ISSN 1644-0633
www.acta.media.pl

ACTA *Acta Sci. Pol. Architectura 14 (3) 2015, 35–43*

GABION WALL TESTING DURING THE FORCED OVERLOADING IN THE GEOTECHNICAL CENTRIFUGE

Edyta E. Malinowska
Warsaw University of Life Sciences – SGGW

Abstract. The paper is referring to the geotechnical centrifuge modelling that is used to prove the gabion facing wall stability. The gabion reinforcement wall is 15.3 meters tall and 17 meters length. The centrifuge model was speed up to 50 g and 75 g, and hadn't failure. The test results show that the largest settlements under 75 g speed was about 2.25 meters vertically and mainly in the gabion wall and just behind the gabion section. The largest settlements under 50 g speed was about 1.07 meter vertically and 1.8 meters horizontally. The value of the settlement increases with the shortness of the reinforcement. The value of the settlement decreases with the reduction of the gabion spacing in the wall facing. Reinforced gabion retaining wall can work safely. Nevertheless, mechanical and deformation behaviors need to be studied for wide applying in a practical engineering.

Key words: gabion wall, geotechnical centrifuge, physical and mechanical parameters

INTRODUCTION

Nowadays, centrifuge modelling is used for better understanding the geotechnical processes because then the realistic failure can be observed. The main advantage of centrifuge is that results are realistic and not predetermined as in other form of analysis. The sponsors of the engineering projects always would like to have the knowledge of the construction behavior. In geotechnical centrifuge, it is possible to have a good control over the soil model and determine important parameters.

Centrifuge modeling deals with reproducing an event comparable to what might exist in the prototype and plays a fundamental role in the geotechnical engineering. These tests are able to reproduce the soil behavior in terms of stresses, strength and stiffness. The centrifuge subjects the model to an inertial acceleration field which is like a gravitational acceleration field but N-times stronger than Earth's gravity. If the same soil is used both

Corresponding author – Adres do korespondencji: Edyta E. Malinowska, Warsaw University of Life Sciences – SGGW, Faculty of Civil and Environmental Engineering, Water Centre Laboratory, 6 Ciszewskiego St., 02-776 Warsaw, e-mail: edyta_malinowska@sggw.pl

in the model and in the prototype and a similar stress history is ensured, then the model subjected to an inertial acceleration and will have a vertical stress at depth hm equal to that corresponding in the prototype at depth hp with a scaling factor of N : 1.

Centrifuge experiments were conducted to model the real behavior of the gabion wall. Modeling a full-scale structure gives the opportunity to obtain a complete picture of the performance of MES structures with reinforcement at large vertical displacements.

Lately, a great deal of research containing geosynthetics and geotechnical materials, back analysis and monitoring have been published. The behavior of the materials and geotechnical processes is much more understood. Therefore more cost-effective and technically efficient structures can be built in the future.

LITERATURE REVIEW

The geotechnical centrifuge modelling is undertaken by many researches.

Bucky, by comparing the behavior of a structure with that of a small scale model, made of the same materials as its prototype, the principle states that if in the model the force of gravity on each part can be increased in the same proportion as the linear scale is decreased, then the unit stresses at similar points in the model and prototype will be the same, and the displacement or deflection of any point in the model will represent to scale the displacement of the corresponding point in the prototype. The effect of an increase in gravity may be obtained by substituting a centrifugal for the gravitational field, i.e., placing the model in a suitable designed centrifugal machine, or centrifuge [Bucky 1935].

Sawicki [1998] proposed simple approach to the analysis of centrifuge model tests performed on reinforced earth retaining walls. It enables determination of the centrifugal acceleration scale factor N corresponding to the initiation of failure at the toe of the structure and the factors corresponding to the development of failure up to the total collapse of the structure. These theoretical predictions were based on the approach proposed are very close to the experimental results reported by Bolton and Pang [1982], Jaber and Mitchell [1990] and Atkinson [1993]. Porbaha and Goodings [1996] had built twenty-four reduced scale models of vertical and steeply sloping (1H : 6V) reinforced soil walls using kaolin as the backfill, reinforced with a nonwoven geotextile simulant, and loaded to failure under increasing self-weight in the geotechnical centrifuge. Models built on firm foundations showed better performance than identical models built on rigid foundations. A stability analysis using the simplified, two-dimensional limit-equilibrium simplified Bishop method incorporating reinforcement was found to be a good predictor of the behavior of the models based on calculated factors of safety at failure. It was found that the development of tension cracks in the backfill as walls underwent prefailure deformations led to stress concentrations in the geosynthetics and should be avoided in practice [Porbaha and Goodings 1996]. Some other researches had used the geotechnical centrifuge to model test of geosynthetics reinforced retaining walls [Zhang et al. 2000, Kazimierowicz-Frankowska 2005]. A clayey vertical geotextile-reinforced earth wall (VGREW) in a wet state due to poor drainage conditions after several consecutive days of heavy rainfall was simulated by a series of centrifuge VGREW models. For the reinforcement length, there exists a critical beyond which no further improvement can be attained, while smaller vertical reinforcement spacing leads to shorter critical reinforcement length [Chen et al. 2007].

