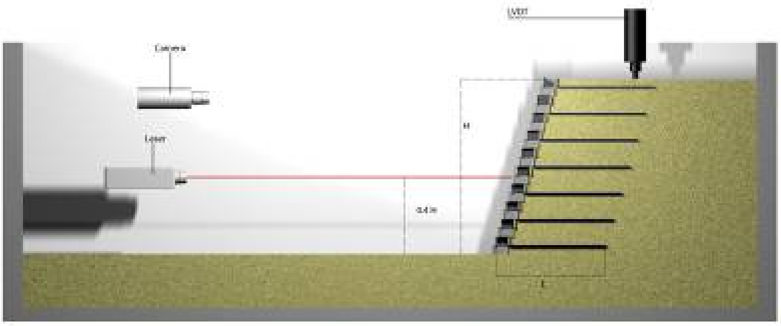


Figure 5: Model cross-section with instrumentations and dimensions

Figure 6: Model in place.

TEST PROGRAM

The test program was divided in two main phases. In Phase 1, three tests were performed in order to understand the model behaviour and to study the failure mechanism; in Phase 2, four tests were conducted to focus on studying the performance and deformation of the structure under a fixed value of gravity (20 g).

As listed in Table 1, each test is named with a label consisting of a **T** (for test) followed by a serial number indicating the test chronology; a **L** (for length) followed by the percentage of the height that was used for the reinforcement length (described only by the decimal part; for example L4 means 40% of the height). A **S** (for the reinforcement spacing) followed by the percentage of the height of the model with which the reinforcement are spaced (for a spacing of 15 or 20% of the height 15 or 20 follow the S in the test name). The last symbol in the test name, after the slash, represents the value of g reached during the test (20 g, for example, or F if the test was run until a catastrophic failure).

Table 1. Test Program

Test	Length	Spacing	g value
T1L0S0/F	0	0	Failure
T2L3S15/F	0.3 H	0.15 H	Failure
T3L5S15/66	0.5 H	0.15 H	66
T4L4S15/20	0.4 H	0.15 H	20
T5L6S15/20	0.6 H	0.15 H	20
T6L6S20/20	0.6 H	0.2 H	20
T7L4S20/20	0.4 H	0.2 H	20

The model built in Test 1 (T1L0S0/F) was made without the reinforcements and the acceleration was increased until a catastrophic failure was reached (Catastrophic failure is considered where the structure and wall collapsed).

In Test 2 (T2L3S15/F), the model was built with a 0.3H reinforcement length (where H is the height of the model as showed in Figure 5) and a spacing of 0.15H (3 block spacing). Also in this case the gravity acceleration was increased until catastrophic failure was reached. In the third model (T3L5S15/66), the length of the reinforcement was 0.5H with the same spacing of the previous test and the acceleration was increased until the value at which the previous test had reached a catastrophic failure.

In the Phase 2 (Tests 4,5,6 and 7) the gravity acceleration was fixed at 20 g to study the deformations and the performance of the structure respecting the scaling laws since, as stated before, the blocks and the reinforcements were designed particularly for this value of acceleration.

In Phase 1, three main failure types were noticed:

- a failure characterized by a relatively small displacement and a failure surface close to the end of the reinforcement (not elevated g values);
- a failure with a more significant displacement and a deeper failure surface (higher g values);
- a catastrophic failure with the pull-out of the reinforcement and the fall down of the bricks that made up the wall.

With the intention of better understanding the first type of failure mechanism (that is a major design concern) Test 4, which was at first performed at 20 g, was carried out again until 30 g, where a failure of the first kind was detected (as shown in Table 2).

Table 2. Test 4 (at 30g)

Test	Length	Spacing	g value
T4_2L4S15/30	0.4 H	0.15 H	30

In this case, the increment in the g value gave a “non respected” dimension value, but allowed to detect the failure surface and to evaluate how the spacing influences the failure surface (will be detailed later).

