General Report of TC 207
Foundations and Retaining Structures

Rapport général du TC 207
Fondations et ouvrages de soutènement

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ABSTRACT: Forty nine papers were included in the theme Soil Structure Interaction. These papers were divided into those related to foundations and retaining structures. The number of research papers and case histories are almost equal, showing equilibrium between academicians and practicioneers. Different types of foundations are presented, as well as different types of retaining structures.

RÉSUMÉ : Quarante neuf articles ont été inclus dans le thème « Interaction Sol-Structure ». Ces documents ont été divisés entre ceux qui sont liés aux fondations et ceux liés aux ouvrages de soutènement. Le nombre d´articles de recherche et d'études de cas sont presque égaux, montant l'équilibre entre les universitaires et les practiciens. Sont présentés différents types de fondations, ainsi que différents types d'ouvrages de soutènement.

KEYWORDS: soil-structure interaction, foundation, retaining structure, excavation.

1 INTRODUCTION

Foundations and retaining structures are traditional and widely used geotechnical structures in which soil-structure interaction plays a major role. For this reason, this technical session was organized by TC 207 – Soil Structure Interaction.

A total of 49 papers were included in this session, 12 focused on foundations and 37 about retaining structures. Contributions came from 28 countries, divided regionally as presented in Figure 1. Almost ¾ of all technical papers come from Europe.

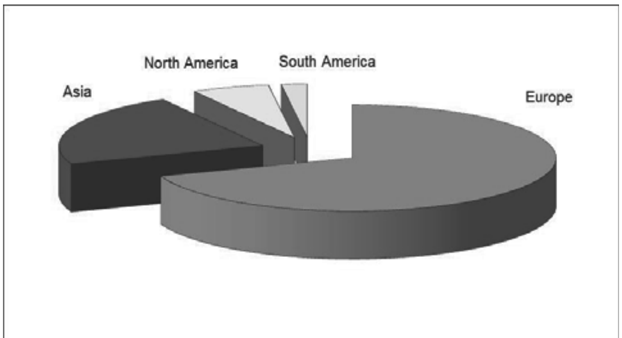

Figure 1. Origin of published papers: Europe – 39, Asia – 11, North America – 3 and 1 – South America.

23 papers present case histories and 26 research results, which show a desired equilibrium between academia and practice.

This report includes:

- A brief summary of the papers related to foundations;
- Some selected topics related to foundations;
- A brief summary of the papers related to retaining structures;
- Some selected topics related to retaining structures;
- Conclusions.

2 BRIEF REVIEW OF PAPERS RELATED TO FOUNDATIONS

12 papers focusing on foundations were selected for this session, 5 of them describing case histories and 7 presenting research results. Variable topics were presented and discussed, including shallow and deep foundations, as well as soil structure intereaction, specially the interaction between foundations and deep excavations.

M. Bidasaria presents a case history about the cofferdam for the Indira Sagar Project in India. This cofferdam was built as a gravity dam, using precast hollow concrete blocks on the upstream and downstream faces. Between the two faces, rubble was filled and later grouted by a cement-sand mixture, forming a so called stonecrete. The paper presents interesting constructive details about the construction of the cofferdam.

E. M. Comodromos et al. present numerical simulations to evaluate the influence of diaphragm wall construction on adjacent buildings. The 3D simulations are specific about the excavation phase, where soil is substituted by bentonite slurry, and the concrete tremied into the pannel. Obtained results showed maximum settlements in the order of 5 mm, for a 6 story building founded on direct footings located closely to the wall.

F. Cuira and B. Simon present an analytical model to evaluate soil reinforced by vertical inclusions, considering the interaction between the reinforced and un-reinforced soil along their boundary. An analytical method is compared to 3D FE simulations and good results are obtained. Further research using centrifugues is recommended in the conclusions.

W. Guo and J. Chu present results of model tests of suction caissons, focusing on shallow water for near shore use. The obtained results were in good agreement with an analytical results.

G. Hannink and O. Oung present a case history with prediction and monitoring results of the induced movements of a 9 story high apartment building, due to excavation of a 20 m deep closely located (7m distance) excavation, retained by strutted diaphragm walls. Measured horizontal and vertical movements of the apartment building were in the order of 10 mm.

Horn-Da Lin et al. present numerical simulation results, where the influence of a deep excavation on nearby located buildings is evaluated. The excavation depth is around 20 m. As benchmark, results of a documented published case history are used, and good agreement was obtained. Horizontal wall deflections were in the order of 110 mm and maximum settlements at the surface, around 80 mm.

R. Katzenbach and S. Leppla describe results of ground heave and settlement due to excavations, building construction and de-construction. The measured behavior is time dependent and occurs during years and the magnitude of the displacements is in the order of several cm. The soil responsible for this time dependent behavior is the overconsolidated Frankfurt clay. An empirical formulation that approximately describes the time dependent behavior is also proposed.

M. Korff and R. Mair present building settlement results due to deep excavations in Amsterdam. The difference between ground surface and building response as a function of foundation is highlighted and a methodology to evaluate buildings response is presented. Surface settlements in the order of 70 to 110 mm are presented, while the piled building settles only in the order of 20 to 40 mm.

T. Mizutani and Y.Kikuchi describe shaking table model tests to test seismic behavior of caisson type quay walls. The aim of the tests was to verify the possibility to increase water depth in front of the quay after soil treatment – "solidification" in the caisson foundation. It was found, that six different factors affect the caissons improved by the "solidification". Further research will be performed to allow the development of a design methodology.

T. Pucker and J. Grabe present the structural optimization method applied to geotechnical engineering design. This use is new and, according to the authors, promising results were obtained, showing potential economy and/or improvement in performance.

V.Sesov et al. present a methodology developed for the evaluation of seismic response of historical monuments in Macedonia. 3 Case histories are presented, where this methodology was used.