The centrifuge modelling experiments are also designed to investigate mass movement processes on slopes. Centrifuge modelling of geotextile-reinforced slopes is also subjected to differential settlements in the situations that foundation conditions have been shown to adversely affect the stability and deformation behaviour of overlying geosynthetic-reinforced slopes and walls. Analysis of geotextile strain results have showed that the location of the maximum peak reinforcement strain occurs along the bottom-most reinforcement layer at the onset of differential settlements, at the point directly below the crest of the slope [Viswanadham and Konig 2009]. It was confirmed by the centrifuge tests that the hybrid geosynthetics increases the stability of low permeable slope subjected to water table rise [Raisinghani and Viswanadham 2011].

Geosynthetics are widely used to reinforce slopes due to their successful performance and economic efficiency. A series of centrifuge model tests was co ducted in order to investigate the behavior of the geotextile-reinforced cohesive slopes and to compare their behavior to unreinforced slopes. The reinforcement can take effect when its length is longer than the effective reinforcement length. The effective reinforcement length usually increases with increasing elevation and is significantly affected by the inclination of the slope [Hu et al. 2010].

The later publications considering reinforced slopes by gabion wall indicated a great value of geotechnical centrifuge modelling in the slope behavior. Ling et al. demonstrated the use of a centrifuge modelling technique in studying slope instability prepared from sand, and sand mixed with 15 and 30% fines by weight, compacted at optimum water content. The Bishop's circular mechanism, together with the extended Mohr-Coulomb failure criterion, was able to simulate the slope failure reasonably well. The rainfall of different intensities was then induced on the 60° stable slopes of sand with 15% fines. It was found that the failure of slope under rainfall may be interpreted as a reduction in apparent cohesion. The centrifuge tests also allowed the rainfall intensity-duration threshold curve (local curve) to be generated for the test slopes, and the accumulated rainfall corresponded well to some of the reported field observations [Ling et al. 2009]. The influence of the earth reinforced structures length was found out to be the leading parameter, reducing facial deformations up to five times, and the spacing playing an important role especially in unstable configurations. When failure occurred, failure surface was characterized by the same shape (circular) and depth, regardless of the reinforcement configuration [Iacorossi et al. 2013].

MATERIAL AND METHODS

The tests were performed in the 200 g geotechnical centrifuge during the forced overloading. The apparatus was installed in the in the Carleton Laboratory in 2004 in the Civil Engineering and Engineering Mechanics Faculty at Columbia University. The first paper, published with the results obtained from this apparatus was Bucky in 1935 [Bucky et al. 1935]. The centrifuge and numerical modelling are important in the analyses of complicated structures, where a real behavior of structure-soil should be modelled.

Constructing a full-scale structure provide engineers a complete picture of the performance of MSE structures with reinforcement at large vertical spacing. Also it is currently used in a wide array of geotechnical research fields, such as slope failure analysis, levy failure, lateral loading of pile foundations and saturation experiments (Fig. 1).

