Acta Sci. Pol.
Architectura 17 (2) 2018, 77–84
acta_architectura.sggw.pl ISSN 1644-0633 eISSN 2544-1760 DOI: 10.22630/ASPA.2018.17.2.16

ORIGINAL PAPER

Received: 25.04.2018
Accepted: 17.05.2018

THE NUMERICAL ANALYSIS OF THE INFLUENCE OF CHANGING THE GROUND ELASTICITY ON THE DEFORMATION OF STEEL MESHES USED IN THE SOIL REINFORCEMENT

Marcin Ćwirko✉, Małgorzata Jastrzębska

Faculty of Civil Engineering, Silesian University of Technology, Gliwice

ABSTRACT

Retaining walls with the use of reinforced soil technology are frequently used in building light retaining constructions, whose facing is made from gabion baskets. Geosynthetics or steel double woven mesh play the role of reinforcement rod in this type of structures. A good alternative for steel woven mesh is welded mesh, which is not prone to the change of mesh geometry during stretching in the main direction. The objective of this dissertation is to find an answer to the question of the steel welded mesh applicability as ground reinforcement in light gabion retaining structures, as well as the comparison of deformations of both meshes types in different ground conditions. The work contains the numerical analysis of meshes stretching, including their assembling in soil using different vulnerability coefficient value. The article has been summarized with conclusions, plans for further experimental research as well as a comparison with previous numerical analyzes.

Key words: retaining structures, gabions, welded mesh

INTRODUCTION

The dynamic development of road and rail infrastructure means that it is obligatory to build new bridges and viaducts, as well as embankments on access roads to them. All bridge structures are characterized by much more rigidity out of the soil construction, therefore it is necessary to ensure as small deformation of embankments as possible when approaching these structures.

The retaining walls with the use of reinforced soil technology (Ciomcia, 2014) are a frequently used method of manufacturing light retaining structures. One of them are gabion structures, which are pro-ecological mainly due to the use of low-processed and recyclable materials, which is a part of the sustainable development trend (Najder & Najder, 2005). Light gabion structures using reinforced soil (in contrast to massive ones) consist of facing with gabion baskets as well as reinforced soil. The comparison of massive and reinforced soil structures is shown in Figure 1. The role of reinforcement in such type of structure is most often played by geosynthetics or double-woven steel meshes (Koerner & Soong, 2001; Kosiński, 2010; Kuc, 2012).

Welded meshes are a different option for double-woven ones, which are more susceptible to change the geometry of the mesh aperture while stretching in the main direction. An exemplary gabion basket from a welded mesh is depicted in Figure 2.

A significant condition for the analysis of the suitability of steel meshes for soil reinforcement is their corrosion resistance mainly obtained due to zinc-aluminum or zinc coatings with an additional coating of

✉marcin.cwirko@polsl.pl

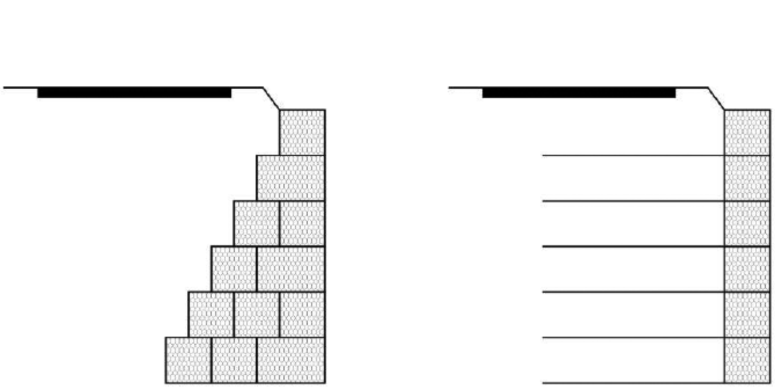

Fig. 1. Comparison of gabions structures: massive (on the left) and with soil reinforcement (on the right) (Kosiński, 2010)

