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General Report TC 205: Safety and Serviceability in Geotechnical Design

Rapport général du TC 205 : Sécurité et maintenance en conception géotechnique

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ABSTRACT: A series of papers in the section of TC205 demonstrates the wideness of breadth in current geotechnical design. The overview presented below shows the stretch of applicability of geotechnical engineering practice in the development of contemporary civil infrastructure. The concept of Safety and Serviceability is used as a general guideline for resolving design issues while clearly some design concepts, in particular Soil-Structure Interaction gains in applicability while relying on deeper understanding of boundary value problems. This is usually achieved by advanced numerical analyses, which are now routinely carried out within 3D boundary conditions. The technical advancement in the use of geosynthetics remains in the forefront of the widening of the applicability of soil reinforcement technology gaining novel applications in foundation and soil improvement. This paper highlights the key issues that were raised within the context of the papers that were submitted to TC 205 topics in 19th ICSMGE.

RÉSUMÉ : Une série d'articles dans la section du TC 205 démontre la largeur de manœuvre dans la conception géotechnique actuelle. L'aperçu présenté ci-dessous montre l'étendue de l'applicabilité de la pratique de l'ingénierie géotechnique dans le développement de l'infrastructure civile contemporaine. Le concept de sécurité et de maintenance est utilisé comme ligne directrice générale pour résoudre les problèmes de conception, alors que certains concepts de design, en particulier l'interaction structure/sol, augmente l'applicabilité tout en s'appuyant sur une compréhension plus approfondie du problème aux limites considérées. Ceci est généralement réalisé par des analyses numériques avancées qui sont maintenant exécutées de manière routinière dans des conditions aux limites 3D. Le progrès technique dans l'utilisation des géosynthétiques demeure au premier rang concernant le développement de l'applicabilité de la technologie de renforcement des sols, rendu possible grâce à de nouvelles applications dans les fondations et à l'amélioration des sols. Cet article met en évidence les questions clés qui ont été soulevées dans le contexte des articles soumis au TC 205 au 19e CIMSG.

KEYWORDS: Foundation, Soil Structure Interaction, Maritime and Port Infrastructure, Soil Reinforcement, Geosynthetics

1 INTRODUCTION.

In total 21 contributions were submitted on the topic of Safety and Serviceability in Geotechnical Design, which is associated to TC205. In this overview an attempt is made to make a comparison between the different design practices across the world. This is not intended to be in the form of which different standard would geotechnical engineers use in different countries but how the uncertainties between loads and resistances, or more precisely between loads and soil material parameters, are addressed for a variety of different geotechnical problems.

The topics of the papers are broadly divided into several fields while considering that the content of some of the papers can extend to more than one field. The contributions are divided into the following main field topics: Foundation, Soil Structure Interaction, Maritime and Port Infrastructure, Soil Reinforcement Using Geosynthetics and Specific Field Applications. The overview that follows addresses the key issues that were raised within the context of a particular paper and tries to locate interactions between different approaches to overlapping topics.

2 FOUNDATION

2 .1 *Settlement of a high-rise building under construction – measurement and modelling (Buttling & Rui, 2017)*

A useful example of the use of soil structure interaction analyses to aid foundation design is demonstrated by Buttling & Rui, (2017). The building to be founded on a mat foundation on 399 piles comprised three 70-storey towers constructed in Bangkok. In this case it was not possible to use a piled raft foundation, since the superficial soils were incapable of supporting the concentrated building loads, and the surface subsidence meant that, over time, the soils were likely to settle away from the underside of a raft rather than provide support.

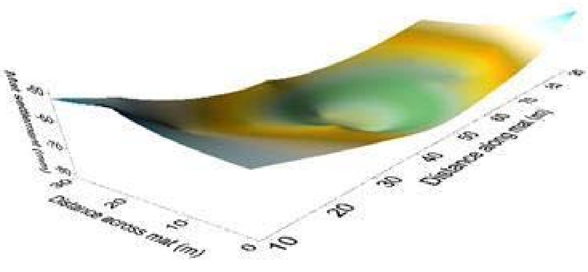

Figure 1. Deformed shape of mat foundation as a result of relative stiffness of foundation soil and the structure, after Buttling & Rui, 2017

The design process, which included analyses of relative stiffness of the structures and the soil, highlighted some of the complexities of combining structural models with geotechnical models. As anticipated, the soil-structure analyses acknowledged that the relative stiffness of the soil and the structure would control the distribution of pile loads. This is demonstrated in Figure 1, in which the results of the settlement monitoring were presented in the form of deformed mat foundation. In comparison to traditional analytical solutions that treated piles as linear elastic springs the soil-structure interaction analyses showed different distribution of the load to the piles. The results of monitoring nicely demonstrated the need for these more complex analyses as the traditional methods would have led to oversimplified and incorrect design.

2.2 *Hydraulic Heave – From numerical investigations via new design formula through to a design tool (Aulbach & Ziegler, 2017)*

The design tool was developed by Aulbach & Ziegler (2017) on the basis of 3D numerical analyses of hydraulic heave for a simplified boundary value problem of an excavation pit in homogenous ground conditions. To determine accurately the embedded length required for the safety against hydraulic heave, several 3D ground water flow calculations were carried out. To aid the design process the authors developed a geotechnical model of generalized boundary conditions shown in Figure 2.