FAILURE MECHANISM

The tests performed allowed to detect three main types of failure mechanism:

- A first failure surface close to the end of the reinforcement (described with 1 and with a blue line in Figure 7)
- A second failure surface that is deeper than 1 (described with 2 and a green line in Figure 7)
- A third failure with pull out of the reinforcement and failure at the connection between the bricks that is defined as catastrophic failure (shown in Figures 8a and b)

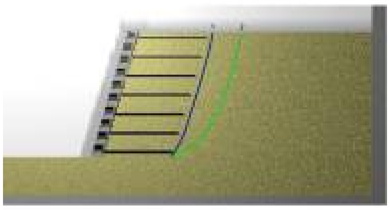


Figure 7: 1) first failure surface (blue line)
2) deep failure surface (green line)

a) front view b) lateral view

Figure 8:Catastrophic failure T2L3S15/F.

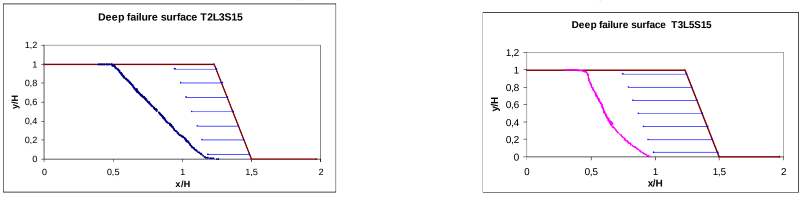
In all the cases, the failure occurred externally. The model was build with a very loose material (uncemented sand with a low relative density) and a relatively strong reinforcement. The failure detected by the tests was external due to the high strength of the reinforcements. The first failure surface obtained at low g value was close to the end of the reinforcement and it became closer as the length of the reinforcement was increased.

Increasing the acceleration of gravity after the first failure gave a deeper failure surface. After the deeper failure surface was developed increasing the acceleration of gravity lead to the catastrophic failure of the structure. The three types of failure mechanisms are described below and explained in detail.

Deep failure surface

As described before, this kind of failure occurred at a higher g values than the first kind of failure, which took place close to the end of the reinforcements. In addition, it had a bigger radius and it occurred only after the first one.

The failure surface was observed, drawn on a transparent paper and digitalized. In Figures 9a and b, the normalized failure surfaces are reported; the shape of this failure surfaces was influenced by the length of the reinforcement. The failure surface becomes deeper as the reinforcement length increased.



a) T2L3S15 b) T3L5S15

Figure 9: Normalized shape of the deep failure surface

Catastrophic Failure

After the deep failure happened, a pull-out disconnection of the reinforcement followed by the disconnection of the bricks was detected. The catastrophic failure occurred only when the reinforcement and blocks lost their connections. By investigating the facial displacement of the wall, it is possible to detect the time at which failure occurred. The reinforcements tolerated an increase in the value of maximum displacement at which the catastrophic failure occurs (see Table 3).

Table 3. Maximum wall displacements at failure

Test	Maximum displacement*	g value	Length of Reinforcement
T1L0S0/F	2.4 %	33→ catastrophic failure	none
T2L3S15/F	4.8 %	66→ catastrophic failure	0.3H
T3L5S15/66	3.2%	66 (no catastrophic failure)	0.5H

*The displacements are expressed as percent of the wall height and represented the displacements in the model just before a catastrophic failure (if any).

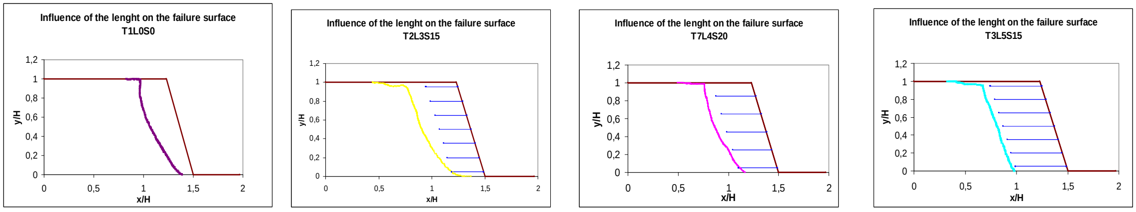
Test T3L5S15/66 was conducted until the g value where failure was detected in the previous test (T2L3S15/F). No catastrophic failure was detected in this Test.