A. Siemińska-Lewandowska et al. describe different uses of diaphragm walls: retaining structures and foundations. Vertical load test results are presented, with up to 7,5 mm settlement for 150% of the working load. Interesting retaining structures using T shaped diaphragm walls are also presented.

3 SELECTED TOPICS RELATED TO FOUNDATIONS

The papers presented related to foundations cover a wide range of issues and foundation types:

Direct foundations:

- Gravity "concrete" dam;
- shallow footings (influence by diaphragm wall construction; influence by nearby deep excavations);
- caissons – quay wall;
- suction caissons;

Soil treatment for vertical loads by rigid inclusions;

Deep foundations:

- Driven timber piles (influenced by nearby excavation);
- Precast concrete piles (influenced by nearby excavation);
- Barrettes and Diaphragm walls (as foundations and retaining structures);

Seismic design and retrofitting of different foundations;

Long term settlement and heave in highly overconsolidated clay;

Structural optimization technique – use of new technique to optimize foundations.

Two topics were selected, among this wide range presented, and are discussed in more detail.

Specifically seismic issues will not be discussed in detail in this session, as a specific session at this same conference deals with the theme.

3.1 *Influence of Excavations on Foundations*

The evaluations of *E. M. Comodromos et al.* showed that the construction of diaphragm walls alone lead to settlement of closely located direct foundations in the order of 5 mm. The approach presented considered complex 3D nonlinear modeling, where the excavated soil is replaced by bentonite slurry.

Aditionally to this theoretical aspect, it could be added that, in the field, several times, especially in sandy soil below the groundwater level or soft clays, the operation and movements of the excavation equipment (clam shell, etc) can generate temporary negative suction pressures, leading to "cave-ins" and additional settlements, that can be in the order of several cm.

M. Korff and R. Mair and *G. Hannink and O. Oung*, present monitoring results, as well as simulations of settlements induced by deep excavations.

The results presented show significant difference between measured settlements: *Korff and Mair* show settlements, in Amsterdam, at the ground surface of more than 100 mm and, at 10 m from a 31 m deep excavation, building settlements of almost 40 mm. *G. Hannink and O. Oung*, on the other hand, present settlement measurements, in Rotterdam, of less than 10 mm for a building located 7 m from a 20 m deep excavation. Both excavations are supported by braced diaphragm walls. Possible explanations for these differences are probably:

- Different soil profiles;
- Different excavation depths;
- Different diaphragm and bracing stiffnesses;

Appart from these rather obvious aspects, certainly:

- Different pile length: in the case of the excavation in Amsterdam, the piles are located well above the excavation bottom, but in the case of Rotterdam, pile toes are located almost at the same elevations;
- Location of the buildings in relation to the excavation. No specific information is available from Amsterdam, but in Rotterdam, the building is located close to the excavation, as can be seen in figure 2.

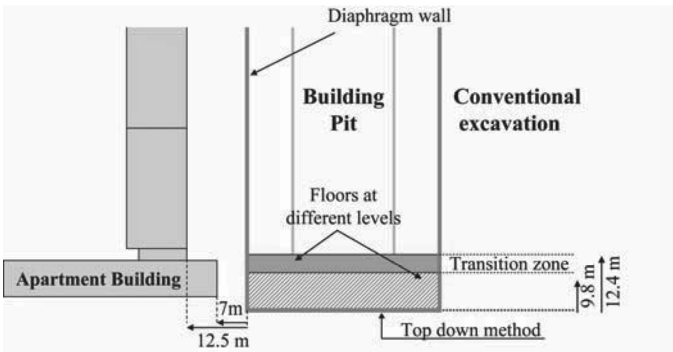

Figure 2. Position of building with relation to excavation (*G. Hannink and O. Oung*)

This last topic can be confirmed by the analysis of the results presented by *Horn-Da Lin et al*: the evaluations presented show, qualitatively, that close to the excavation borders, settlements are significantly lower than in the central part, as can be seen in figure 3. The arrows show an approximate possible position of the apartment building. It is clear that the settlements are significantly lower than in the central part.

Depending of the geometrical conditions, it becomes clear that 3D analyses may be necessary to adequately evaluate soil-structure interaction.

With relation to settlements induced by excavation, in the author´s opinion, the methodologies presented and discussed in *Korff and Mair* present tools to adequately predict building response to deep excavations, in the case of deep foundations.

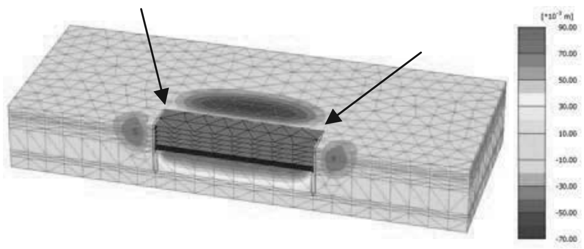

Figure 3. Settlements due to excavation (*Horn-Da Lin et al.*).

3.2 Loading and Unloading due to high rise buildings and excavations

The paper presented by *R. Katzenbach and S. Leppla* presents results of ground heave and settlement measurements due to excavations, building construction and de-construction. This behavior, which could be expected not only in Frankfurt, but also in other geological environments, was adequately documented during a significant time period for some buildings.

The first important issue, often neglected due to lack of reliable information, is the fact that unloading generates significant upward movement, in the order of some or even several cm.

The second issue is the time dependent behavior: a significant part of total displacements are measured at the end of construction, but between 30 and 50% of the observed behavior, occur during months or years after completion of the construction works.

Katzenbach and Leppla propose an empirical equation to represent this time dependent behavior. Just as an exercise, Figure 4 presents monitoring results and the equation proposed by *Katzenbach and Leppla*, and, additionally, settlements estimated using conventional consolidation theory. A consolidation coefficient at the recompression stage of $c_v = 9 \times 10^{-2}$ cm/s was backanalyzed from the measured settlements. This value can be considered representative of overconsolidated clays.