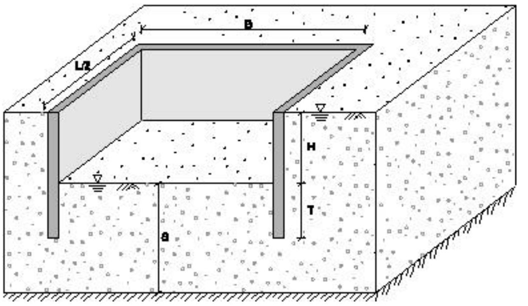

Figure 2. System sketch of a construction pit including notation of generalized boundary conditions, after Aulbach & Ziegler (2017)

On the basis of extensive numerical analyses the dimensionless design charts and accompanying formulae have been developed by the authors. By the use of the formulae and the design charts the required embedded length related to the difference of the ground water table can be easily determined considering different boundary conditions including the width and the length of the construction pit or thickness of the aquifer. The general solution allows determination of the safety level according to Eurocode 7-1 or any safety level, which needs to be considered. Finally, a free software design tool was made available on request by the authors.

2.3 *Three dimensional analysis of corner effects of deep excavations using soil nailing method (Ali Zad & Farnegin, 2017)*

The results of 3D finite elements parametric study were used by Ali Zad & Farnegin (2017) to analyse the optimization of soil nailing method for supporting system of 15m deep excavation. The finite element mesh of a 3D boundary value problem is shown in Figure 3. The disposition including horizontal and vertical distance of nails and the type of constitutive soil models were varied. Based on the results of the parametric study, it was concluded that the soil nail distance could be increased around the concave corners without the increase of the overall horizontal displacements.

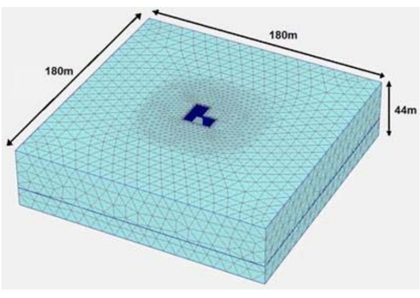

Figure 3. The disposition of the excavation pit – 3D finite element mesh, after Ali Zad & Farnegin (2017)

2.4 *Stability of Buildings Near Shallow Excavations (Mofidi et al. 2017)*

A numerical study of the influence of the shallow excavation on the bearing capacity of a foundation of an adjacent building is presented by Mofidi et al. (2017). Generalized boundary conditions, shown in Figure 4, were defined and the main effects of the depth of excavation were evaluated relative to the width of the foundation.

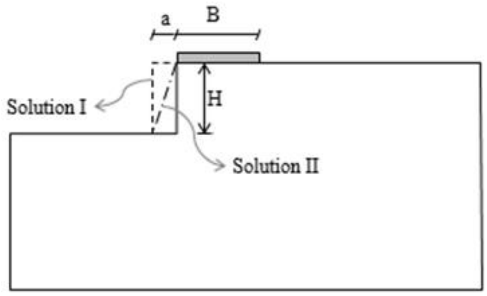

Figure 4. Generalized boundary conditions for numerical study and a schematic of two remedial solutions proposed to reduce the influence of shallow vertical excavations to adjacent foundations, after Mofidi et al. (2017)

The results indicate that the bearing capacity reduces more than 50 % when the depth of the excavation reaches about half of the footing width. The paper also presents a study of the possible remedial solutions giving the guidance on the geometry of the slope from the footing edge that lower the effect of the excavation, as indicated in Figure 4.

2.5 *Bearing capacity of shallow impervious footing in soil under sub-vertical seepage (Franco et al. 2017)*

The contribution by Franco et al. (2017) evaluates the influence of the impervious foundations on the flow net in the conditions of seepage below the foundations. The impervious foundation affects the seepage forces and thus changes the effective stresses and consequently the bearing capacity of the surrounding soil. The results of parametric numerical study, carried out for the predetermined boundary conditions given in Figure 5, showed that for the upwards seepage the effect of the impervious footing is quite significant and leads to an important decrease of the bearing capacity.

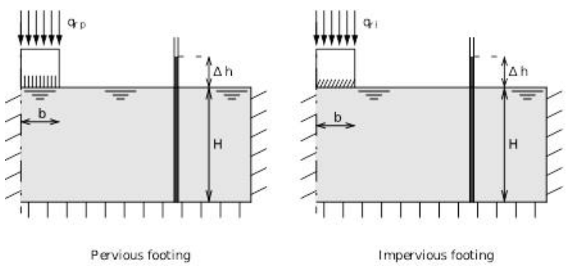

Figure 5. Schematic representation of the boundary conditions for the study on the influence of impervious foundations on the flow net in the conditions of seepage below the foundations, after Franco et al. (2017)

Finite element method, with the capability of performing seepage and upper-bound plastic calculations, was used for the study. A parametric analysis of geometric (soil height to footing width ratio), hydraulic (average gradient) and mechanical (soil friction angle) parameters was performed and their influence on the bearing capacity and on the failure mechanisms was analysed. The results, presented in Figure 6, show that: (1) the effect on the bearing capacity is greater for soils with lower friction angles; (2) this effect is nonlinear and therefore cannot be described by a change in the soil unit weight only; and (3) for the same average hydraulic gradient, the geometric parameter has little influence on the bearing capacity.