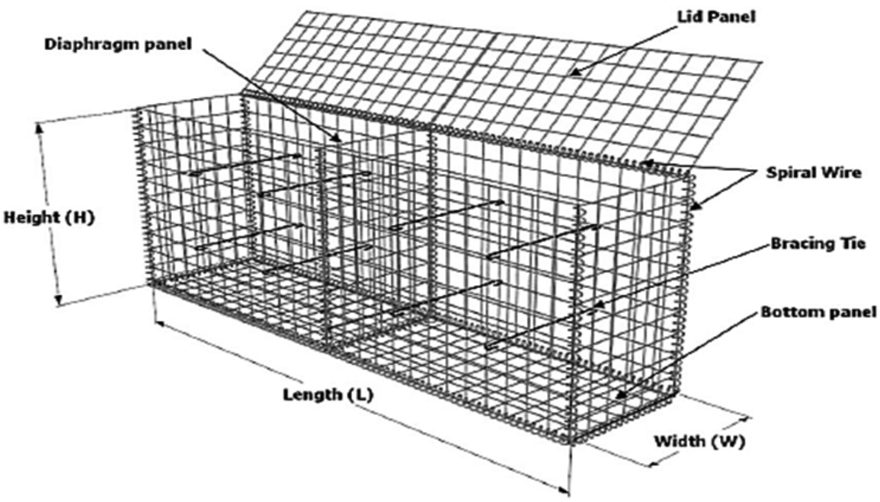

Fig. 2. A schematic picture of the welded mesh gabion basket (Werner, 2013)

polyvinyl chloride (PVC), which makes gabion structures as durable as other types of retaining structures commonly used (Ramil, Karasu & Dawood, 2013).

Bearing in mind the practical applications of welded meshes, the authors of this study made a decision to develop the authorial research Ćwirko, Jastrzębska and Kwiecień (2017) and by numerical analysis to compare the behavior of welded and double-woven meshes assembled in structures depending on the soil vulnerability coefficient (*Kz*).

In particular, the own distortions of welded and double-woven meshes (built-up and unbuilt-up in the ground) were taken into consideration while stretching them with evenly distributed and focused force. Meshes (aperture size and wire diameter) commonly available on the market were used for calculations. The work is a direct development of the article (Ćwirko, 2017), in which the author presented the results of numerical tests of stretching steel meshes, especially their deformations, both without and with taking into account their assemblage in the soil, taking one specific value of soil vulnerability coefficient (*Kz*).

Simultaneously as a part of the results verification, a cycle of laboratory model tests is planned for the future.

NUMERICAL ANALYSIS

The study was conducted by means of numerical analysis using the Autodesk Robot program. There are two variants of stretching tests for both types of meshes, i.e. with a uniformly distributed force load over the width of the mesh as well as with a concentrated load attached to a single middle wire of the model.

Meshes geometry

Considering the future model laboratory tests, and in particular the geometry of the target testing apparatus, the overall size of the mesh sheets with dimensions of approximately 1,000 × 500 mm was assumed. The meshes will be stretched towards the longer side. With such dimensions in the direction of the force action, there will be simultaneously from 7 to 14 wires depending on the mesh type.

In accordance with the manufacturer's specifications (Werner, 2014) the standard aperture size of the welded mesh is 76.2 × 76.2 mm +/–2.5 mm (Fig. 3a), whereas the aperture size used in woven meshes is about 80 × 100 mm to 80 × 120 mm, and the bending angle of the wires is about 135°, as shown in Figure 3b. In both types of mesh a 2.7 mm diameter wire was adopted.

LOADING

The parameters of the material from which the steel wire is made have been adopted in the numerical model as follows:

– tensile yield stress f_y = 305 MPa,
– modulus of elasticity E = 205 GPa,
– Poisson's ratio in elastic stage v = 0.3,
– shear modulus G = 80 GPa.

In order to limit the distortions of the target structure, it was decided to choose the stretching force in such a way that the expanded mesh wires would not become plasticised. Due to the above, the elastic model of material work was used in the numerical model, and the applied force had the value of 12 kN, similar to that one in Ćwirko et al. (2017).