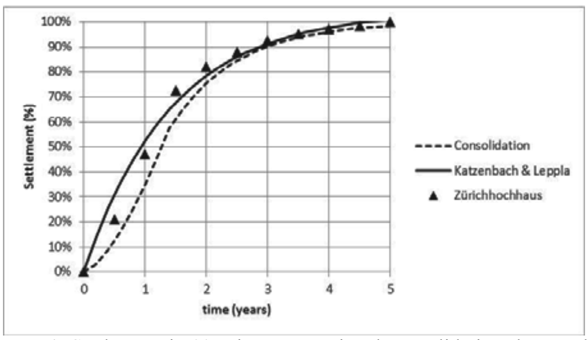

Figure 4. Settlement in % using conventional consolidation theory, the equation proposed by Katzenbach & Leppla and monitoring results.

From the discussion above, it becomes clear that, especially in urban environments, even for material considered relatively stiff, time dependent behavior cannot be neglected, depending of local geology.

4 BRIEF REVIEW OF PAPERS RELATED TO RETAINING STRUCTURES

37 papers focusing on retaining structures were selected for this session, 18 of them associated to case histories and 19 with research results. A broad range of topics related to retaining structures was presented.

M. Abramento et al. present a case history from Brazil, of a mixed retaining structure, reinforced earth at the top and anchored wall at the bottom, in a geotechnical environment of expansive soils. The case history includes laboratory tests of the expansive soils and anchor pull out tests, demonstrating that injection pressures have significant impact on anchor resistance. Monitoring results of the retaining structure are also presented, showing significant horizontal displacement of the reinforced earth face, and negligible horizontal displacements of the anchored stretch.

D. Alexiew and H. Hangen discuss a case history from Bulgaria, where reinforced earth structures were used as retaining structures. Relatively steep, 1H:10V, and high, over 20 m, structures are presented; constructive details are included. Design considerations, including seismic actions, are also discussed.

S. Baghery present the case history of the deep excavation, in marl and weather marl, associated to the construction of the “Tour Odeon” in Monaco. The excavation is more than 70 m deep and the excavation is supported by anchors.

Ö. Bilgin and E. Mansour discuss theoretical analysis of sheet piles in expansive soils. For a typical sheet pile wall, 10 m high and with an anchor level at 2,5 m, significant increases in anchor reactions and bending moments occur, as swelling pressure increases. Higher wall penetrations also become necessary. Swelling pressures were associated to the Plasticity Index and moisture content variations.

C. M. Chow and Y.C. Tan. present data related the performance of soil nails in weathered granite and fill. Several soil nail pull out tests were performed in excavations up to 20 m depth. Lateral friction measurement results varied between 50 and 140 KPa. A conservative correlation for lateral friction of 5 x SPT (in KPa) blowcount is also proposed.

I.P. Damians et al. discuss the influence of vertical facing stiffness on reinforced soil wall design. Numerical results showed that the loads at the base of the vertical facing and in the reinforcement are affected by the backfill and foundation material, and that the face stiffness also affects reinforcement tensile forces.

T. Durgunoglu et al. present a case history from Turkey, an over 20 m deep excavation close to the Bosphorus. Top down construction method was used, including excavation of rock sockets into rock with a uniaxial compressive strength varying between less than 10 MPa, up to almost 100 MPa.

R.J. Finno et al. discuss ground movements due to top-down construction in Chicago. For this type of construction, according to these authors, normalized horizontal movements of 0,15% to 0,2% are expected. Approximately 40% of these movements can be attributed to time dependent behavior of the concrete slabs. Significant movements can be associated to activities other than the excavation, like potholing.

R. Frischknecht et al. present an environmental impact evaluation, comparing a conventional concrete structure with a geosynthetic reinforced earth structure. The conclusion of the evaluation is that geosynthetic retaining structure shows a 63% to 87% lower environmental impact.

P.P. Ganne and X. Raucroix discuss the design of cantilever walls with a relief floor. For unsaturated, sandy, silty and alluvial clayey soils, an analytical design methodology is proposed, including pre-design recommendations.

A. Gomes Correia et al. present a case history of a 13 m high CSM anchored retaining wall built in Portugal. The CSM wall was built in fill, sands and weathered sandstone, reinforced by steel beams with a horizontal spacing of 1,1m. Maximum measured horizontal displacements were of 16 mm.

A. Guilloux et al. discuss the design, modeling and monitoring of the Tour Odeon, also presented by *Baghery*. A 3D numerical model is presented as main design tool. The use of the observational model with a maximum horizontal displacement of 17 mm is described.

E. Guler et al. present the case history of a 23 m deep excavation in Istanbul. 2D and 3D numerical modeling was used to evaluate interaction between 2 tunnels, a circular shaft and a deep braced excavation. 2D and 3D models were compared and the 2D analysis showed results on the safe side. Monitoring results obtained during construction yielded reduced horizontal displacements, in the order of 8 mm, compatible with the 3D FE analysis.

I. Gutjahr et al. discuss comparisons between subgrade reaction calculations, FE analysis using 2 different softwares and monitoring results of an anchored retaining structure of the Vieux Blanc-Mesnil Basin, in France.

V.A.Ilyichev and Y.A. Gotman present a method to optimize diaphragm wall displacements in deep excavations, by means of using soil cement mix in the active and passive parts of the soil massif. The dimensions and stiffness of the soil cement mix can be estimated using the proposed computational method. FE calculations were used to calibrate the proposed calculation method and good agreement was obtained.

Y. S. Jang et al. discuss two case histories from Korea of deep excavations supported by diaphragm walls. Excavations depths of 1 case is 20 m and of the other, 31 m. The retaining walls are concrete diaphragm walls, steel profiles and timber, and steel profiles and shotcrete. Horizontally, the walls are supported by anchors, in one case, and by steel struts, in the other case. Horizontal movements of 30 to almost 100 mm were measured. Forces in anchors and struts were also measured and compared to numerical simulations.

S. Jessee and K. Rollins present model tests to evaluate the passive pressure on skewed bridge abutments. The performed tests showed that a significant reduction was measured, as the skew angle increases. These results were compatible with numerical simulations and a simple correction factor is proposed.