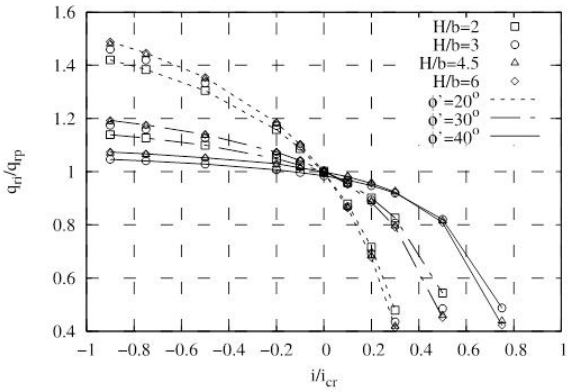

Figure 6. A diagram showing a normalized flow (q_{ri}/q_{rp}) beneath impermeable relative to permeable foundation against the hydraulic gradient relative to critical gradient (i/i_{cr}), after Franco et al. (2017)

As it can be seen in the figure the effect of the impervious footing is quite significant and leads to an important decrease of the bearing capacity. The results obtained for the impervious footing highlighted the changes that its influence on the head distribution and on the seepage forces has on the bearing capacity, changing the mechanisms involved in collapse. The results for the pervious footing confirm the expected behaviour of an increase of the bearing capacity, which allows for the use of bearing capacity equations corrected with the appropriate value of the soil unit weight.

2. 6 *Failure probability calculation for machine foundations coupled rocking and sliding vibration on soil with random elastic parameters (Kholmyansky, 2017)*

Probabilistic approach was used to analyse a two degrees of freedom system to simulate the coupled rocking and sliding of the rigid foundation for a machine. The most common cases of massive (block-like) and the wall-like machine foundations were considered. The dynamic load was taken as sinusoidal function having random amplitude with Rayleigh distribution. The vibration amplitude was made dependent on the soil shear elasticity modulus, for which was assumed to have lognormal distribution.

This contribution highlights the point that in the terms of soil dynamic response the partial reduction in soil parameters is not necessarily on the conservative side. Considering the dynamic loads both overestimation and underestimation of soil stiffness may lead to underestimation of vibration level; the latter may be significant in case of resonance. As a consequence, the application of partial reliability factors might lead to errors in design. By employing a probabilistic approach the degree of uncertainty of dynamic soil behaviour is reduced. It was demonstrated that coupled sliding and rocking sinusoidal vibration of rigid foundation may be reliably analysed taking into account probabilistic values of the both soil parameters and dynamic load amplitude.

3 SOIL STRUCTURE INTERACTION

3 .1 *Sensitivity of soil structure interaction for NPP footing bottom on static and seismic loading (Vaniček et al. 2017)*

An overview of the feasibility study of the foundation of nuclear power plant (NPP) in the area with complicated subsoil conditions subjected to seismic loading is presented by Vaniček et al. (2017). The focus of the paper is given to: a) the measures to eliminate potential risk with respect to differential settlement including ground improvement and b) the numerical modelling of the soil structure interaction under seismic loading. The paper is an illustrative example on how to approach uncertainties related to a particular NPP foundation.

Two basic methods were proposed for the subsoil improvement. The first one is based on the subsoil replacement, in which the part of compressible layer (loess) is substituted by a sandy-gravel cushion. The total thickness of the reinforced cushion is assumed to be between 4.5 and 6 m. The group of piles, which are embedded into gravel layer, are used for the second method of subsoil improvement. In the upper part they are interconnected by reinforced concrete slab. In both cases 0.5m thick very well compacted gravel layer is proposed between the zone of improvement and foundation slab, as shown in Figure 7.

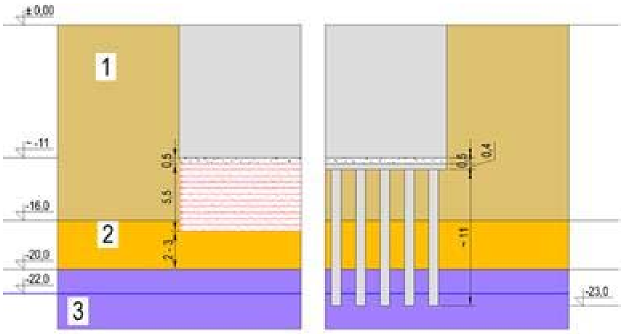

Figure 7. Variants of subsoil improvement methods proposed for a NPP: (left) soil replacement and (right) the group of piles (1.loesses, 2.alluvial clays, 3.gravels), after Vaniček et al. (2017)

A numerical study of soil structure interaction was used to evaluate the appropriateness of the location for NPP for the given geological and geotechnical conditions considering the recommended seismic load. Numerical modelling was instrumental in defining the magnitude of the movement of the studied object during seismic event as well as for the determination of the residual vertical or horizontal deformation following the seismic event.

3. 2 *Slope stabilization using anchored shafts (Katzenbach et al. 2017)*

An innovative method for slope stabilization comprising 45m deep shafts with a diameter of 6.6m tied back by long permanent anchors was developed and presented in the paper by Katzenbach et al.(2017).

