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Experimental and Numerical Analysis of a PVC Textile-Sand Confined Structure

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Abstract

Experimental and numerical analyses of the mechanical behavior of a composite textile-sand structure are carried out in this work. A wall shaped structure might have many applications in the field of geotechnical engineering (building; retaining structure; etc.), or environmental engineering (waste confining system; bank protection; etc.).

To this end, and in order to understand bending and bearing mechanisms as well as mechanical and deformability behavior, an experimental handling is firstly conducted on fabric-confined sand specimens of the analyzed structure. Thereafter, an experimental analysis on a scale model of the composite wall is also carried out.

Finally, and in order to identify the flexional behavior of the so-called structure and estimate its bearing capacity a numerical simulation of the confined structure, using the commercial finite element code ANSYS is conducted. The comparison between the finite element results and those of experimental analysis obtained from the reduced model showed a good agreement.

Keywords: PVC textile; sand; confining; behavior; bending; finite elements.

1. INTRODUCTION

The idea began when a team from the University of Moscow research laboratory headed by Professor Vacilkov B.C. [1], for the first time developed and designed a composite wall using flexible textile (PVC) constituting the envelope with granular filling (sand).

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The vertical wall, with varying cross section area in height, can constitute a building structural element with any shape in plan, for temporary use in non accessible areas such as Sahara (Fig.1). In this work, is considered the design alternatives of the analyzed structure. Indeed, mechanical properties of the wall constitutive materials (sand and PVC textile), such as deformability and strength of the PVC along with sand properties have been thoroughly examined. Furthermore, the sand characteristics consisting of the grain sizes distribution and its moisture have been determined.

Then, taking the above mentioned work as basis, Menaa L. undertook an experimental analysis of the new structure, in which a qualitative study of the mechanical behaviour is carried out. In addition, the bearing capacity along with stability, at least under horizontal loads, was estimated [2]. The main results obtained were as follow:

- The strength at failure of used and tested PVC textile was about 118 kgf/3cm (i.e.: 39 kN/m); the respective deformation was about 37 %.
- The compression strength of confined cubic specimens was about 5.2 kgf/cm^2 which corresponds to an axial compression load of about 2120 kgf.

In the current paper, and in order to continue and push forward the done work, an experimental study, where more parameters were introduced in the same research axis, is carried out. Among these parameters we can quote: a loading surface, sizes of granular filling, etc... Also, the analysis of the wall reduced model under lateral loading was considered, to understand the confining process which may be, certainly, behind the global stability of the wall [3]. These loads may represent those of seismic or wind origin. The wall can be used for applications other than building such as geotechnical and the geo-environmental areas.

2. SPECIMEN TESTS

To set up experimental sizes of used specimens, Menaa et al., 2007, carried out many experiments in the aim to determine the size effect on the confined cubic textile-sand specimens [4]. Appropriate sizes have been used in the experimental work of the present study. The next subsection focuses on shear test, whereas, the following subsections focuse in turn, on compression and bending experiments. They involve the determination of equivalent characteristics of the composite wall structure and then more understanding of its mechanical behavior.

2.1. Shear test on cubic specimens (20x20x20) cm^3

2.1.1. Experimental procedure

Figure 2 shows three (03) testing specimens with cubic shape. Using the testing stand of the figure 3, the shear test, is conducted through many steps in which vertical and horizontal loads were simultaneously applied. The horizontal load is applied with an increment of 20 kg. The waiting time between loading increments is around 5 minutes. This time is based only on the principle of the progressive loading, to secure stability of the whole experimental system [2].

After applying the last load increment, the specimen is unloaded and reloaded three hours later. The obtained results of the test are illustrated by load-displacement curves in figures 4, 5 and 6.