M. Long et al. present a number of case histories of excavations in glacial tills of Ireland. 12 cases are presented, where horizontal displacements were measured. The displacements were, in most of the cases, less than 0,1% H. The conclusion of the authors are that design has been conservative and more realistic design methods and construction methods can lead to more economic design.

D. Loukidis and R. Salgado discuss the results of numerical simulations of earth pressure on walls supporting granular soils. The simulations, using Ottawa and Toyoura sands, with varying relative densities, showed that a minimum active pressure is obtained at 0,5% H displacement. But with higher displacements, in the order of 10% H, critical state inside the soil mass is mobilized. An equation is proposed to estimate the variation of the earth pressure coefficient as a function of the wall crest displacement.

R. Lüftenegger et al. present case histories of non conventional retaining structures. The structures were conceived based on the necessity to avoid the installation under neighboring buildings. 3D FE analyses were used to understand behavior. Good adherence between prediction and monitoring was not obtained, and for this reason the use of the observational method is recommended.

T. Maeda et al. discuss the use of inclined braceless retaining structures in sandy soil. Instead of using a vertical face, inclining it slightly, 10^o, allowed the excavation of an almost 10 m deep excavation without any bracing or anchor. An analytical design method was developed and verified by centrifuge tests. Monitoring results from the site showed that the design method lead to results on the safe side.

S. Nakajima et al. present a methodology to inspect exiting retaining structures. The methodology includes percussion tests and vibration tests, where the natural frequency of the structures is measured to evaluate its condition.

C.Y. Ou et al. discuss the mechanism of settlement influence zone due to deep excavation in soft clay. The USC model is used for parametric analyses a method for predicting the settlements is proposed.

J. Philipsen discusses the case history of a braced excavation, built under difficult conditions, in Copenhagen. The excavation was built in quaternary clays and sands, overlaying limestone.

A. Pinto et al. present a case history of an anchored excavation in Lisbon. The excavation was 13 m deep and supported by vertical steel profiles associated to a CSM wall and anchors. The geotechnical profile includes superficial fill, medium sands and sandstones, and GWT 5 m below the surface. The excavation was monitored through inclinometers, with maximum horizontal displacements close to the surface of around 40 mm.

Another paper by *A. Pinto et al.* present the case history of excavations for the Leixões Terminal in Portugal. 2 different solutions are presented: CSM panels with steel profiles and CSM panels with micropiles. The excavation is around 6,5 m deep and the geotechnical profile includes hydraulic fill placed on weathered schist. CSM UCS minimum measured values were of 4 MPa.

H. Popa et al. discuss a case history from Bucharest. 16 m had to be excavated to accommodate a 4 to 6 m deep basement mat and 2 basements. The subsoil profile included interbedded layers of medium to compact sands and medium to stiff clays, with groundwater level 2 to 3 m above the excavation bottom. An anchored diaphragm wall was designed, built and monitored, with maximum horizontal displacements of less than 10 mm.

C. di Prisco and F. Pisanò, present a new anchor type. FE analyses are used to evaluate the pull out behavior of the anchor. Based on the FE analyses, an analytical method is also developed and presented.

N. Sanvitale et al. discuss the role of the facing on the behaviour of soil-nailed slopes under surcharge loading, using small physical models in sand. Flexional and axial stiffness influence the performance of the soil nailing system.

T. Tanaka et al. present results of physical and numerical models, where 3D seepage effects influence stability. Uniform sand are used for the evaluations and results show that the 3D conditions differs from those of typical 2D conditions. Correction factors from an axisymmetric simulation to no axisymmetric conditions are also presented.

P. Turček et al. discuss case histories of deep excavations in Bratislava. Local subsoil includes superficial quaternary sediments, mainly gravel and sand, overlaying neogene marine sediments, mainly stiff clays. Groundwater is normally at shallow depth and its control is one of the main challenges for successful construction.

M J Turner and N A Smith present a case history of the stabilization of a gravity quay wall in the UK. The 17 m high wall, originally built at the end of the 19^{th} century, suffered stability problems since the mid 1980s, with horizontal displacements of around 400 mm. Evaluations showed that the difference between the high tidal variations, more than 6 m, and the groundwater level behind the wall, were leading to increasing horizontal displacements. Stabilization measures included groundwater lowering and installation of anchors.

L. Vollmert et al. discuss results of large scale in situ tests, as well as long term monitoring results of a reinforced earth structure. For the monitored cases, with full height panel walls as facing, the actual lateral stress measured is significantly lower than FE calculations or classic earth pressure theory, showing that current design methods are on the safe side and, possibly, a correction factor can be introduced to EBGEO design methodology.

G. Vukotić et al. present results of anchor bond measurements in different soils and anchor length. The influence of the fixed anchor lengths is evaluated, showing that longer anchors are less efficient than shorter anchors. A proposition or design methodology is presented, including possible use of single bore multiple anchors – "SBMA".

L. Warren et al. discuss the use of drystone retaining walls, including model tests performed in the UK. Different types of walls, based on their construction methods, horizontal, vertical and random, are discussed. The type of wall is presented as a sustainable type of structure, due to lack of mortar, use of local materials and providing habitat for animals and plants.

C. A. Wiggan et al. present a numerical evaluation of potential pore pressure reduction on retaining walls due to the flow between piles. Not considering a wall of secant of contiguous piles impermeable, lead pore pressure reductions that act on the wall. Results of parametric evaluations are presented, where the distance between the piles are varied, showing significant pore pressure reductions. This approach, however, leads to increased settlements at the surface.

C. Yoo and D.W. Jang discuss results of laboratory tests performed on reduced models, to evaluate the influence of rainfall on the performance of reinforced earth structures. Test results showed that wetting and drying cycles may have cause additional wall displacements, especially for structures with low safety factor.