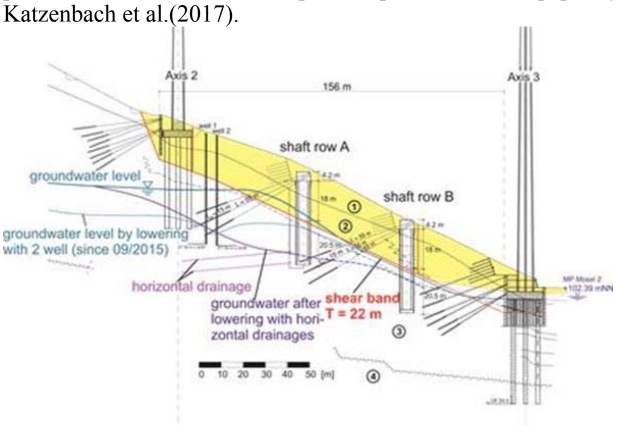

Figure 8. Slope stabilisation measures using deep shafts, after Katzenbach et al. (2017)

The slope stabilization measures, shown in Figure 8, were needed to stabilise the valley with steep and unstable slopes for the installation of 160 m high piers of 1.7 km long motorway bridge. The construction of shafts is planned to be complemented with the deep drainage measures. For the load transfer the shafts are connected with a 4.2 m x 6.3 m thick and 32 m long strongly reinforced head board and are tied back with up to 55 m long permanent anchors of the nominal design load of 3.0MN.

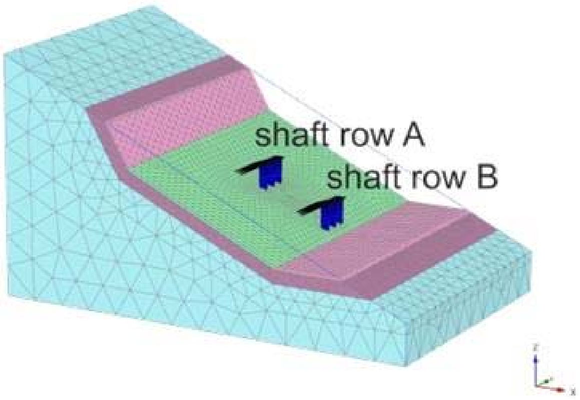

Figure 9. 3D finite element mesh of soil structure analyses, after Katzenbach et al. (2017)

3D Numerical analyses of soil structure interaction, the model of which is shown in Figure 9, were carried out to prove the efficacy of the developed slope stabilization measures. It was concluded by the authors that the 3D-Finite-Element Model was a necessary tool needed to prove and confirm the stabilization load that had been previously calculated using the simple model with the transferable force. Soil structure analyses demonstrated that the planned slope stabilization construction is able to absorb the load, which might occur by the slope failure, so that the bedding of the piers could be conserved.

4 MARITIME AND PORT INFRASTRUCTURE

4.1 Performance of a full-scale embankment test on soft organic silt improved with hybrid concrete-stone columns in the reclaimed area of the existing basin (Mitrosz et al. 2017)

An interesting case study detailing the use of hybrid concrete-stone columns to support the pavement structure in the quay wall area at the Port Gdansk is presented by Mitrosz et al. (2017). The case study concentrates on a concept, in which the upper granular layer interacts with the stone columns so that the homogenised and compacted upper granular platform was formed.

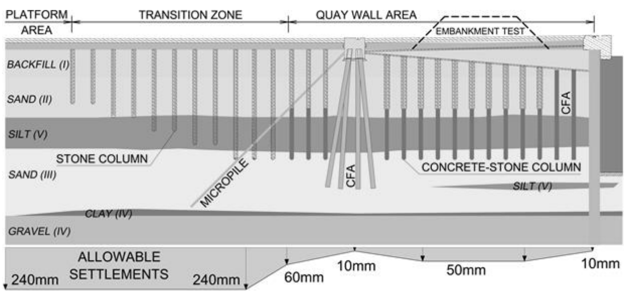

Figure 10. The longitudinal section along the quay wall area at the port of Gdansk, showing allowable settlements at different zones, after Mitrosz et al. (2017)

The intention was to transfer the load to bearing strata by the concrete part of the hybrid columns. Ground improvement in the quay wall area was aimed not only to reduce the settlements of the pavement under the surcharge load but also to reduce the earth pressure on the quay wall structure. The longitudinal section along the quay wall area is shown in Figure 10. The authors made use of a full-scale instrumented test section, which was constructed as part of a field trial program. The test section simulated the weight of the engineered fill, pavement and surcharge load. The settlements and pore water pressures were monitored during the construction of the test section. The measurements were compared with the calculated and allowable values from the preliminary design.

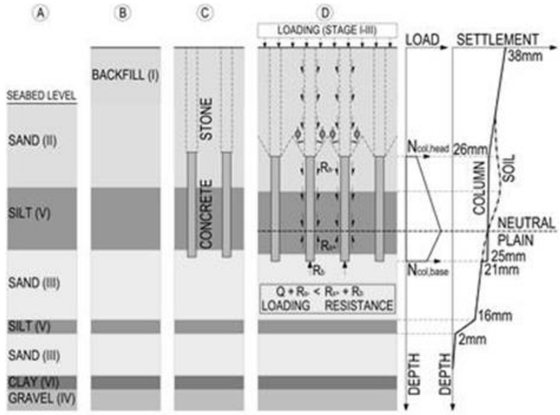

Figure 11. Soil-column interaction diagram with phases: A – initial, B – backfilling, C – soil improvement, D – embankment test, after Mitrosz et al. (2017)

The results of the embankment test show that improving the existing upper granular layer can work as a load transfer platform by utilizing the arching effect to spread the applied load to the columns over the soft organic layer. This soil-column interaction effect is shown in the form of a load to settlement diagram in Figure 11. Finally, the authors conclude that the construction of embankment layer and the installation of monitoring equipment were worthwhile and successful. The measured values of deformations were in good agreement with the design assumptions, which were confirmed by the quick stabilization of the settlements.