Woven mesh working feature

While stretching with the force spread over the entire width of the woven mesh, it has a continuous tendency to narrow its width. In the case of a concentrated load, this force is transmitted by means of diagonal wires to the edge wires on both sides of the mesh. The narrowing phenomenon is the smaller the higher the value of the coefficient *Kz* is, but still the woven mesh loaded with the concentrated load shows displacements by up to two orders of magnitude higher than with the applied uniformly distributed load. An exemplary character of the woven mesh working and displacement, for the Kz = 0.001 kN·mm^{-2}, is presented in Figure 4.

a

b

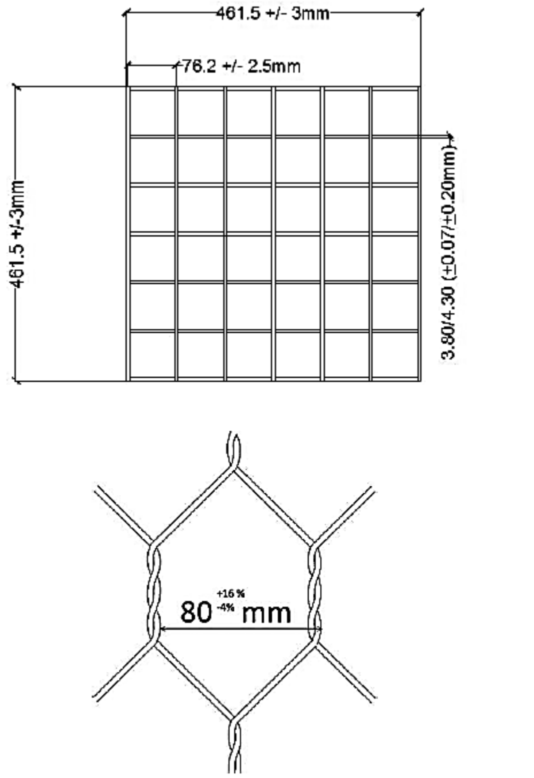

Fig. 3. Geometry of: a – welded mesh (Werner, 2014), b – woven mesh (Kosiński, 2010)

a b

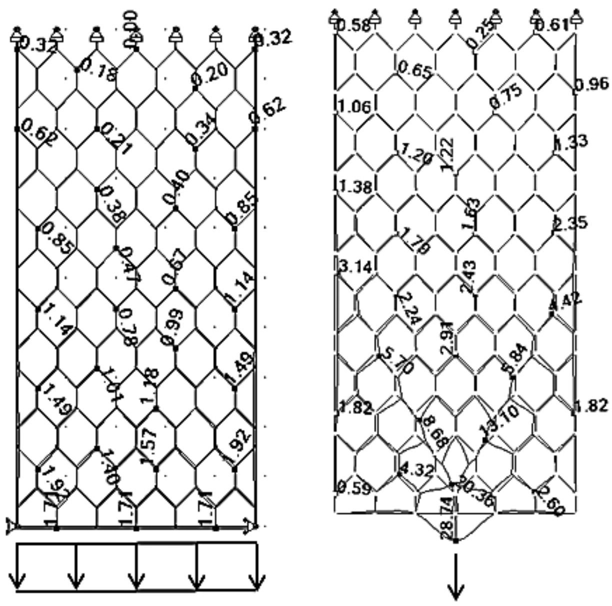

Fig. 4. Woven mesh working feature build-up in the soil and loaded with: a – evenly distributed force, b – concentrated force

Welded mesh working feature

Welded mesh stretched with uniformly distributed load shows a displacement depending only on the stiffness of the wires. Nevertheless, when stretching with concentrated force, the maximum displacement of the node depends chiefly on the stiffness of the wire to which this applied force has been applied. Neighbouring wires are involved into cooperation to a negligible extent. Welded mesh during stretching behaves very predictably. An exemplary character of welded mesh working and displacement, for the $Kz = 0.001\ kN \cdot mm^{-2}$, is shown in Figure 5.