5 SELECTED TOPICS RELATED TO RETAINING STRUCTURES

The technical papers related to retaining structures cover a wide range of topics, including:

Reinforced soil –5 papers;
Diaphragm walls – 4 papers;
Secant pile walls – 1 paper;
Sheet pile walls – 3 papers;
Soldier type walls – 3 papers;
Mixed in place soil structures – 5 papers;
Soil nailing and anchors – 3 papers;
Gravity and cantilver walls – 3 papers;
Others.

From this wide range, some topics were selected and are discussed in more detail:

- Horizontal displacements:
- Earth pressures;
- Soil nailing and anchor lateral friction;
- Soil-cement mixtures.

Unfortunately, not all papers present sufficient technical data, to allow analyses and comparisons.

5.1 Horizontal displacements

The selected papers present, in some cases, monitoring results, specifically, horizontal displacements, which are summarized in Figure 5 and 6.

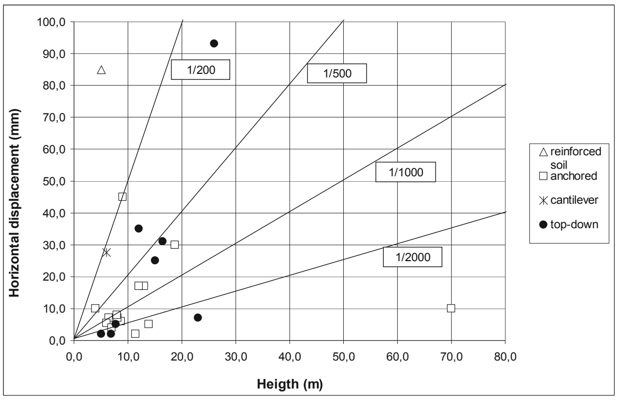

Figure 5.Horizontal displacements x excavation depths.

Very variable results can be seen; horizontal displacements / heights (H/D) from less than 1/2000 to more than 1/200 were presented.

No clear tendency can be identified in figure 5. Visually, one possible conclusion is that deeper excavations, apparently, present lower D/H values, meaning that this type of construction is, due to its complexity, designed and built with higher safety margins and possibly, more rigid. Figure 6 below presents the same data, showing normalized horizontal displacements and excluding 1 extreme value: the 70 m high excavation (in rock) presented by *S. Baghery* and *A. Guilloux et al.*

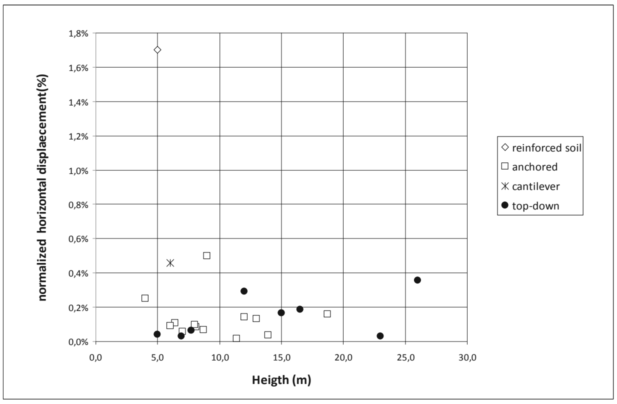

Figure 6. Normalized horizontal displacements with respect to excavation heights (depths)

In comparison to other retaining structures, relatively high horizontal displacements (85 mm =>1,7%) were measured for a reinforced earth structure (*M. Abramento et al.*). However, this magnitude of displacement, according to common practice, can be considered normal for reinforced soil structures (Sayão et al., 2004).

Figure 7 shows the same results, plotted together with the data presented by Long (2001).

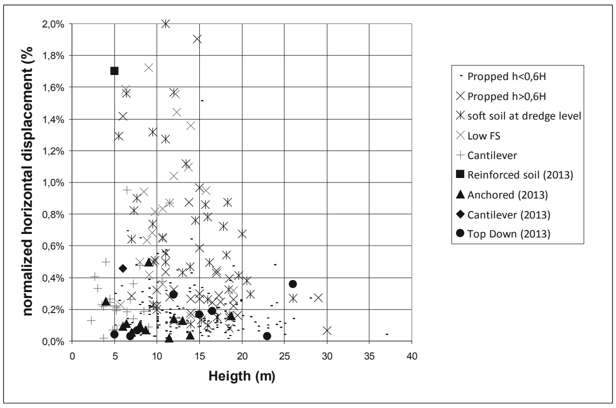

Figure 7. Normalized horizontal displacements x excavation heights, including data presented by Long (2001).

It can be seen that the published horizontal displacements are compatible with several other measurements as compiled and published in 2001.

Other published databases are also compatible with the presented data:

- Leung and Ng (2007): 0,13 %H to 0,23 % H, depending on soil stiffness;
- Wang et al. (2010): 0,27%H to 1,5%H, depending of retaining structure type and soil stiffness.

Common conclusion of Long (2001), Leung and Ng (2007) and Wang et al. (2010) are that horizontal displacements are affected mainly by safety margins, system stiffness, soil type and construction method.

Finally, the conclusions presented by *R.J. Finno et al.* are interesting: for the cases where small displacements are measured, a significant part of these displacements may be caused by time dependant behavior of concrete floor slabs.

5.2 Earth Pressures

Four papers deal specifically with earth pressures: *Ö. Bilgin and E. Mansour*, *S. Jessee and K. Rollins*, *D. Loukidis and R. Salgado*, *T. Maeda et al.*

Ö. Bilgin and E. Mansour discuss theoretical analysis of sheet piles in expansive soils. The presented analyses are based on a correlation between the plasticity index (PI) and swelling potential. The analyses presented assume that swelling pressure will act in the zone where moisture varies, relatively close to the surface. Figure 8 presents results of the authors analyses, correlating anchor loads of sheet pile wall to the PI

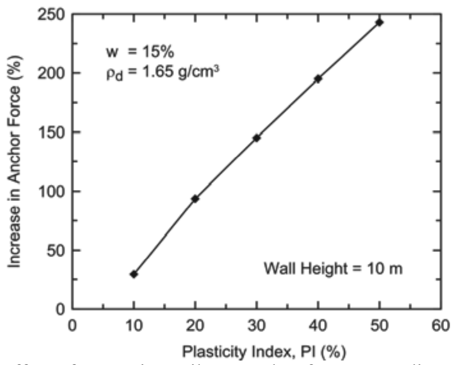

Figure 8. Effect of expansive soils on anchor force, according to *Ö. Bilgin and E. Mansour*

S. Jessee and K. Rollins present model tests to evaluate passive earth pressure on a "skewed" surface. Figure 9 presents a proposed reduction factor for the passive force, as a function of the skew angle.