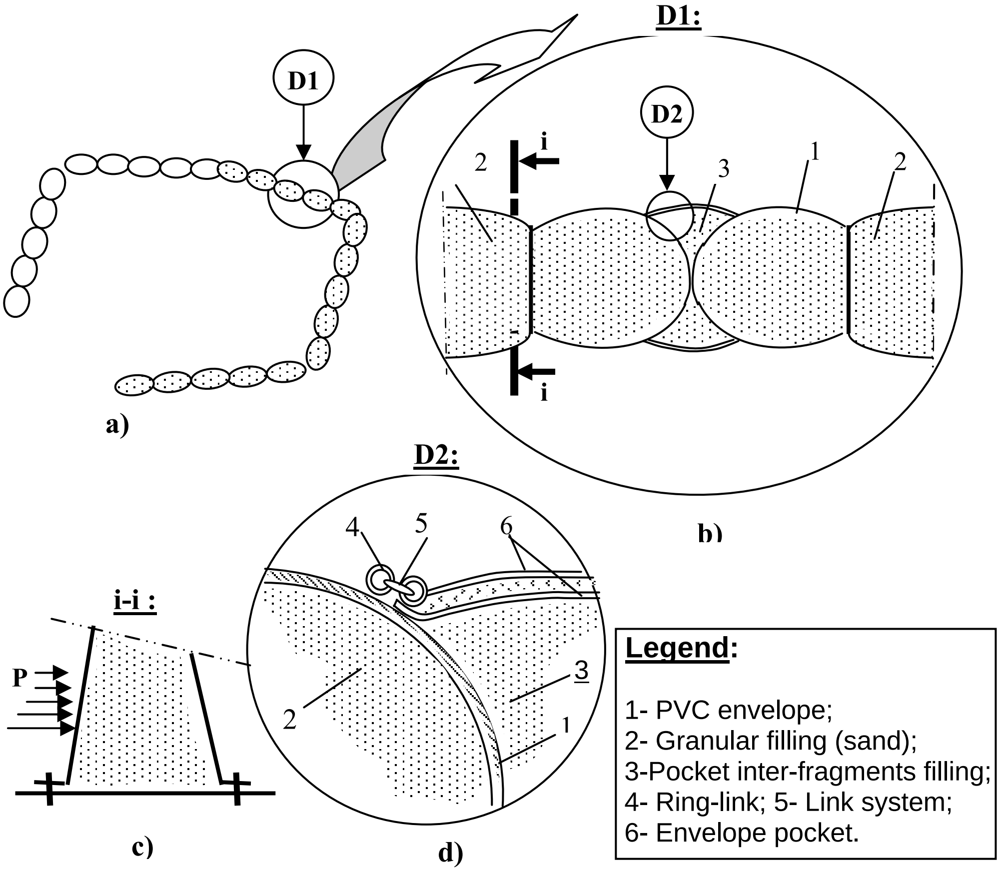
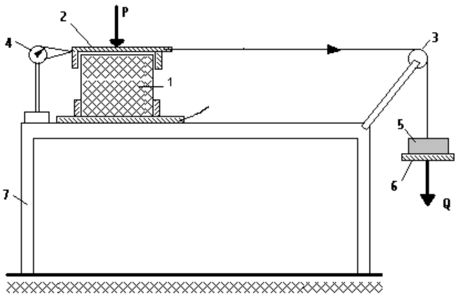


Fig. 1: a)- Shape in plane of building with wall fragments; b)- Detail (D1) of constituted fragment wall; c)-Vertical cross section (i-i) of the wall. d)- Detail (D2) of fragments connecting.

Fig. 2: Used cubic specimens.



Legend:
1-Specimen; 2-cap;
3-Pulley;
4-Comparator (dials);
5-Mass;
6-Platform;
7- Testing table.

Fig. 3: Shear testing stand.

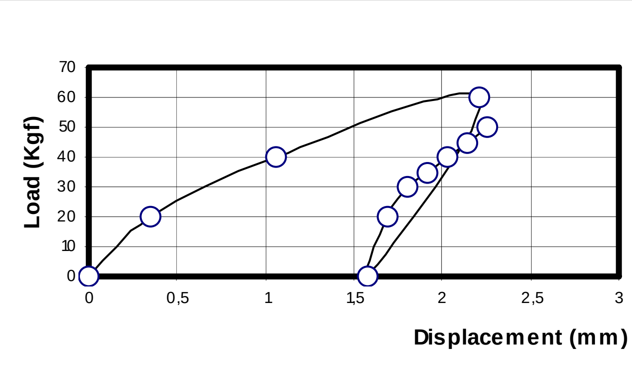


Fig. 4: Average loading-reloading curve.