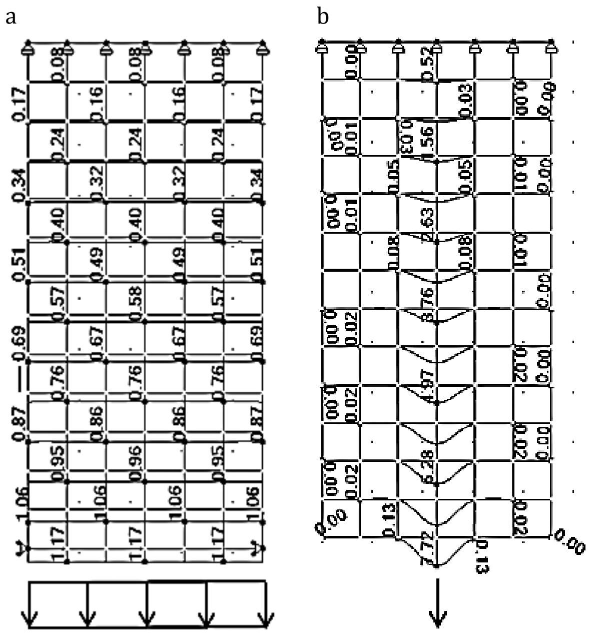

Fig. 5. Welded mesh working feature build-up in the soil and loaded with: a – evenly distributed force, b – concentrated force

RESULTS AND DISCUSSION

The influence of the coefficient *Kz* on the change of displacements of the mesh models was analyzed for the range of the $Kz \in \langle 0.0001;\ 1.0 \rangle\ kN \cdot mm^{-2}$. The attention should be paid on the fact that on the horizontal axes of the graphs the value of *Kz* changes in a logarithmic way. As the initial length of the analysed meshes is about 1.00 m, the values of the obtained displacement in mm are almost equal to the relative deformation value presented in ‰, e.g. displacement $u = 7.54$ mm corresponds to the relative deformation $\varepsilon \approx 7.5$‰ (Figs. 6–9).

The curved lines for soil assembled meshes visible in Figures 6–9 are convergent to two horizontal asymptotes, i.e. to the straight line for which the deformations assume a value of 0 ($u = 0$) and to a straight line for which the deformations are equal deformations determined in numerical analyses for the soil non-built-up mesh. Furthermore, all curve lines are characterized by a similar course (qualitative consistency), and both types of meshes in the entire examined range of the *Kz* substrate deformation coefficient change deform less if they are loaded with the evenly distributed force instead of a concentrated one, which is in line with predictions. The observations made allow us to believe that the study was conducted properly.

It is worth noting that in almost the entire examined range of changes in the coefficient *Kz* with concentrated force, the woven mesh shows an order of magnitude greater deformability (Fig. 6) compared to the welded mesh (Fig. 8). The only exception is the range $Kz > 0.01\ kN \cdot mm^{-2}$, in which the woven mesh shows up to 26% less total deformation. This is related to the elongation of the wire itself to which the load has been applied. In the welded mesh model, it is almost twice longer and it has a half smaller section area, since in the woven mesh the longitudinal wire is double-woven as shown in Figure 3b.

In addition, the results obtained during the testing of woven and welded meshes in the case of uniformly distributed force load were compared in Figure 10. Such a load scheme in the most faithful way reflects the way the soil reinforcement works in a retaining structure. Based on the course of the curve lines, it can be seen that they intersect at $Kz = 0.01\ kN \cdot mm^{-2}$. In the range $Kz > 0.01\ kN \cdot mm^{-2}$ displacements obtained for both types of mesh are almost identical. In the remaining range, i.e. for $Kz < 0.01\ kN \cdot mm^{-2}$, the welded mesh has less deformability. This allows to think that above a certain limit value of the substrate stiffness, both types of mesh deform in a similar degree.