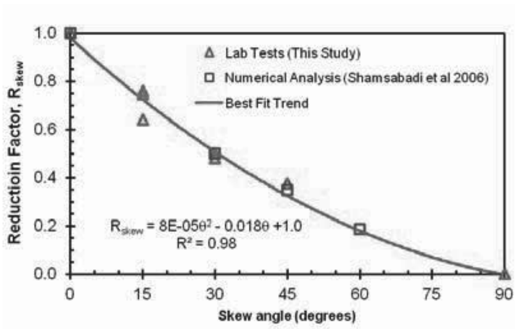

Figure 9. Test results presented by *S. Jessee and K. Rollins*.

The performed tests showed that a significant reduction was obtained as the skew angle increases. These results were compatible with numerical simulations and a simple correction factor is proposed. Peak passive pressure was developed at 2,5% to 3,5% of abutment height. Significant reductions in passive pressure were measured beyond peak (4% to 6%), with a residual stress around 40%.

Results are interesting, but direct use of results for design shall be evaluated with care.

D. Loukidis and R. Salgado present the results of sophisticated numerical simulations of variation of earth pressure on walls supporting granular soils. Figure 10 present one of the presented outputs and some interesting qualitative conclusions can be drawn:

For horizontal displacements of around 0,5%, minimum lateral earth pressure develops. Considering K_0 around 0,5, K_a results around 0,125. As horizontal displacement increases, K_a results in the order of 0,2. The authors state that the minimum earth pressure coefficient should not be used, at least for ultimate limit state design. However, when analyzing figure 7, where a significant number of case histories showed horizontal displacements of less than 0,4 %, possibly some optimization in terms of design earth pressures can be possible.

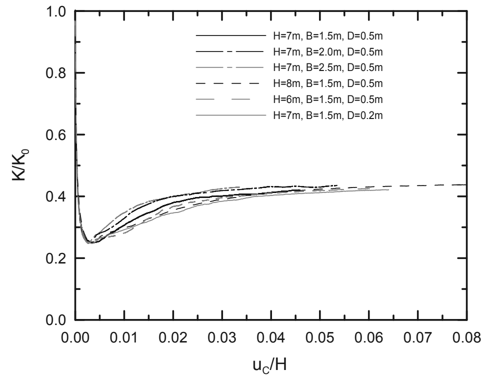

Figure 10. Results presented by *D. Loukidis and R. Salgado*: Variation of normalized lateral earth pressure coefficient with wall crest displacement from analyses with medium dense Toyoura sand (D_R=60%)

T. Maeda et al. discuss the use of inclined braceless retaining structures in sandy soil. The presented evaluations showed that significant reduction in earth pressures acting on a cantilever wall can be obtained by inclining the wall facing. Figure 11 present horizontal displacements measured on model tests. It can be seen that, even for a reduced inclination of 10^o, horizontal displacements reduced around 30%.

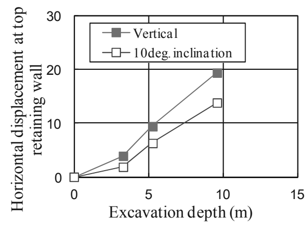

Figure 11. Relationship between excavation depth and horizontal displacement of retaining walls, considering horizontal and inclined structures, presented by *T. Maeda et al.*

Figure 12 presents earth pressures for the inclined and the vertical structure. It can be seen that, especially for deeper excavations, a significant reduction in earth pressures occurs.

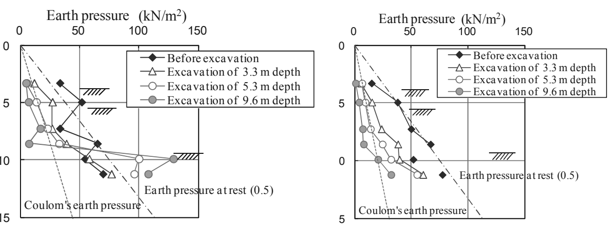

Figure 12. Earth pressures for vertical and inclined structure, presented by *T. Maeda et al.*

In the author´s opinion, the simple approach of inclining slightly a cantilever structure can bring significant saving, should be further investigated and can be used in practice.

5.3 Soil nailing and anchor lateral resistance

C. M. Chow and Y.C. Tan. present data related to the performance of soil nails in weathered granite and fill. Several soil nail pull out tests were performed in excavations of up to 20 m depth. Figure 13 presents typical pull out results, showing that maximum load is obtained between 4 and 6 mm of displacement. After a peak value, only slight increases can be seen.

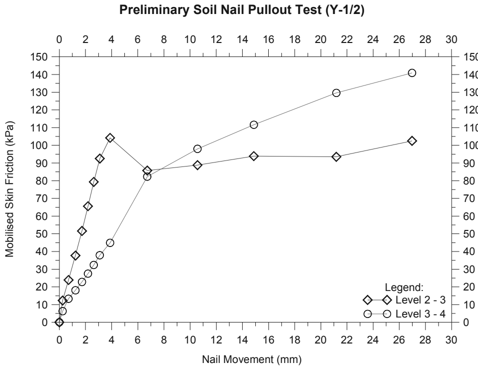

Figure 13. Pull out test results, presented by *C. M. Chow and Y.C. Tan*.