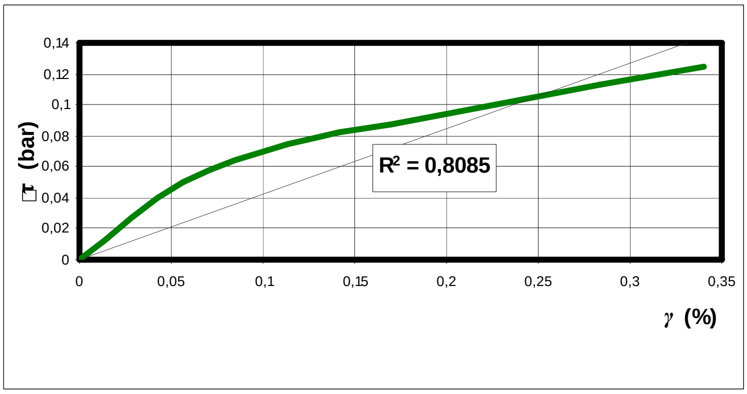


Fig.5: Average stress-strain curve (with tendency curve).

2.1.2. Interpretation of the results

The results of the shear test allowed us to make the following remarks and statements:

- Figure 4 shows, that the load-displacement relationship is clearly nonlinear; hence the specimen behavior is elastoplastic. Figure 5 illustrates average stress-strain curve with tendency curve.
- For the reloading branch of the load-displacements curve, an approximate elastic behavior is observed. The correlation coefficient of 80% seems accurate and acceptable. Thus, the repeated loading-unloading operation will make the deformability behavior more elastic than in the simple loading process.
- In the case of small deformations, the initial shear modulus "G" (slope at the origin) is close to 88 kgf/cm² with a deformation level of 0.056%. Beyond a strain value of 0.17%, the secant shear modulus is reduced to a half with respect to an initial modulus (around 43 bars).

2.2. Bending test

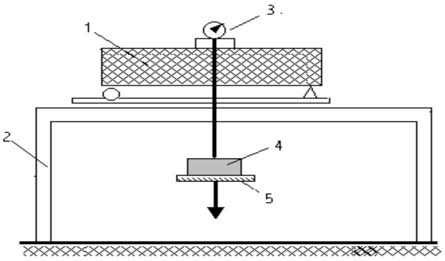
2.2.1. Experimental procedure

Figure 6 illustrates a prismatic shaped specimen of dimensions (20x20x60) cm^3.Three (03) of these specimens have been used in this bending test [2].

Using the testing stand, this test, was carried out in the same lab, (Fig. 7), and was conducted applying vertical increment loadings principle. The method is based on the international standard ISO 4013, 1978 (F). This allows determination of a bending strength by applying a concentrated load in middle of specimen through a loading roller. The first loading is applied by increments of 5 kgf. The test-tube is unloaded when 20 kgf of loading is reached, and reloaded with 20 kg of loading a few hours later.

The displacements under loading were measured using comparator for each loading step (20 kgf) using 0, 1 and 5 minutes. The test results are illustrated by load-displacement curves in figures 8 and 9.

Fig.6: Prismatic specimen.



Legends:

1- Specimen;
2- Testing table;
3- Comparator;
4- Mass;
5- Mass platform.

Fig. 7: Bending testing stand.

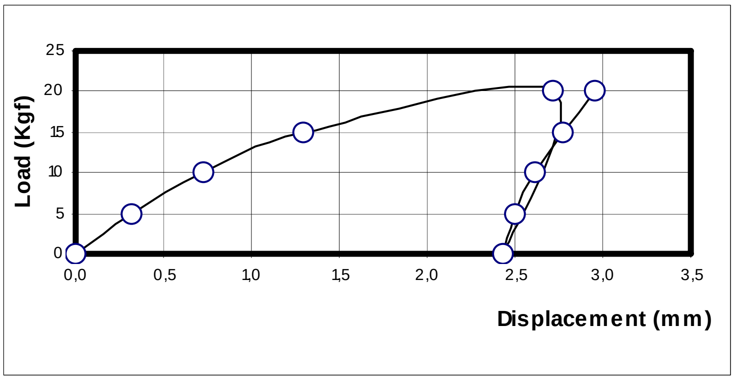


Fig. 8: Average loading-reloading curve.