4.2 Design and construction issues for deepening and strengthening of existing quay walls (Bauduin et al. 2017)

A thorough discussion on the difficulties in carrying out the upgrade of existing Port Infrastructure, which usually involves significant and different risks compared to building of new infrastructure, is discussed by Bauduin et al. (2017).

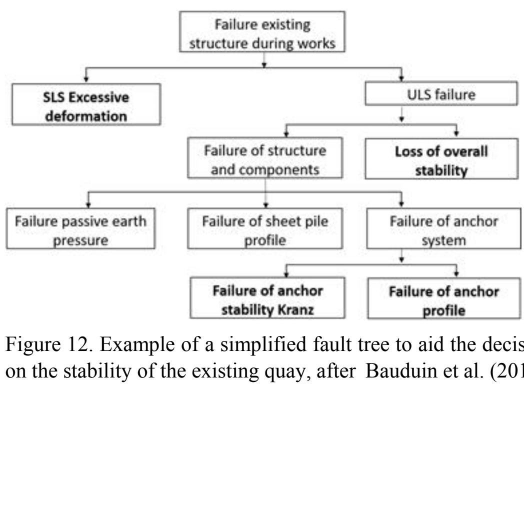

Figure 12. Example of a simplified fault tree to aid the decision making on the stability of the existing quay, after Bauduin et al. (2017)

A set of guidance recommendation is given to complement decision making. The paper contains some general guidelines for an integrated design and construction approach, combining risk fault tree analyses, robust and flexible design, and the construction and monitoring methods. Examples of projects in which different types of existing quay walls were strengthened and deepened are presented to illustrate the main points.

The authors demonstrate the practicality of the use of fault trees (example shown in Figure 12), which allows for an integrated approach during the complete assessment-design-procurement-execution process. It is regarded as a powerful risk management tool supporting decision at each stage of the project developed in conditions of significant remaining doubts, which remain even after careful geotechnical investigation and assessment of the existing structure. The authors conclude that the monitoring during construction, and especially when combined with the observational method, developed together with the robust design and the flexible execution methods, have proven to reduce efficiently operational risks.

4.3 Review on standards and a proposal for stability safety factors of a breakwater in different load cases for different sliding surfaces (Tavallali et al. 2017)

A comprehensive overview on the requirements on the design values for the factor of safety when analysing the stability of breakwaters is presented by Tavallali et al. (2017). The three critical conditions selected in the form of: a) wave action, b) possible failure surface and c) the influence of the short-term/long term conditions were discussed considering the requirements given in different guidelines/standards. A set of recommendations is given for the required factors of safety when analysing slope stability analysis under different load cases.

A very valuable part of the paper is discussion on the use the three standards: “Eurocode”, “US Army Corps of Engineers, USACE”, and “Recommendations for Maritime Works, ROM”, which are all relevant for the breakwater stability analysis. The authors discuss the long-term and short-term conditions and conclude that both should be considered for the foundation material properties and also for the load conditions.

4.4 Design Capacity of Partially Plugged Piles at Port of Koper (Jovičić et al. 2017)

Theoretical and empirical considerations of the partial pile plugging of hollow circular steel piles were presented by Jovičić et al. (2017). Empirical correlations were used to re-interpret the static and dynamic load test data carried out on piles of 0,8m diameter to estimate their capacity at the location of Terminal One at port of Koper.

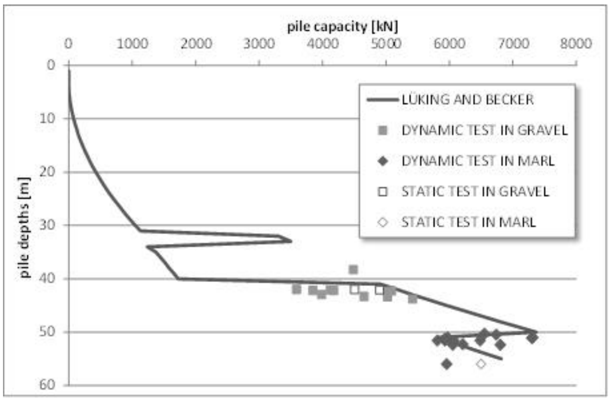

Figure 13. The comparison between the calculated and the measured pile capacities for piles Ø812/12.5 mm, after Jovičić et al. (2017)

The results of the back analyses of the both static and dynamic tests for piles Ø812/12.5mm, shown in Figure 13, demonstrated a good agreement between the measured and calculated pile capacities, which indicated that the empirical method of Luking and Becker is more applicable to the given site conditions than the other available models. Further series of dynamic and static pile tests were requested prior to the execution of the pile driving to validate the proposed approach for the calculation of design capacity of the partially plugged piles at a particular location.

4.5 Effect of flexural rigidity of piles on the horizontal resistance of a reinforced gravity-type breakwater with steel piles (Kikuchi et al. 2017)

A method for reinforcing a caisson-type composite breakwater designed to resist tsunami attacks is presented by Kikuchi et al. (2017). The additional resistance is achieved by placing steel pipe piles behind the breakwater and filling the area between the breakwater and the piles with backfill material, as schematically presented in Figure 14.