From these tests, it is possible to infer that the value of maximum displacement that occurred before the catastrophic failure increased with the length of reinforcements. The g value at which failure was detected increased with the length of the reinforcements. The reinforcements gave more resistance and more flexibility to the structure as a whole.

First failure

In the other tests, the attention was focused on the analysis of the first failure that occurred close to the end of the reinforcement. This failure was the one that first occurred and should be avoided in a safe design. The shape of this failure surface was influenced by the length of the reinforcement. The longer the reinforcement, the deeper the critical surface, and the higher the g value at which failure occurred.

The reinforcements moved the critical surface far from the face of the wall due to its tensile resistance. Figures 10a to d show the shapes of the failure surface under different lengths of reinforcement.

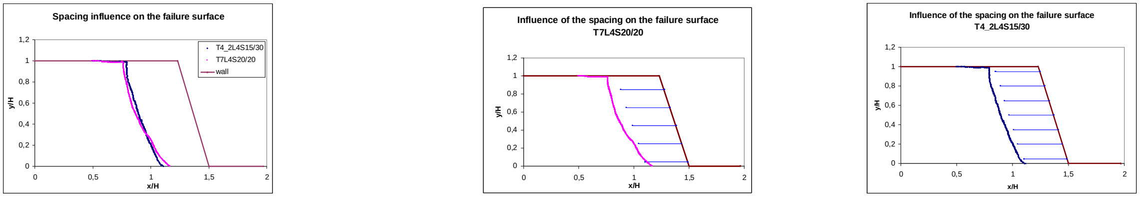


a) T1L0S0 b) T2L3S15 c) T7L4S20 d) T3L5S15

Figure 10: Normalized failure surface for various reinforcement lengths

To investigate the influence of spacing, Test 4 (with a reinforcement length of 0.4H and a spacing of 0.15H) once performed at 20 g, was run again until the wall reached failure. The failure happened around 30 g and the failure surface was drawn. The influence of spacing on the shape of the normalized failure surface was negligible. In fact, the normalized failure surfaces for tests T4_2L4S15/30 and T7L4S20/20 (both showed in Figure 11a) had almost the same shape. In Figures 11b and c, the failure surface and the reinforcement for each test are shown.

The spacings of the reinforcement were rather close in this study, thus they did not influence the shape of the failure surface. The main difference between the two failures was the g values at which failure occurred. The failure of the model with 0.15H occurred at almost 30 g while in the model with 0.2H it occurred at 20 g. This means that between the two prototypes represented by the models described, there was a difference in the failure height.



a) T4_2L4S15/30 and T7L4S20/20 b) T7L4S20/20 c) T4_2L4S15/30

Figure 11: Normalized failure surface for different spacings

FACIAL DEFORMATION

The second phase of testing was focused on the study of the facial deformation and the vertical displacement of the backfill. In the second phase, all the centrifuge tests were conducted at 20 g, value at which the model was designed for.

The facial deformations were measured using a laser transducer and the investigation was implemented with the observations. The facial deformed shape, at the end of the test, was drawn in function of the wall height. Figure 12 shows the facial deformation for different tests. To compare the observation with the measured results obtained from the laser transducer, some assumptions were made: the transducer, placed at 0.4 the height of the wall, measured the maximum displacement and the point at the top of the wall did not have any horizontal displacement. From the observation, only qualitative information could be obtained. This qualitative information together with the accurate measurement obtained by the laser transducer described the trend of deformation reasonably well.