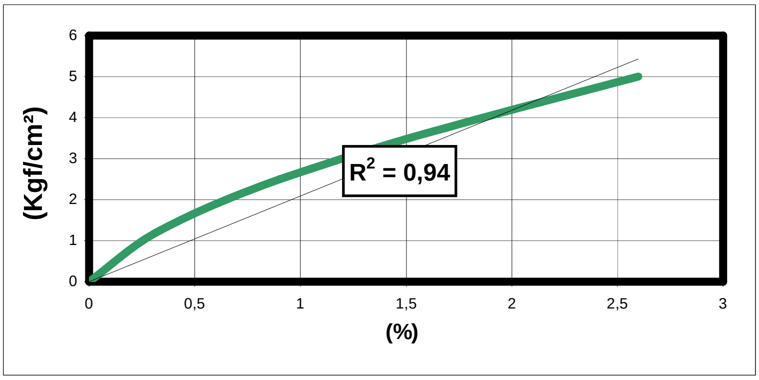


Fig.9: Stress-strain curve (with tendency curve).

2.2.2. Interpretation of the results :

- Through the examination of the load-displacement curve, presented in the figure 8, two points deserve to be considered. Firstly, a non linear relationship is observed. Secondly, the unloading and the reloading branches are nearly identical. This means that the bending test exhibits a more elastic behavior.
- Figure 9 illustrates average stress-strain curve with tendency curve. Here, the elastic behavior is more pronounced, where the correlation coefficient of 94%, confirms the linear tendency of the reloading part.
- The initial flexural modulus "E" (slope at the origin) is close to 250 bars. For a deformation level of 5%, the value of the secant modulus is around 130 bars, which represents a half of the value of the initial modulus. This has also been observed in the shear test of cubic specimens.

3. WALL REDUCED MODEL TESTING

3.1. Model conception and testing preparation

Relatively to the above experimental set objectives, this section is devoted to the performance analysis of a wall under horizontal loading. Thus, a uniformly distributed load (pressure) was applied, by increments, on the vertical wall until the loss of its stability. A pulley system is used to apply the horizontal load.

Based on the similitude principles, table 1 shows the geometric and loading characteristics of the wall reduced model.

Table 1: Characteristics of the wall reduced model.

Characteristics	Reduced model	Prototype
Scale reduction :		
- Dimensions	1/5	1
- loads	1/ 25	1
Dimensions of the wall :		
- Length (m)	0.6	3.0
- height (m)	1.0	5.0
- thickness (m)	0.2	1.0
Horizontal applied load (Kg/ml)	133	3325

In order to avoid any possible displacement at its basis, the conceived reduced model, is indeed restrained, by using wood beams on 20 cm of depth at the bottom (perfectly restrained). The sand is confined within an envelope made of a PVC technical fabric (textile). The closing of the top of the envelope is assured using a manual sewing. As the sole strength parameter we need within the envelope is the lateral sand pressure, and to avoid an eventual sand-fabric friction and any gondolement of the textile, the filling of the fabric envelope is done manually by properly compacting successive layers. The applied compaction pressure generates a confining pressure on the envelope and opens the cylindrical containers according to their genetrices (Fig. 10).

The displacement indicators (dials) are placed on the wall in order to measure displacements at the middle and at the top of the tested wall. Measures are taken for each increment loading.

To follow the evolution of the tension involved in the fabric envelope, a one-dimensional deformation gauge was glued on the central zone of the wall, situated on the external side (front face) of the fabric envelope, subjected to tension.

During the filling of the envelope, the horizontal pressure acts and grows progressively and the fabric area deforms and simply stretches and tights. The friction angle reaches approximately 5%.

a) **b)**

Fig.10: Reduced model using fabric envelope and filling sand.

3.2. Results of a wall reduced model testing

In this experimental procedure, figure 11 shows the deformed shape under lateral loading. Measured displacement has been monitored at the top of the wall, along with displacement at mid-height. The evolution of these displacements has been reported against increasing applied load in the figure 12.

Fig. 11: Reduced model after deformation.

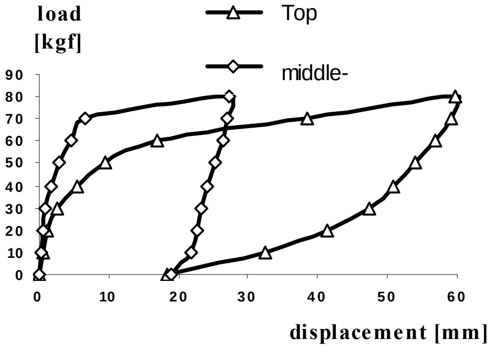


Fig. 12: Loading-reloading displacement curve.