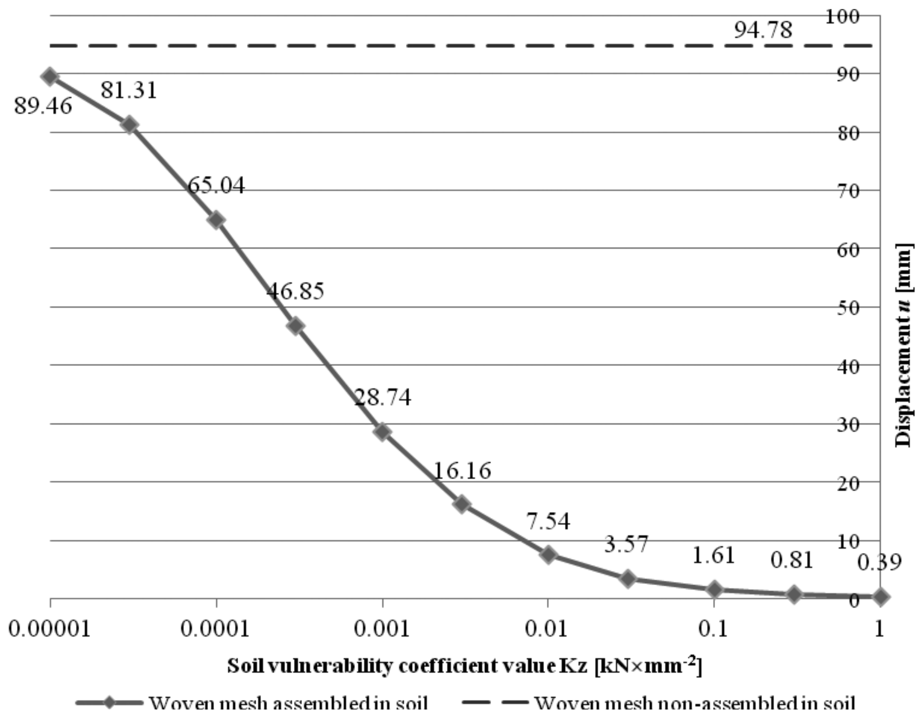

Fig. 6. Displacements obtained during the test for a woven mesh loaded with concentrated force for variable coefficient *Kz*

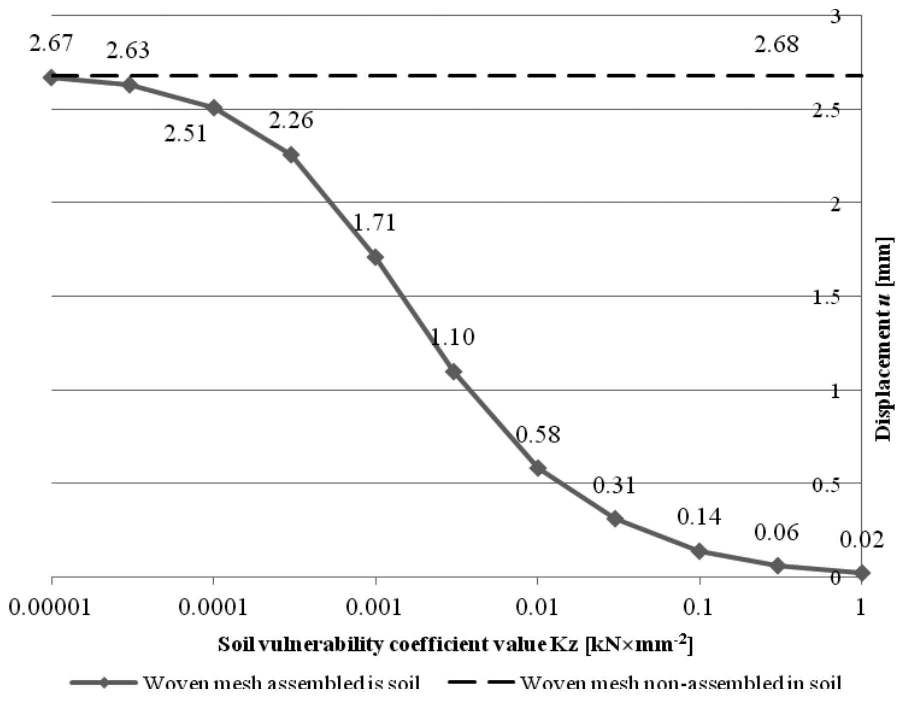

Fig. 7. Displacements obtained during the test for a woven mesh loaded with evenly distributed force for variable coefficient *Kz*