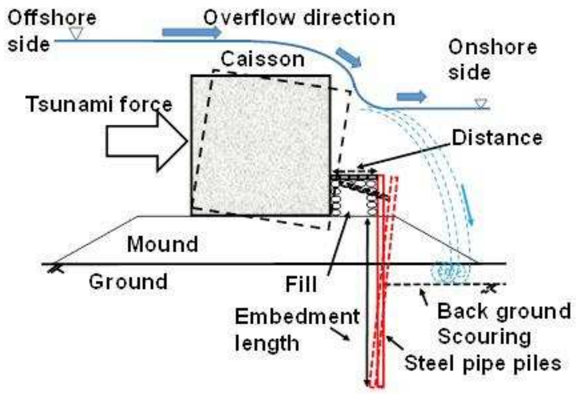

Figure 14. Schematic of the reinforced gravity-type composite breakwater with steel piles, after Kikuchi et al.(2017)

The effect of the flexural rigidity of the steel piles on improving the resistance of the caisson was evaluated by performing horizontal static loading experiments. The effect of the flexural rigidity of the piles on the resistance of the reinforced breakwater was investigated in a series of experiments using models of the breakwater. In these experiments, plate-type piles were used, and the pile thickness and the number of piles used in each experiment were varied. The results of the study are shown in Figure 15. It can be seen that the resistance of the caisson was primarily affected by the total flexural rigidity of the piles along the unit length of the breakwater.

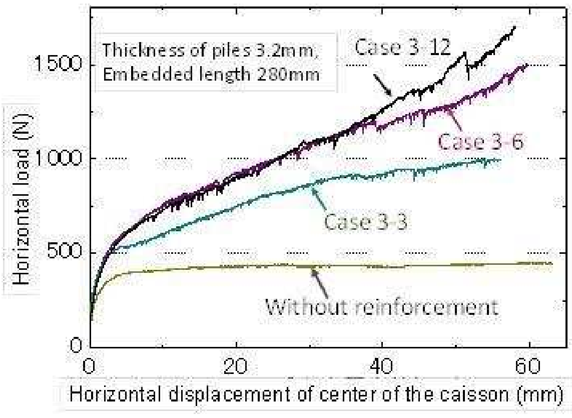

Figure 15. Relation between the load and horizontal displacement of the caisson for different number of piles, after Kikuchi et al. (2017)

The study was also useful in clarifying the distribution and the intensity of the load acting on the piles. It was shown that the change in resistance of the caisson was primarily affected by the total flexural rigidity of the piles along the unit length of the breakwater. The authors finally concluded that the effect of the examined set up increased the resistance of the backwater by the factor of three.

5 SOIL REINFORCEMENT USING GEOSYNTHETICS

5. 1 Investigations on a geosynthetic reinforced bearing layer under static and cyclic loading (Lehn & Moormann, 2017)

An introduction in the study on the use of geosynthetic for the improvement of temporary working platforms for heavy construction machines is given by Lehn & Moormann, (2017). The working platforms for heavy machinery, which are often used in geotechnical works, are often causes of accidents due to insufficient bearing capacity. The working platforms and the underlying soft grounds or fillings have to be designed to guarantee a safe operation of the construction machines. The influence of the height of the bearing layer, the relevant mechanical parameters of the soft soil and the different geotextiles were investigated. A comprehensive set of the results obtained from the model tests, shown in Figure 16, demonstrate that the geosynthetic reinforcement increases the bearing capacity resistance of the test working platform by 22%.

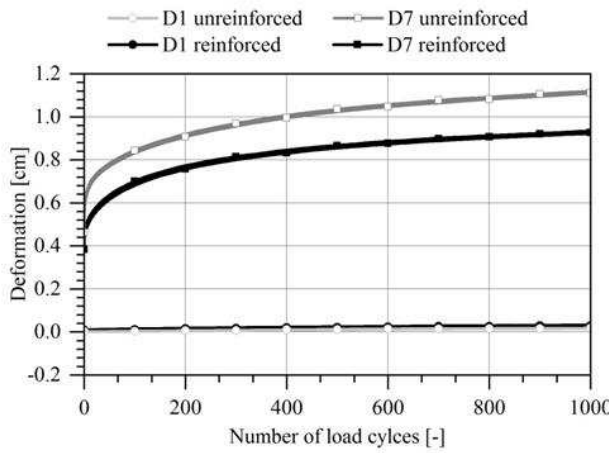

Figure 16. Settlement of the unreinforced and the unreinforced system at different points D1 and D7 located at the test working platform for different number of load cycles, after Lehn & Moormann, (2017)

It was further concluded by the authors that the strain measurements show that the geogrid is more effective under the higher loads and deformations. The future work would include the parametric studies with an aim to develop uniform calculation approach for unreinforced and reinforced working platforms including different input parameters considering the soft soil conditions, the angle of internal friction of the bearing layer and the maximum tensile strength and the axial stiffness of the geosynthetic.

5. 2 Pullout resistance of an innovative geogrid system embedded in a granular soil (Mosallanezhad at al., 2017)

A novel ground reinforcement system using geosinthetics is presented by Mosallanezhad at al., (2017). The system was applied on a large-scale laboratory set-up in a sandy soil and tested on the pull-out capacity. This system, schematically presented in Figure 17, is called “anchored geogrid (AG) as it contains an addition to the conventional HDPE geogrids using rigid bearing transversal elements (anchor is defined as a set of steel angles).