3.3. Interpretation of results and concluding remarks

- At first insight, curve trend of the figure 12, illustrates elastoplastic behaviour of the composite structure. In fact, the wall behaves elastically until an applied load of 20 kgf (distributed load of 33.33kgf/ml) is reached. The latter corresponds to a displacement of 1.23 mm, which means approximately 1% of the wall height. Beyond this elastic threshold, the strains became non-reversible.

- Plastic displacements of magnitude of 20 mm (about 33% of total strain) appear after the total unloading.
- The displacement at the wall top is about 6 cm for a lateral load of 80 kgf, which corresponds to a distributed load of 133.33 kgf/ml. This displacement represents 6 % of the wall height. On another hand, measured displacement at wall mid-height is approximately a half of that measured at the top.
- This potential capability of deforming without failure might be considered as one of most important advantages of reinforcement by confining techniques. This is probably due to the sand dilatancy phenomenon, which generates confining pressure on the structural envelope. Indeed, this can allow high strain thresholds to be introduced in new design rules for flexible structures.
- According to the evolution of wall deformations of varying cross-section in elevation, a rotating movement of the wall with respect to a point situated at the third of the wall height from its basis has been observed.
- With the increasing of the load, the wall stiffness increases progressively from the basis to the top. This experiment shows that the failure tends to occur by a forward overturning of the wall and this can be merely explained by crushing of the lower third of the wall. This point seems to be situated at 30 cm from the basis of the wall. All this happens like if the wall has been auto generated over a new fictitious embedment length of 30 cm.
- The wall rotation of the top with regard to this point can be computed using experimental results. Indeed, for a displacement of 60 mm, the rotation α can be evaluated such as: $\mathrm{tg}\,\alpha = 60/1000 = 0.06$.
- An accelerating process of displacements for a load of 30 kgf has been noted in this experiment.
- Finally, with increasing of horizontal load, important distortions take place in sand (already dense) which is the consequence of strong rate of the shearing effort. In fact, sand grains tend to dilate. However, as they are totally confined by the textile, the latter stands against the dilatancy phenomenon, by tension in order to recover the global equilibrium.

4. FINITE ELEMENT CALCULATION OF THE WALL MODEL

Using ANSYS, the commercial finite element code, we have proceeded to numerically analyze of the stress-deformation state of the wall reduced model. The computed results can be used for comparison with those previously obtained results.

The wall was assumed to be restrained at its basis and uniformly loaded on one of its vertical faces by horizontal pressure. The adopted mesh principle is based on the idea to refine the meshing close to the restrained bottom and with condition that the finite element sizes do not exceed the transversal size of the wall thickness (Fig. 13).

The chosen finite element is a volume, tetrahedral element (solid95). Such type of elements can constitute a well compromise between accuracy and computation time. This element can properly simulate the three-dimensional behaviour (tetrahedral element) for bending problems, as it has quadratic approximation of displacements [5].

As a constitutive model, non linear elastoplastic law with hardening, considering the dilatancy character of the granular material (sand) was used [6].

Numerical data are given in the previous paragraph, where mechanics properties for both materials (textile and sand) were obtained by experimenting cubic and prismatic specimens under shear, bending and compression tests. Principally, we need both shear and bending modulus of elasticity for the present numerical finite element simulation.

Figure 14 shows the iso-displacement diagram carried out using the finite elements "ANSYS" code, whereas the figures 15 illustrate the comparative curves between both experimental and numerical computed displacements.

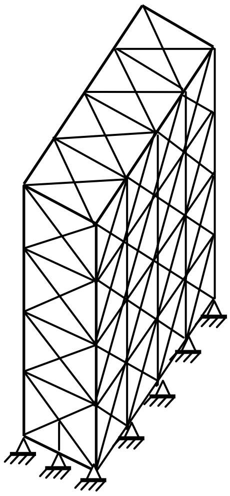


Fig. 13: Meshing of model.