Lateral friction measurement results varied between 50 and 140 KPa. A conservative correlation for lateral friction of 5 x SPT (in KPa) blowcount is also proposed.

These results are comparable with data presented in Ortigão and Sayão (2004): for sands, approximate ratio between SPT blowcount and lateral friction is around 5, and for clays, around 3,4.

M. Abramento et al. presented results of pull out tests of anchors for different grouting conditions and resulting lateral friction between 80 KPa and 140 KPa. The soil where the anchors were built has an approximate SPT blowcount between 20 and 30.

Finally, just for comparison, Décourt (1982) presented a correlation between SPT blowcount and lateral friction for piles:

Lateral friction = 10 x (SPT / 3 + 1).

Figure 14 presents graphically the lateral frictions and corresponding SPT blowcount values.

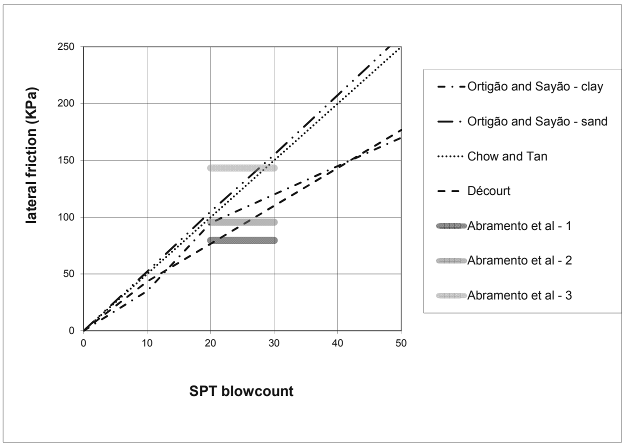

Figure 14. Lateral friction results, presented by *C. M. Chow and Y.C. Tan*, including values published by Ortigão and Sayão (2004) and Décourt (1982).

A. Gomes Correia et al. present results of anchor tests in medium dense sands, resulting in a lateral friction of 275 KPa. Similar results and even higher lateral frictions are presented by *G. Vukotic et al.* for tests in different soils. Unfortunately, there is no specific information available about the SPT blowcount, but probably results will be well above the graphs presented in Figure 14. Possibly, this difference occurs due the use of pressure grouting.

Even considering the limitations of the SPT blowcount as geotechnical design parameter, the correlations between the SPT and lateral friction proposed by *C. M. Chow and Y.C. Tan* seem compatible with previously published results for soil nails. Grout injection influence, in the author´s opinion, shall be further investigated. Special anchor devices, like the one presented by *C.di Prisco and F. Pisanò* work completely different from cylindrical nails / anchors and further research is necessary to allow reliable comparisons.

5.4 Soil mixing compressive strength

A. Gomes Correia et al. present a case history where CSM material, with a cement consumption of 600 kg/m^3, was tested and a minimum uniaxial compressive strength of 4 MPa was obtained. Minimum E_{50} values were 1 GPa. Unfortunately, few results with information about this important design parameter were presented. As complementary information, Figure 15 presents data published by Bilfinger et al, with results from uniaxial compressive strength tests results in soil treated with jet grouting technology.

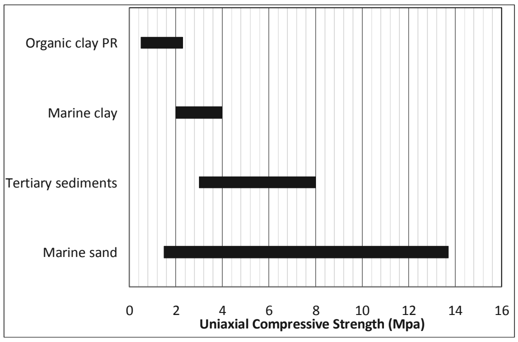

Figure 15. Uniaxial compressive strength, Bilfinger et al. (2012).

It can be seen that soil type has major influence on uniaxial compressive strength, specially the organic matter content.

6 CONCLUSIONS

The technical papers included in this session cover a wide range of topics. In items 3 and 5 some of these topics were discussed in more detail.

Some conclusions may be drawn with relation to three areas:

Design: No detailed design procedures were presented, but some interesting conclusions can be drawn from the published papers:

- Numerical modeling is a common tool to model soil and structure interaction;
- Limit equilibrium analysis and beam-spring models continue to be used in design practice;
- The observational method, meaning, the use of monitoring to control and, possibly, adjust the design, is a widespread design “phylosophy”.

Construction: Different construction techniques and structures are discussed and presented:

- Foundations: direct footings, caissons and suction caissons, barretes and diphragm walls, soil treatment by rigid inclusions;
- Retaining structures: diphragm walls, secant pile walls, sheet pile walls, soldier type walls, mixed in place structures, anchored and nailed structures, reinforced soil, cantilever and gravity walls.

Most of these construction techniques and structures are already well known and the focus and innovation presented in the papers are performance, size, depth and proximity to other structures. Two exceptions are: soil treatment techniques, used in different conditions and suction caissons.

Research: Different research themes were presented, but one of the important investigated issues is earth pressures for different conditions. Another topic researched are mathematical models associated to techniques to optimize design procedures, and not to represent soil constitutive models.

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Wang, J., Xu, Z., and Wang, W. (2010). "Wall and Ground Movements due to Deep Excavations in Shanghai Soft Soils." *J. Geotech. Geoenviron. Eng., 136*(7), 985–994.

APPENDIX - List of papers submitted for this session:

FOUNDATIONS:

Bidasaria, M. Foundation and Geotechnical Problems, Geology, Design and Construction of Coffer Dam on Narmada River for Indira Sagar Project in Central India.

Comodromos E. M., Papadopoulou, M.C., Konstantinidis, G.K. Effects on adjacent buildings from diaphragm wall installation.

Cuira, F., Simon, B. Prise en compte des effets de bord dans un massif renforcé par inclusions rigides.

Guo, W., Chu, J. Suction Caisson Installation in Shallow Water: Model Tests and Prediction.