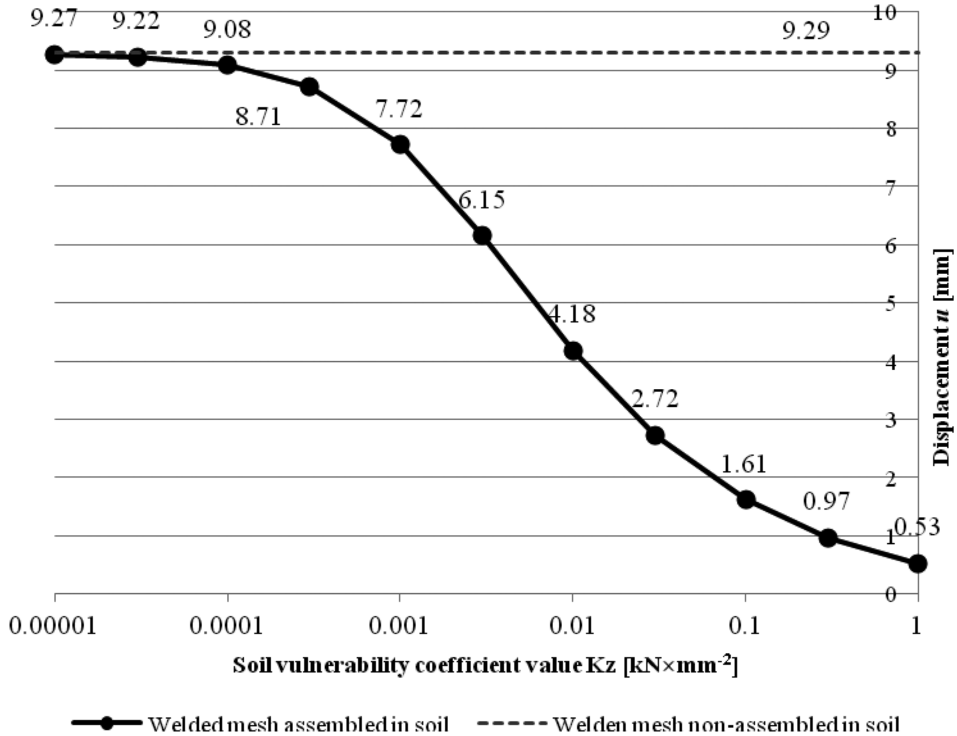

Fig. 8. Displacements obtained during the test for a welded mesh loaded with concentrated force for variable coefficient *Kz*