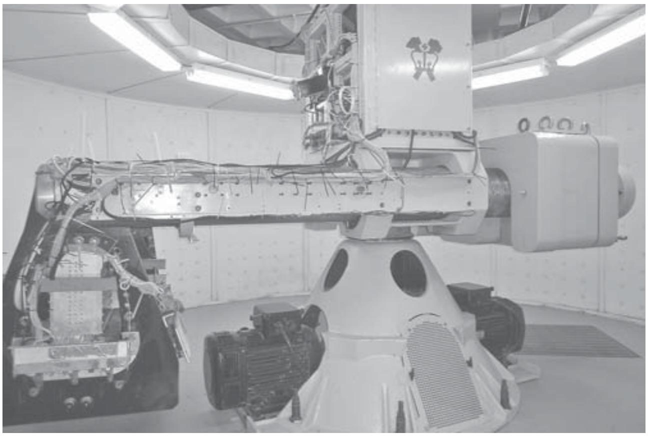

Fig. 1. Geotechnical centrifuge at Carleton Laboratory, Columbia University

The wall-facing of the model was build from gabions made of a galvanized steel mesh and river stones as a inner fill. The backfill of the model was build from layers of sand. The average initial angle deviation was 1.5°. The real high of the construction should be 15.3 meters and the length 17.5 meters.

The wall facing was made from gabions (Fig. 2). The stone used in the prototype gabions have a diameter of 100–200 mm [Maccafferi 2012]. The total unit weight was 20 kN·m^{-3}. The backfill was made from Nevada sand, with mean diameter D50 of 0.15 mm, the maximum dry unit weight of 16.6 kN·m^{-3}, model dry unit weight of 15.0 kN·m^{-3}, total unit weight of 15.75 kN·m^{-3} and the angle of internal friction equal 30° (Fig. 3) [Lin et al. 2013].

A fiberglass mesh coated in polymetric film was used in the model to simulated the Paralink reinforcement (400 UTS). The dimensions of the reinforcement for the model were 20 cm wide and 35 cm long.

This length of 35 cm was determined from applying the scale factor of 50. Thus, the prototype reinforcement length was 17.5 m. Tensile tests were conducted on 5 specimens of dimensions 20 cm long and 5 cm wide to determine the tensile strength of 10.4 kN·m^{-3} and initial modulus equal 474.5 kN·m^{-3}. The friction angle between the reinforcement and sand was 28.2° (Fig. 4) [Lin et al. 2013].

The centrifuge spins-up by an artificial overloading to the value of wanted load. It is important to simulate the behaviour of the stress- strain in large engineering constructions. Centrifuge modelling simulates soil-structure systems under different loading. The aim of the experiment was to find out the value of the settlement and total change in the geometry. The construction was designed to work up to tensile forces of 50 kN and the shape should provide the minimum friction and passive resistance. Also, the change of tensile stress distribution along the reinforcement strip should be as less as possible.