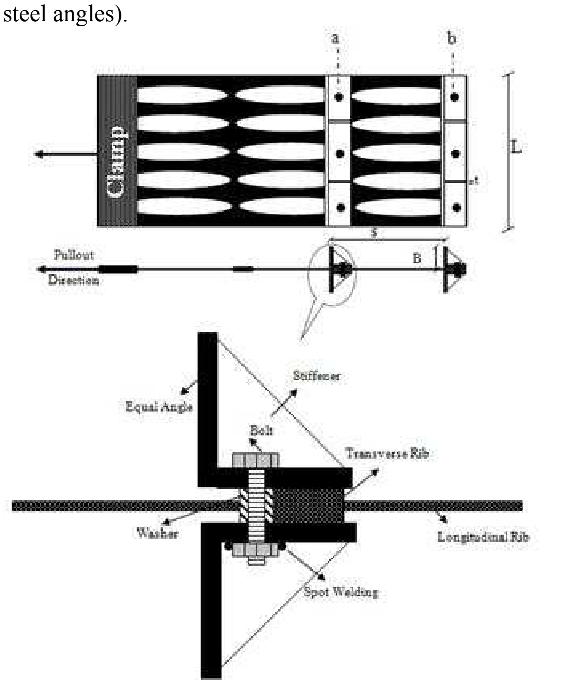

Figure 17. The features of the reinforcement system of anchored geogrid (AG), after Mosallanezhad at al., 2017

It was demonstrated in the laboratory that AG system, with the optimum spacing-to-depth ratio (s/d=2) is capable of increasing the pullout resistance of the ordinary geogrid system by up to three times. It was further concluded by the authors that the system could be capable of completely anchoring the end of the base geogrid in the soil in the pullout mechanism, until the predetermined displacement is reached.

5. 3 Bridging embedded pipelines: some options and recent tests (Napolitano at al., 2017)

The use of geosynthetics to aid the bearing capacity of the layer above the buried pipelines is presented by Napolitano at al., (2017). The structural and serviceability calculations for buried pipelines in the case the new infrastructure is built on the surface located on the top of them are addressed in the paper. The mitigation measures using geogrid are developed and tested in the field to reduce the soil stresses that reach the pipe. The layout of the model test is shown in Figure 18.

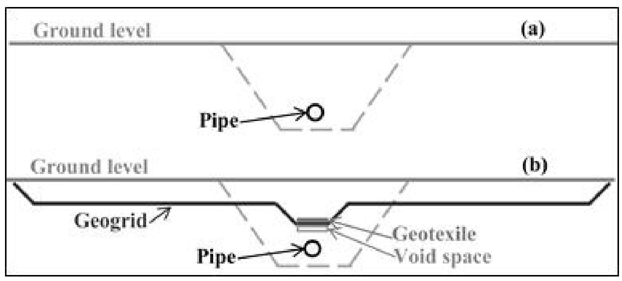

Figure 18. Layout scheme of the field test: (a) control case; (b) geogrid configuration case, after Napolitano at al., (2017)

The results show that high tensile low-strain geogrid can be successfully used to reduce the overall stress induced on the buried pipelines by additional loads, avoiding the pipe damage.

5.4 Experimental study on aseismic countermeasure of existing masonry walls available for various site condition (Nakajima at al., 2017)

An experimental study on the development of aseismic reinforcement methodology for the masonry retaining walls is discussed in the paper presented by Nakajima at al., (2017). Based on the knowledge of the failure mechanism of the masonry retaining wall, an aseismic counter measure, shown in Figure 19, which was tested at the shaking table, is developed by combining the soil reinforcement with the net installed at the wall facing.

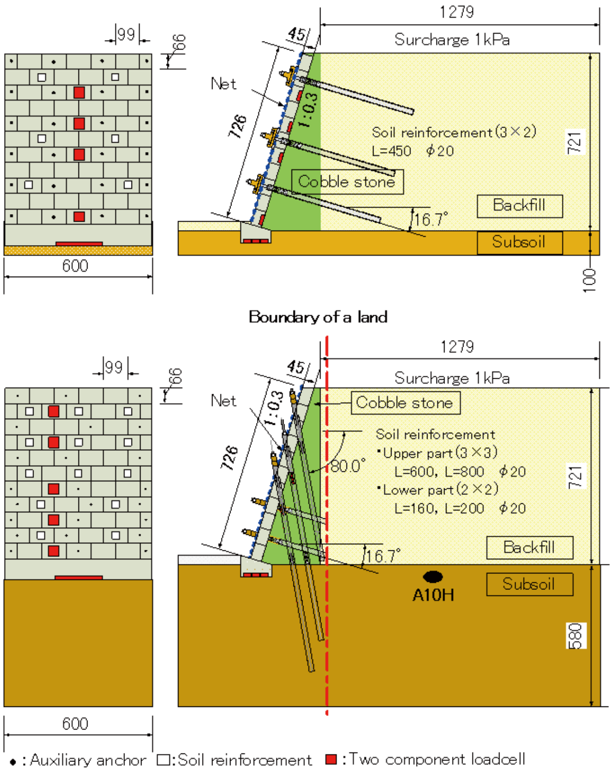

Figure 19. Outlines of the shaking table model tests of the two reinforced masonry retaining walls (units in mm), after Nakajima at al., (2017)

Based on the shaking table model tests and the relevant analyses the authors concluded that aseismic reinforcement by combining the soil reinforcement and the installation of the net in front of the wall facing block, increased the wall stability resistance by the factor of 3. Also, the protection net installed at the wall facing was found to be highly effective in propagating the resistance mobilized by the soil reinforcement.