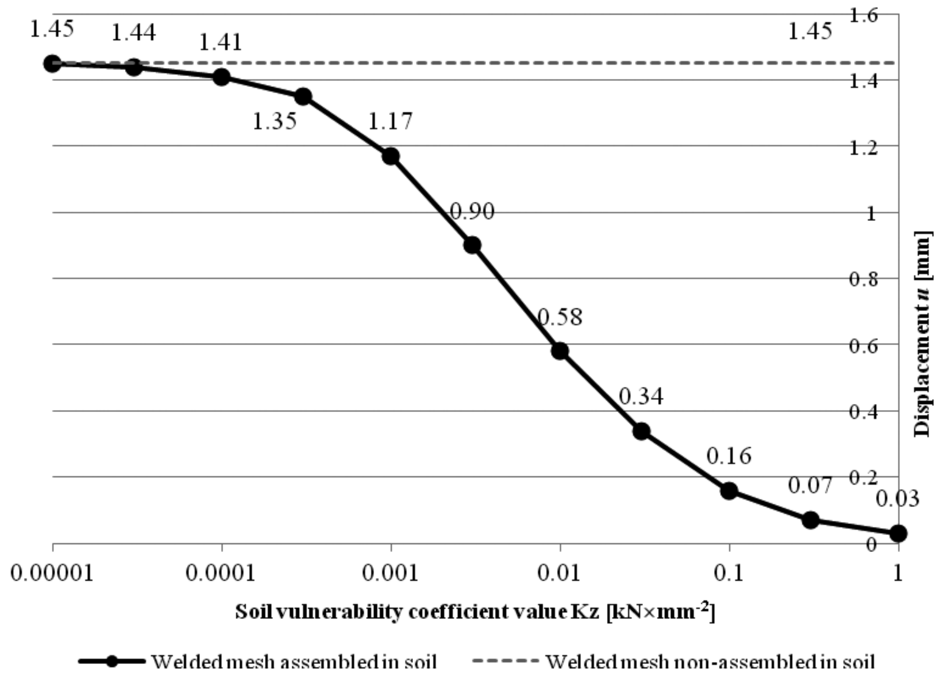

Fig. 9. Displacements obtained during the test for a welded mesh loaded with evenly distributed force for variable coefficient *Kz*

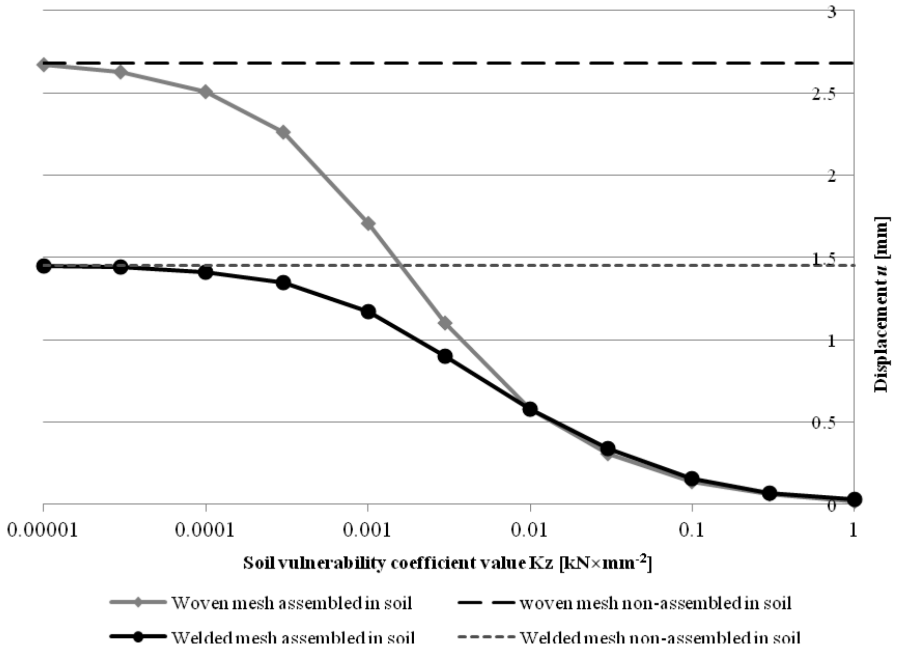

Fig. 10. Comparison of displacements obtained during the test for woven and welded mesh loaded with evenly distributed force for variable coefficient *Kz*

FURTHER RESEARCH PROPOSAL

The most important test from the point of view of the obtained results will be the implementation of the planned laboratory modeling study for the stretching of steel meshes built in various types of soil. Thus, by means of a back analysis on a calibrated computer model, it would allow to obtain the real value of the soil compliance factor (*Kz*) depending on the type of soil used as well as its density.

The next step would be to determine, also on the basis of laboratory tests, the ability of welded meshes to anchor in different types of soil during stretching. Work is also planned on the durability issue of the proposed type of construction under cyclic loading conditions and in the water environment of hydrotechnical constructions.