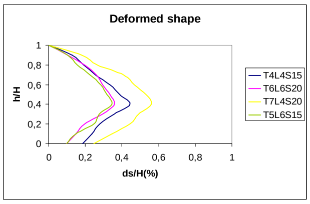
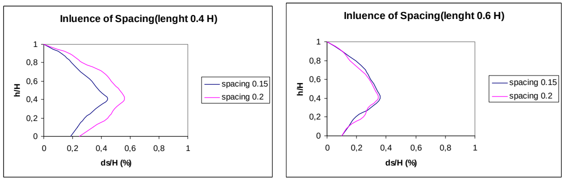


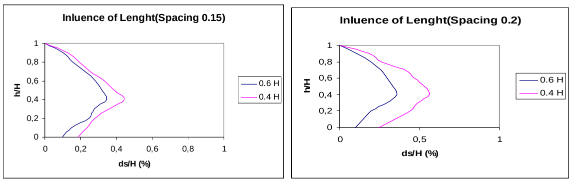
Figure 12: Normalized facial deformation

The facial deformation was influenced by the spacing and the length of the reinforcements. Two series of tests with the same length and different spacing were done in order to study the combined influence of these two factors. Figure 13 shows how, for a fixed length of the reinforcement, the deformed shape varied in function of the spacing used in the model. This effect was more evident in the case of a short reinforcement length (Figure 13a). For a length of 0.6H, in fact, the displacement was so small that the divergence of the facial deformed shape between the different spacing was not appreciable (Figure 13 b). The influence of the length of the reinforcement was also evident. Figure 14 shows how this parameter influenced the deformed shape of the wall. It is seen that by varying the length of the reinforcement the deformation became bigger. From Figures 13 and 14, the combined influence of spacing and length of the reinforcement can be deduced. The smaller the length of the reinforcement, the larger the facial deformation. In addition, the larger the spacing, the larger the deformation.



a) length 0.4H b) length 0.6H

Figure 13: Influence of spacing on facial deformation



a) spacing 0.15H b) spacing 0.2H

Figure 14: Influence of length on facial deformation

VERTICAL DEFORMATION

During the test, the vertical deformation was recorded at one point using the LVDT placed on the top of the backfill. This was done only for Tests 4 to 7. From the vertical displacement, it is possible to determine the moment when failure occurred. From the facial displacement it is more difficult to determine when the failure occurred. In Figure 15, the vertical displacements are plotted in function of increasing g value.

In T7L4S20/20, the vertical displacement had an abrupt change at 20 g, from less than 0.5% of H to 2%. This large change represented failure in the wall. This failure occurred at 20 g value at which the dimensions are respected. From these data, it is possible to deduce that the design of Test 7 (L= 0.4H; S= 0.2H) would lead to failure of the wall even under static conditions (with the backfill and reinforcement material used in this study).

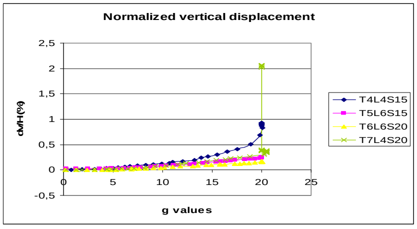
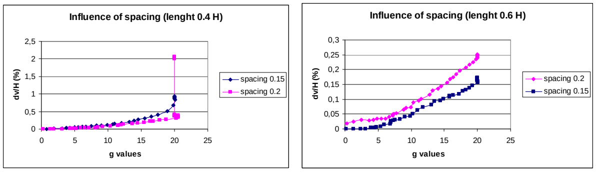


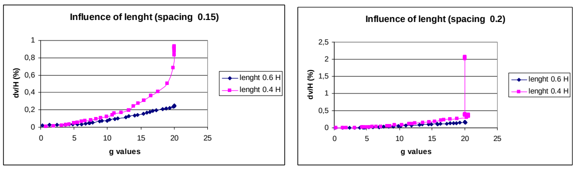
Figure 15: Normalized vertical displacement