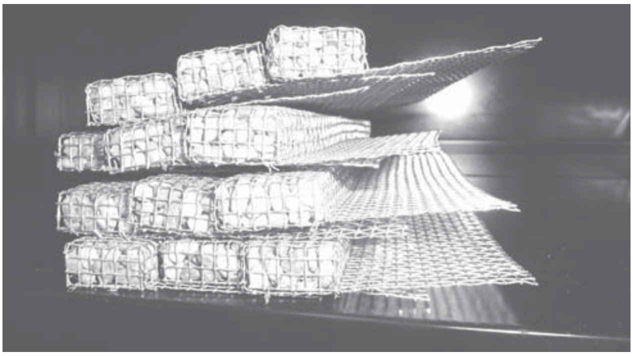

Fig. 2. Wall facing – gabions

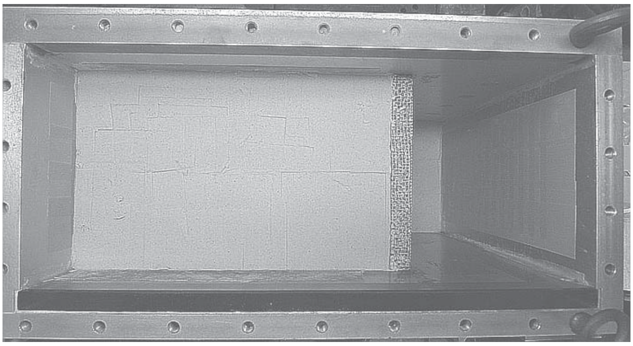

Fig. 3. Backfill Surface of gabion wall – view from above

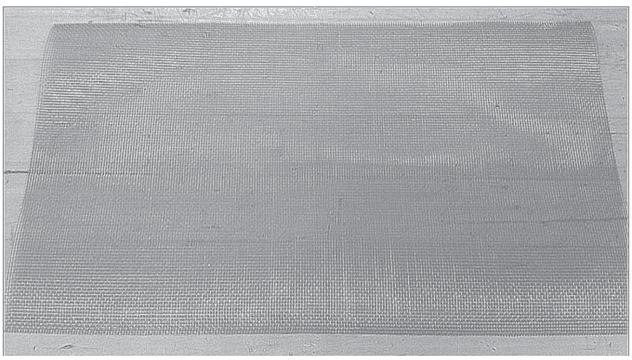

Fig. 4. Fiberglass Screen Reinforcement

RESULTS

The centrifuge modelling was performed to obtain the real behaviour of large engineering construction. The experiments were made under the Collin Group advisory panel. The aim of the project was to update by researches designed vertical gabion reinforcement for engineering construction. Among others the receiver was Ling's research group.

The gabion wall of total high 15.3 meters was used as a reinforcement. It was necessary to provide the data to complete the picture of the performance of MSE structures with the reinforcement at large vertical spacing.

Two of three tests were performed on the model of 35 cm long and 32 cm high. The third was 17.5 cm long and 32 cm high. Also, two of three tests were performed on model with vertical spacing 2 cm (Test 2 and 3), and Test 1 was performed on model with the vertical spacing of 4 cm, that is 2 meters in the prototype.

The centrifuge tests were performed to model the gabion wall stability and displacements.

The model in Test 1 of the reinforcement length of 35 cm was spun up to 75 g and didn't collapse at all. The gabion wall displacements vertically about 2 m in the prototype wall at 50 g. The gabion wall moved 1.5 cm vertically and 0.5 cm horizontally, which is respectively 0.75 m and 0.25 m in the prototype wall at 75 g.

The gabion wall in the Test 2 of the reinforcement length of 35 cm, after reaching 50 g, displacements vertically 1.07 m and horizontally 1.82 m, in prototype scale.

The gabion wall in Test 3 of the reinforcement length of 17.5 cm, after reaching 50 g, displacements in the prototype scale vertically 2.1 m and horizontally 2.26 m [Lin et al. 2013].

The tests number 1 is presented in Figure 5, where the vertical and horizontal displacements are shown. It can be seen on Figure 5b that the gabion wall is moved down and backward.

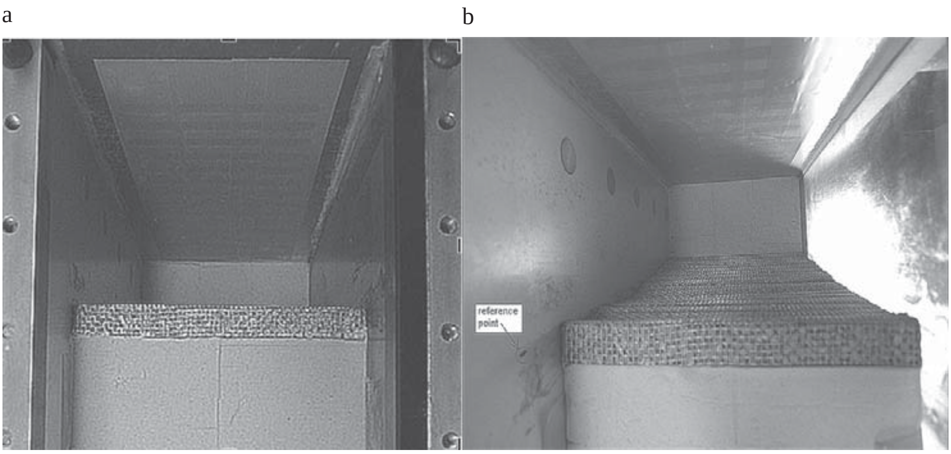

Fig. 5. View from above of model 1: a – before test number 1, b – after test number 1 with the reference point

The distribution of the strain in different point of length reinforcement is presented in Figure 6. The relationship between settlement and gabion spacing is presented in Figure 7.