6 SPECIFIC FIELD APPLICATIONS

6.1 Evaluation of Lateral Stress States for a Compacted Highly Expansive Soil (Abbas at al., 2017)

An interesting contribution on the increase of the lateral pressure of an active clay under the condition of lateral confinement is presented by Abbas at al., (2017). The behaviour of Al-Qatif clay was tested under constant stress and constant volume conditions in oedometer apparatus. The amount of the increase of lateral stress was measured relative to the increase of axial stress pre and after the wetting. The results of an extensive experimental program to evaluate lateral stresses developed in compacted highly expansive soil under two different boundary conditions; namely, constant axial stress and constant volume test are presented in the paper. The authors quantified the variation of the change in lateral stress due to wetting, and concluded that in general wetting results in an increase of the lateral stress for both examined boundary conditions.

6.2 Development of urban debris flow vulnerability assessment model (Ki Kim at al., 2017)

An assessment model to the urban debris flow vulnerability, which is quantitatively evaluated considering the overlap of physical vulnerability and the socio-economic impact of the local area, is presented by Ki Kim at al., (2017). For the assessment of socio-economic vulnerability the used model consists of three evaluation indicators: a) demographic and social indicator, b) trigger secondary-damage indicator and c) preparatory and response indicator. The physical assessment of vulnerability considered both the reinforced concrete frame structures and the non-concrete frame structures. The debris-flow vulnerability map, developed as an overlap of the two affects, is shown in the paper for Seoul and Busan in South Korea. The map is used as a decision making tool to select the priority regions for prevention program against debris flow disasters.

6.3 Actual performance of geotechnical structures accessible in GEOTAC database (Turk at al., 2017)

The database, which is used to store the monitoring data of geotechnical structures including the information on the ground and structure displacements, anchor forces, water table levels, and the results of visual inspections for the construction and post construction period is comprehensively presented by Turk at al., (2017). The use of the database, utilised on Slovenian motorway network since year 1997, is demonstrated on the example of a 250 m long anchored retaining wall which has been monitored for 17 years. Measured anchor forces at different sections of this wall are shown in Figure 20.

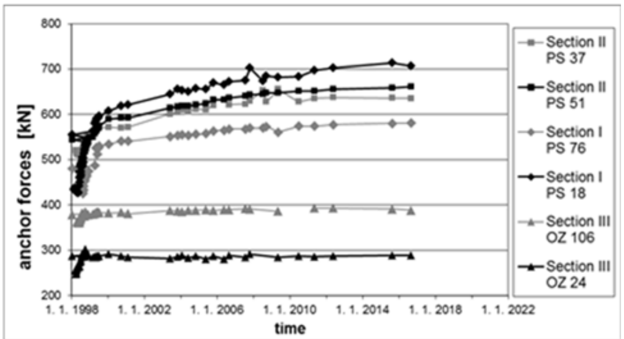

Figure 20. Measured anchor forces since 1998 in section I, II and III, after Turk at al., (2017)

The long term monitoring revealed post−construction ground displacements towards the cut in the years following the completion of works. The gained experience shows that tectonically altered clayey schists, within which the wall was built, are susceptible to large displacements in the ground and weathering at newly formed cracks. The authors highlight the importance of the records of the actual performance of the structures to monitor their safety and serviceability, as well as to store the useful data for the future construction in similar geotechnical conditions.

6.4 Modelling the influence of rock variability on geotechnical structures (Pedro at al., 2017)

The influence of introducing variability in numerical analysis was assessed Pedro at al., (2017) through the modelling of the excavation of a deep circular tunnel in a rock mass characterised by a uniform and isotropic stress state. Variability was introduced assuming a Gaussian distribution for the GSI, which was then related to the strength parameters of the Hoek-Brown failure criterion and to the stiffness of the rock mass. As a result of the study it was possible to establish a reliable distribution of the displacements and of the envelopes of the hoop forces acting on the tunnel lining relative to the variation in rock mass parameters, including the presence of anisotropy.

7 SUMMARY AND CONCLUSIONS

Clearly, the contributions demonstrate the stretch of applicability of Geotechnical engineering practice in the development of contemporary civil infrastructure. The most frequently addressed topic is Foundation with seven categorizations while the topic of Soil Structure Interaction overlaps with the most of the other topics. There is variety of contributions on Maritime and Port Infrastructure, in this case clearly surpassing traditional common topics of Road or Railway Infrastructure. A topic of Specific Field Applications covers variety of interesting subjects, which cannot be categorized elsewhere. The strong topic of Soil Reinforcement Using Geosynthetics clearly shows the widening of the applicability of the soil reinforcement technology by gaining some novel applications in foundation and soil improvement.

The requirements of safety and serviceability must be met by geotechnical designer. Each geotechnical structure, in the endless variety of natural occurrences that define the boundary conditions of geotechnical problems, is a unique and separate challenge in a sense of correct determination of limit states. Guidance, codes or prescriptions on the identification of limit states are not necessarily the adequate advises as each specific design check must be well thought out and based on the fundamental understanding of soil mechanics. Across the overview of the contributions to this session we can see the struggle of the designers to understand the key risks and the probabilities for the occurrence of limit states. Further efforts are needed not only to understand the soil behaviour as an extremely complex natural material but also to better understand the circumstances of actions, which can produce the loads acting on geotechnical structures. Among all these challenges there is only a single pivot point; that is the decision of geotechnical designer to keep all these uncertainties within the allowable and acceptable limits.

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