Hannink, G., Oung, O. Displacement of an apartment building next to a deep excavation in Rotterdam.

Lin, H.D., Dang, H.P., Hsieh, Y.M.Assessment of Ground and Building Responses Due to Nearby Excavations Using 3D Simulation.

Katzenbach, R., Leppla, S. Deformation behaviour of clay due to unloading and the consequences on construction problems in inner cities.

Korff, M., Mair, R.J. Response of piled buildings to deep excavations in soft soils.

Mizutani, T., Kikuchi, Y. Shaking table tests on caisson-type quay wall with stabilized mound.

Pucker, T., Grabe, J. Structural Optimization in Geotechnical Engineering.

Sesov, V., Cvetanovska, J., Edip, K. Geotechnical aspects in sustainable protection of cultural and historical monuments.

Sieminska-Lewandowska, A., Mitew-Czajewska, M., Tomczak, U. Various use of Diaphragm walls for construction of multilevel road junction - design and monitoring of displacements.

RETAINING STRUCTURES

Abramento, M., Fujii, J., Cogliati, B., Assakura, V. Design, Construction and Monitoring of a Mixed Soil-Reinforced and Anchored Retaining Wall in Expansive Soil.

Alexiew, D., Hangen, H. Design and construction of high bermless geogrid walls in a problematic mountainous seismic region in Bulgaria.

Baghery, S. La Fouille de la Tour Odéon à Monaco : Les quatre éléments remarquables de as conception.

Bilgin, Ö., Mansour, E. Anchored sheet pile wall design in expansive soils.

Chow, C.M., Tan, Y.C. Performance of Soil Nails in Weathered Granite and Fill.

Damians, I.P., Lloret, A., Josa, A., Bathurst, R.J. Influence of facing vertical stiffness on reinforced soil wall design.

Durgunoglu, T., Kulac, F., Ikiz, S., Akcakal, O. Top Down Construction Alongside Of Bosphorus – A Case Study.

Finno, R.J., Arboleda, L. Kern, K., Kim, T., Sarabia, F. Computed and observed ground movements during top-down construction in Chicago.

Frischknecht, R., Büsser-Knöpfel, S., Itten, R., Stucki, M. Comparative Life Cycle Assessment of Geosynthetics versus Concrete Retaining Wall.

Ganne, P.P., Raucroix, X. Design of inverted T-shaped Cantilever Wall with a Relief Floor.

Gomes Correia, A., Tinoco, J., Pinto, A., Tomásio, R. An Anchored Retaining Wall in CSM.

Guilloux, A., Porquet, M., De Lavernée, P., Lyonnet, P., Roman, P. Conception, modélisation et auscultation d'une très grande excavation à Monaco.

Guler, E., Osmanoglu, U., Koç, M. A Case Study of 3D FE Analysis of a Deep Excavation Adjacent to a Tunnel Construction.

Gutjahr, I. Doucerain, M., Schmitt, P. Heumez, S., Maurel, C. Instrumentation de la paroi moulée du bassin de Blanc-Mesnil : retro-analyse et calage des modéles de calcul.

Ilyichev, V.A., Gotman, Y.A. Calculation method of optimization the soil-cement mass dimensions to reduce the enclosure displacements in deep excavations.

Jang, Y.S., Choi, H.C., Shin, S.M., Kim, D.Y. Case Studies of Complicate Urban Excavation from Design to Construction.

Jessee, S., Rollins, K. Passive Pressure on Skewed Bridge Abutments.

Long, M., O`Leary, F., Ryan, M., Looby, M. Deep excavation in Irish glacial deposits.

Loukidis, D., Salgado, R. Active earth thrust on walls supporting granular soils: effect of wall movement.

Lüftenegger, R., Schweiger, H.F., Marte, F. Innovative solutions for supporting excavations in slopes.

Maeda, T., Shimada, Y., Takahashi, S., Sakahira, Y. Design and Construction of Inclined Braceless Excavation Support Applicable to Deep Excavation.

Nakajima, S., Shinoda, M., Abe K. Inspection of structural health of existing railway retaining walls.

Ou, C.Y., Teng, F.C., Hsieh, P.G., Chien, S.C. Mechanism of Settlement Influence due to Deep Excavation in Soft Clay.

Philipsen, J. Establishing a high risk construction pit in a hurry.

Pinto, A, Tomásio, R., Godinho, P. Innovative Solution of King Post Walls combined with CSM Panels.

Pinto, A. Pita, X., Neves, M. Unusual Geotechnical Solutions at the Leixões Cruise Terminal.

Popa, H., Manea, S., Batali, L., Olteanu, A. Aspects on designing and monitoring a deep excavation for a highly important structure.

di Prisco, C., Pisanò, F. FEM – aided design of a novel device for soil anchoring.

Sanvitale , N., Simonini, P., Bisson, A., Cola, S. Role of the facing on the behaviour of soil-nailed slopes under surcharge loading.

Tanaka, T., Kusumi, S., Inoue. K. Effects of plane shapes of a cofferdam on 3D seepage failure stability and axisymmetric approximation.

Turček, P., Frankovská, J., Súľovská, M. Stability and dewatering problems of deep excavations in Bratislava.

Turner, M.J., Smith, N.A. Managed remediation of a large Victorian gravity quay wall using the observational method.

Vollmert, L., Niehues, C. Concrete panel walls – Current development on interaction of earthworks, geosynthetic reinforcement and facing.

Vukotić, G., González, J., Soriano, A. The influence of bond stress distribution on ground anchor fixed length design. Field trial results and proposal for design methodology.

Warren, L., McCombie, P., Donohue, S. The sustainability and assessment of drystone retaining walls.

Wiggan, C., A., Richards, D.J., Powrie, W. Numerical modelling of groundwater flow around contiguous pile retaining walls.

Yoo, C., Jang, D.W. Geosynthetic Reinforced Soil Wall Performance under Heavy Rainfall.