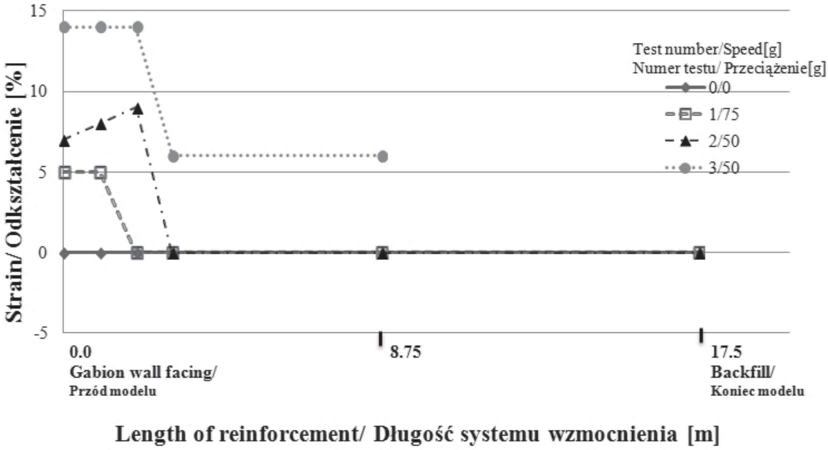

Fig. 6. Strain distributions in different point of reinforcement length under different centrifuge speed

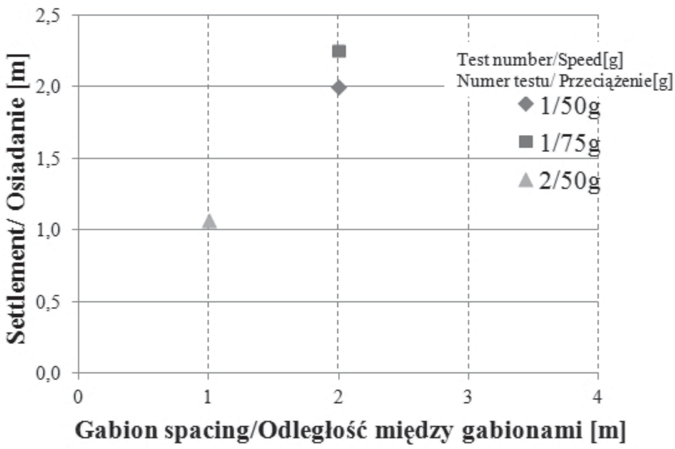

Fig. 7. Settlement vs gabion spacing

CONCLUSIONS

Geosynthetic-reinforced soil structures are widely used to support engineering constructions such as bridge abutments, approach roads and roads embankments in order to traditional techniques. The full scale data can develop the picture of the structures with the reinforcement at large vertical spacing. That's why, the geotechnical centrifuge testing of the gabion retaining wall supplies important information of the real-world behavior of the structure.

The centrifuge model of the gabion facing reinforced soil retaining wall gives the practical view for future models of testing or construction.

The aim of the experiment presented in this paper was to research for the geometric changes of gabion wall during the forced overloading. The sponsor of the project needs to know if the designed reinforcement construction made of gabion system in the facing and layers of sand in the backfill is stable and proper. The construction has been designed to work up to tensile forces of 50 kN and minimalizing the changes in the shape.

The gabion wall reinforced with geosynthetics can be 15.3 meters tall and 17 meters length. This construction hadn't failure under 75 g. The largest vertical displacement would be 1.07 meter and the horizontal 1.82 meters. Reducing the reinforcement length by half gives larger deformations. The settlement decreases when the spacing of gabions was reduced to 1 meter.

In this kind of construction the settlement could depend on gabion spacing and length of reinforcement. This relationship between vertical displacements, gabion spacing and length of reinforcement should be consider as a function:

$$S = f(gs, lr)$$

where: S – settlement [m],
gs – gabion spacing [m],
lr – length of reinforcement [m].

Comparable models should be made to study the failure mechanism of the gabion walls with reduced length of the reinforcement layers, that gives more space and to be more economical.

Reinforced gabion retaining wall can work safely. As for a new structure, mechanical and deformation behaviors need to be studied for widely applying in a practical engineering.

ACKNOWLEDGMENTS

The tests were performed in the Carleton Laboratory, Civil Engineering and Engineering Mechanics Faculty at Columbia University, by Ling's research team for the Collin Group (the sponsor).

I would like to thank Professor Hoe I. Ling from Civil Engineering and Engineering Mechanics Faculty for a help while my stay as a Visiting Scholar at University of Columbia.

REFERENCES

Atkinson, J.H. (1993). An introduction to the mechanics of soils and foundations. McGraw-Hill, London.

Bolton, M.D., Pang, P.L.R. (1982). Collapse limit states of reinforced earth retaining walls. Geotechnique, 32, 4, 349–367.