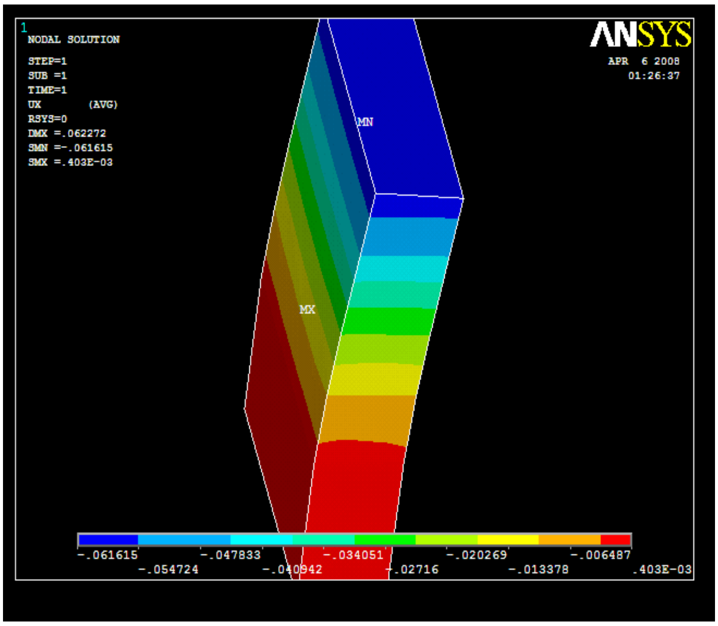
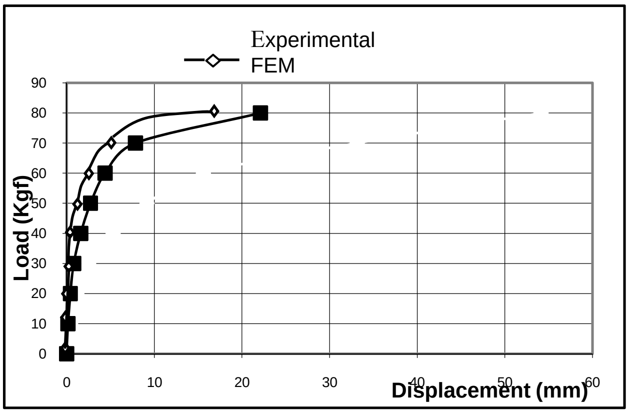


Fig.14: Iso-displacements results.

a)



b)

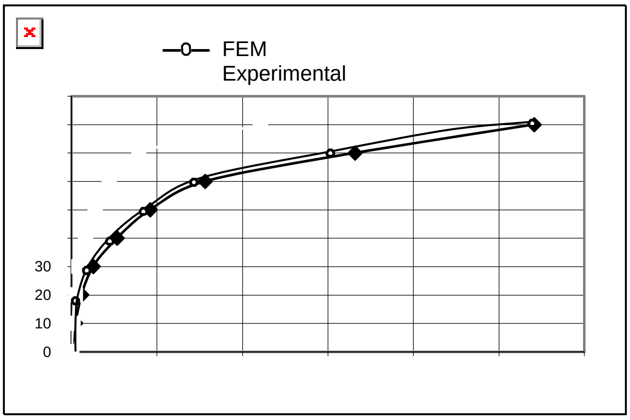


Fig. 15: Load-displacement curves: a) at middle, b) at top.

5. CONCLUSION

To understand the bending behaviour and deformability mechanisms, numerical and experimental analysis have been carried out a composite sand structure. This structure, which has a shape of wall, might have significance in many applications in the field of geotechnical engineering.

Experimental investigation has been achieved through two steps: the first was a shear test and the second was a bending test. For both experiments load-displacement curves along with stress-strain curves have been drawn up and commented. Interpretation of results has been thoroughly described in this work.

On another hand and in order to support what has been done experimentally, Finite element computation, using commercial package "ANSYS", have been concluded. Computed load-displacements curves showed an excellent agreement with those obtained experimentally.

The carried out results related to the wall confined model showed a good-sufficient bearing capacity of the wall, especially under horizontal loading (lateral pressure) normally applied to its plane.

With attention paid to its anchoring situation at basis and by applying a moderate vertical loading on its top, we can increase the stability and bearing ability of the analyzed wall. Therefore, we can obtain a good exploitation of the new conceived wall.

ACKNOWLEDGEMENTS

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