CONCLUSIONS

Based on the analysis presented, the following conclusions can be drawn:

- welded mesh, which was made from the same material and the same wire thickness as the woven mesh, shows less deformation at evenly distributed load, but only to a certain limit value of *Kz* (0.01 kN·mm^{-2}), above which both types of mesh behave almost in the same way;
- in the case of loading both types of mesh with a concentrated force, above a certain limit value of the substrate compliance coefficient ($Kz > 0.01$ kN·mm^{-2}), the woven mesh has less deformability, which may be related to the imperfection of the calculation model, however.

Giving an unambiguous, indisputable answer to the question about the meaning and possibility to use welded meshes in light gabion structures requires a series of further experiments and analyzes.

REFERENCES

Ciomcia, B. (2014). Przyczółki obiektów inżynierskich z gruntu zbrojonego. *Magazyn Autostrady*, *8–9*, 64––67.

Ćwirko, M. (2017). Analiza odkształceń stalowych siatek stosowanych do zbrojenia gruntu. In K. Gromysz & R. Domagała (Eds.), *Wprowadzenie do wybranych zagadnień z inżynierii lądowej* (strony 51–58). Gliwice: Politechnika Śląska.

Ćwirko, M., Jastrzębska, M. & Kwiecień, S. (2017). The analysis of the usefulness of welded meshes to enbankment reinforcement. *Studia Geotechnica et Mechanica*, *39*(3), 3–9.

Koerner, T. & Soong, T. (2001). Geosyntetic reinforced segmental retaining walls. *Geotextiles and Geomembranes*, *19*, 359–386.

Kosiński, T. (2010). Konstrukcje oporowe i nasypy zgruntu zbrojonego elementami stalowymi. In IBDiM i PZWFS, *Konstrukcje stalowe w geotechnice: seminarium* (strony 1–11). Warszawa.

Kuc, M. (2012). Właściwości gabionów wykonanych z siatki splatanej i siatki zgrzewanej. *Magazyn Autostrady*, *7*, 24–26.

Najder, T. & Najder, A. (2005). Gabiony i materace gabionowe jako element budownictwa przyjaznego środowisku. *Materiały Budowlane*, *1*, 87–91.

Ramli, M., Karasu, T. & Dawood, E. (2013). The Stability of gabion walls for earth retaining structures. *Alexandria Engineering Journal*, *52*(4), 705–710.

Werner, F. (2014). *Zincalu welded mesh pre-assembled gabions.* Technical Data Sheet TDS-06-83. Betafence, Group Quality Department.

ANALIZA NUMERYCZNA WPŁYWU ZMIANY SPRĘŻYSTOŚCI PODŁOŻA NA ODKSZTAŁCENIA STALOWYCH SIATEK STOSOWANYCH DO ZBROJENIA GRUNTU

STRESZCZENIE

Bardzo często stosowanym sposobem wykonania lekkich konstrukcji oporowych są ściany oporowe z zastosowaniem technologii gruntu zbrojonego, w którym lico jest wykonane z koszy gabionowych. Funkcję zbrojenia w tego typu konstrukcjach najczęściej pełnią geosyntetyki lub stalowe siatki podwójnie zaplatane. Alternatywą siatek podwójnie zaplatanych mogą być siatki zgrzewane, które są mniej podatne na zmianę geometrii oczek podczas rozciągania w kierunku głównym. Celem niniejszego opracowania jest odpowiedź na pytanie o zasadność stosowania stalowych siatek zgrzewanych jako zbrojenia gruntu w lekkich konstrukcjach oporowych z gabionów, a także porównanie sztywności obydwu typów siatek w różnych warunkach gruntowych. W pracy przeprowadzono analizę numeryczną rozciągania siatek zaplatanych i zgrzewanych wraz z uwzględnieniem ich zabudowania w ośrodku gruntowym. Ośrodek gruntowy odwzorowano za pomocą modelu Winklera z użyciem kilku różnych wariantów wartości współczynnika podatności podłoża. Artykuł podsumowano wnioskami, planami dalszych badań oraz porównaniem z poprzednimi analizami numerycznymi.

Słowa kluczowe: konstrukcje oporowe, gabiony, siatki zgrzewane