The influence of spacing is better understood by analyzing the vertical displacement than the facial deformation. The model with a larger spacing had a larger displacement than the model with smaller spacing. Figure 16 shows also the importance of the length of reinforcements on the performance of the structure. The two graphs shown in Figures 16 (a and b), in fact, have a different scale on the vertical axis. For a length of the reinforcement of 0.6H, the vertical displacements are smaller than 0,25% of the wall height, while for a length of 0.4H they are between 1 and 2 % the wall height. The influence of reinforcements length is also depicted in Figures 17a and b where the spacing was fixed and the two lengths are compared. Figure 17 shows how the length is important with respect to the vertical displacement.



a) length 0.4H b) length 0.6H

Figure 16: Influence of spacing on vertical displacement



a) spacing 0.15H b) spacing 0.2H

Figure 17: Influence of length on vertical displacement

FINITE ELEMENT ANALYSIS

In order to compare the results obtained by the tests in the centrifuge, a finite element model that reproduces the structure behaviour in static 2-D conditions was created. Only a brief description is given due to paper length restriction. For this purpose, models with the full scale dimensions representing the centrifuge models were implemented using the code “Plaxis- Finite Element Code for Soil and Rock Analysis- Version 7.20.” In Table 4, 5 and 6, the properties used for the sand, the modular blocks and the geosynthetic are summarized respectively.

Table 4: Backfill properties

Nevada Sand			
γ_{dry}	14.4 kN/m^3	ν	0.3
γ_{wet}	16.0 kN/m^3	ϕ	31°
E_{ref}	15 MPa		

Table 5: Facing properties

Modular blocks	
γ_{dry}	18 kN/m^3
E_{ref}	250 MPa
ν	0.2

Table 6: Reinforcement properties

Reinforcement	
Geotextile	
EA	150 kN/m

For each test the values obtained from centrifuge tests and the values obtained by the finite element analysis were compared. Good agreement is obtained between the deformed shape in the centrifuge tests and in the numerical analysis. The behaviour of the vertical displacement obtained with the finite element model is in good agreement with the displacement measured in the centrifuge tests. The values of vertical displacement at the top of the structure obtained by the two different procedures are summarized in Table 7.

Table 7: Normalized vertical displacement obtained in the centrifuge and in the finite element model.

Test	Centrifuge (dv/H %)	FEM (dv/H %)
T5L6S15/20	0.2	0.4
T6L6S20/20	0.3	0.6
T4L4S15/20	0.9	1.2
T7L4S20/20	2	1.7

Due to the approximation common to both the methods, a perfect agreement in the numerical values was not expected. It is instead the deformation mechanisms and the order of magnitude of the displacements.

The purpose of the finite element model is to show that the models tested in the centrifuge could represent full scale structures with the same properties of those simulated in the centrifuge. Several differences could be expected by the two models studied (centrifuge and FEM) because he two approaches to the problems were quite different. Even if in two different ways, both centrifuge and finite element model described a failure of the structure with the same stresses reproduced and the same soil properties.

The failure surface detected in the physical model had a comparable shape with the one detectable from the numerical model based on the distribution of the total shear strain and the total displacements.

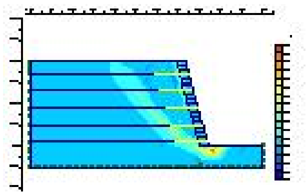


Figure 18: Total shear strain T7L4S20

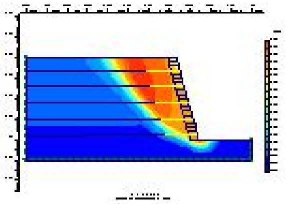


Figure 19: Total displacements T7L4S20

In Test 7, by analyzing the total strain distribution obtained by the model in the numerical analysis, it is possible to detect a zone in which the total strain increased significantly (as shown in Figure 18) and the total displacement are maximum (as shown in Figure 19). This zone corresponded to the failure surface obtained in the centrifuge model. Failure in static condition with respected dimensions was detected only in Test 7, the one in which the total strains result was larger by the finite element analysis.