Bucky, P.B. (1935). Use of Models for the Study of Mining Problems. Technical Publication, 425. American Institute of Mining and Metallurgical Engineers, A, mining methods, 44.

Bucky, P.B., Solakian, A.G., Baldin, L.S. (1935). Centrifugal Method of Testing Models. Civil Engineering, 5 (5), 287–290.

Chen, Huei-Tsyr, Hung, Wen-Yi, Chang, Chin-Chang, Chen, Yuan-Ji, Lee, Chung-Jung (2007): Centrifuge modeling test of a geotextile-reinforced wall with a very wet clayey backfill. Geotextiles and Geomembranes, 25, 346–359.

Hu, Y., Zhang, G., Zhang, Jian-Min, Lee, C.F. (2010). Centrifuge modeling of geotextile-reinforced cohesive slopes. Geotextiles and Geomembranes, 28, 12–22.
Iacorossi, M., Ling, H.I., Gottardi, G., Li, L. (2013). Centrifuge modeling of earth-reinforced retaining walls. Proc. of International Symposium on Design and Practice of Geosynthetic--Reinforced Soil Structures, Bologna.
Jaber, M., Mitchell, J.K. (1990). Behaviour of reinforced soil walls at limit state. In: Performance of reinforced soil structures. Ed. A. McGown, K.C. Yeo, K.Z. Andrawes. Thomas Telford, London, 53–57.
Kazimierowicz-Frankowska, K. (2005). A case study of a geosynthetic reinforced wall with wrap-around facing. Geotextiles and Geomembranes, 23 (1), 107–115.
Lin, H., Ling, H.I., Li, L., Collin, J.G., Leshchinsky, D., Rimoldi, P. (2013). Centrifuge modeling of gabion walls reinforced with geosynthetics. Proc. of International Symposium on Design and Practice of Geosynthetic-Reinforced Soil Structures. Bologna, Italy, 25.
Ling, H., Wu, M., Leshchinsky, D., Leshchinsky B. (2009). Centrifuge Modeling of Slope Instability. J. Geotech. Geoenviron. Eng., 135(6), 758–767.
Maccafferi (2012). Terramesh System: Galvanized and PVC Coated. Product Standard Specifications.
Porbaha, A., Goodings, D. (1996). Centrifuge Modeling of Geotextile-Reinforced Cohesive Soil Retaining Walls. J. Geotech. Engrg., 122(10), 840–848.
Raisinghani, D.V., Viswanadham, B.V.S. (2011). Centrifuge model study on low permeable slope reinforced by hybrid geosynthetics. Geotextiles and Geomembranes, 29, 567–580.
Sawicki, A. (1998). Theoretical analysis of centrifugal model tests on reinforced earth structures. Geotechnique, 48, 4, 563–567.
Viswanadham, B.V.S., Konig, D. (2009). Centrifuge modeling of geotextile-reinforced slopes subjected to differential settlements. Geotextiles and Geomembranes, 27, 77–88.
Zhang, W., Lai, Z., Xu, G. (2000). Centrifuge model tests of geosynthetics reinforced retaining walls. China Civil Engineering Journal, 33 (3), 84–91.

BADANIE ZMIANY GEOMETRII ŚCIANY GABIONOWEJ PODCZAS WYMUSZONEGO PRZECIĄŻENIA

Streszczenie. W artykule przedstawiono zastosowanie centrifuge – wirówki przeciążeniowej w literaturze geotechnicznej. Zaprezentowano realny przykład zachowania się ściany zbudowanej od frontu z gabionu, którą poddano wymuszonemu przeciążeniu siłą 50 g i 75 g. Badania zostały przeprowadzone na zlecenie The Collin Group w Laboratorium Carleton, w Departamencie Civil Engineering and Engineering Mechanics Faculty, University of Columbia. Badania w wirówce przeciążeniowej wykazały, że ściana o początkowej wysokości 15,3 m i długości 17 m została stabilna przy przeciążeniu 75 g. Największe pionowe osiadanie wyniosło 1,07 m, a poziome 1,82 m.

Słowa kluczowe: ściana gabionowa, wirówka przeciążeniowa

Accepted for print: 28.09.2015

For citation: Malinowska, E.E. (2015). Gabion wall testing during the forced overloading in the geotechnical centrifuge. Acta Sci. Pol., Architectura, 14 (3), 35–43.