The main purpose of the finite element analysis is to understand if the values and the mechanism obtained by the centrifuge models could be valid if compared with a full scale model. In this sense the correspondence between the finite element model and the centrifuge models is rather good. A correspondence between the mechanisms obtained in the finite elements models and those in centrifugal field is a very important result.

The finite elements models results demonstrate that the assumption and the problems solutions chosen to build the model in the centrifuge are good enough to simulate the behaviour of a full scale model. The values obtained for the deformations by the two methods are comparable as order of magnitude. The models implemented in two different ways are consistent to each other (i.e. the effect of the spacing and of the length of the reinforcement is very similar using the two different approaches). The two approaches are consistent with the physical process that it is intended to simulate.

CONCLUSION

In the present study, the behaviour of a facing block retaining wall has been analyzed by the centrifuge test for the first time. Using the centrifuge technology it has been possible to analyze the static conditions of the structure, to simulate the failure of the wall and to study how some design factors such as the length and the spacing of the reinforcement can influence the performance of the structure.

The length of the reinforcement proved to have a very important effect on the performance of the structure. From the present study, it has been found that with a reinforcement length ≥ 0.6 H the facial deformation and the vertical displacement were very small. Furthermore, the length of the reinforcement strongly affected the deformation, in fact, using a small length of the reinforcements the displacements increased significantly.

The spacing of the reinforcement has also a very important effect and when the length was relatively short this effect appear to be more important. The results showed that the combined action of spacing and length of the reinforcement has to be taken into consideration in the design of modular blocks facing retaining walls.

In present study, the inadequate design conditions were found (length of the reinforcements 0.4 H and spacing 0.2 H) for which the structure failed at 20 g (that represents the static conditions). This condition has to be avoided in constructing a modular block facing retaining wall.

It has been confirmed that the modular block retaining wall behaved as a very flexible system. Large deformation, compared with other kinds of structures can occur before the system looses its stability. This structure resulted to be very stable, in fact, a very weak material as backfill has to be used to simulate failure under normal static conditions.

Furthermore, the facing seemed to play a very important role in the stability of the system. Using the results of the present study, current specifications guidelines for the modular block retaining wall system have been analyzed from a critical point of view. Specifications guidelines states that the minimum length of the reinforcement shall be 2.5 m or 0.7H for a wall without sloping surcharges and 0.7H for a wall with sloping surcharges in accordance with the AASHTO Standard Specifications for Highway Bridges for an abutment on a spread footing. From present study it is possible to infer that for a good enough soil as backfill (as defined by the AASHTO Standard Specifications for Highway Bridges for an abutment on a spread footing) a smaller reinforcement length could be used in the structure design. Using a reinforcement length of 0.6H or 0.5H with a good backfill soil, the structure design will still have a large safety margin against failure.

The length of reinforcement seemed to be the most important parameter in the wall design but it is important to emphasize also the role played by the spacing on a correct design. Current specifications do not suggest a maximum spacing of the reinforcements to use in the design letting the spacing design to the judgment of the designer. From the present study the spacing appeared to play a fundamental role in the structure performance and stability, and can be as important as the length of the reinforcement. As a suggestion, the most appropriate value that should be used in a safe design of the maximum spacing should be 60 cm that corresponding to three blocks between each reinforcement or for a more general definition 15% of wall height.

Acknowledgements: The author wishes to thank the effort of many individuals that have contributed to this study, such as, A. Pamuk, L. Brant, and J.P. Wang. The first author wishes to thank L.Ubertini and S.Grimaldi and the Honors Center of Italian Universities (H2CU) for the fellowship that supported him during the present study. A special thank also to R.Betti and N. Chiara for their help and support.

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