Concrete panel walls – Current development on interaction of earthworks, geosynthetic reinforcement and facing

Comportement des parements béton de murs de soutènement en sols renforcés – interaction entre les sols remblayés, le renforcement et le parement

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ABSTRACT: Reinforced soil structures have become an appropriate construction method for infrastructural buildings. Several types of facing are commonly used. Full height panels or segmental panels with a certain height are mainly used for flyover constructions and bridge abutments. The design of the constructions depends on the stiffness of the facing element. Large scale test with loads up to 450 kPa at laboratory conditions as well as on site test with one year of continuous measurement under weathering conditions are presented and compared to analytical design and calculations using commercial finite element software. The results indicate that this type of structure can be designed on the safe side using current design standards and benefits given by the interaction of stiff geogrid reinforcement and soil.

RÉSUMÉ : Les ouvrages en remblai renforcé sont devenus une méthode de construction adaptée aux projets d'infrastructures. Plusieurs types de parement sont couramment utilisés. Des panneaux de pleine hauteur, ou panneaux segmentaires avec une certaine hauteur, sont principalement utilisés pour les constructions surélevées et les culées de pont. La conception de ces ouvrages dépend de la rigidité de l'élément de parement. Cet article présente des essais réalisés à grande échelle avec des charges allant jusqu'à 450 kPa, en condition de laboratoire ainsi que sur site, avec une année de mesure en continu en condition de vieillissement. Les résultats sont comparés à la conception analytique et aux calculs réalisés à l'aide d'un logiciel commercial d'éléments finis. Les résultats montrent que ce type d'ouvrage peut être conçu de façon sécuritaire suivant les normes de conceptions actuelles et les avantages apportés par l'interaction d'une géogrille rigide avec le sol.

KEYWORDS: geosynthetic reinforced walls, concrete, design, testing, execution, DIN EN 14475, EBGEO, BS8006

1 INTRODUCTION

Creating robust and sustainable constructions in geotechnical engineering has become an upcoming topic in terms of reduction of carbon footprint as well as on cost reduction on PPP projects. Combining technologies for slim precast concrete panels with stiff geosynthetic reinforced walls allows for the use of local and in some cases even treated soils.

In the last years recent research has led to further understanding of reinforcing interaction, leading to design approaches published in EBGEO and allowing for a reduction of lateral stress on the facing constructions.

Design of precast panels in practice requires attention to the transport phase as well as on the construction steps during execution and serviceability limit state.

2 DESIGN OF REINFORCED STRUCTURES

DIN EN 14475, the British design code BS8006 as well as the German design recommendations EBGEO are state-of-the-art standards in order to safeguard the constructions.

Special attention has to be paid to the design of the facing, as these elements are directly exposed to the environment and deformations of the construction can be seen immediately. The mentioned design codes do not give a unique calculation of lateral stress acting on the facing elements. DIN EN 14475 already differentiates between several types of facing elements, depending on the stiffness:

- Rigid facings, e.g. full height panels
- Semi-flexible facings, e.g. concrete blocks without rigid connections, gabion baskets
- Flexible facings, e.g. wrap-around method

The lateral stress has to be different from the active earth pressure calculated according to Rankine´s theory due to the geosynthetic reinforcing elements, "nailing" the fictive failure zone. As this becomes a hyper static system, the earth pressure distribution on the facing is indifferent.

Nevertheless, the design has to be proper and worked out on the safe side, so additional information has to be gained from sites and large scale tests, especially taking influence of water, subsoil settlements and installation conditions (compaction, construction steps, etc.) into consideration.

3 CURRENT DEVELOPMENT

3.1 *Lateral stress on facing*

Pachomow et al. (2007) collected several test-field data of executed walls in heights between 2.0 m and up to 30 m, with information concerning the lateral pressure on the facing given. It is interesting that the lateral stress gained by self-weight of the construction remained within a range of up to 50 kPa, although significant higher values would have been expected especially for high walls.

Normalising the height of all test field data, and recognising that nearly all data are linked to non-cohesive soils as well as to slope inclinations between 70° and 90°, the relationship between the vertical and lateral stress can be compared to the active earth pressure coefficient, being expected in the range of 0.2 and 0.35, depending on the theory and boundary conditions. Figure 1 indicates that the normalised lateral stress on the facing is significantly less for reinforced structures. Furthermore, the data indicate that the absolute height might not have a decisive influence at all, but the normalised one.

Ruiken et al. (2010) have demonstrated the arching effects close to the facing of a geogrid-reinforced soil sample, using biaxial tests at plane strain conditions. The degree of arching and the absolute value of stress reduction depends on the lateral movement of the facing as well as on the degree of reinforcement, see also Bussert (2006).

Based on full scale tests using several commonly known reinforcing products varying in a small range of nominal strength from 40 kN/m up to 55 kN/m a clear tendency can be obtained concerning the stiffness, described by the secant modulus J of the products:

$$J\ [\mathrm{kN/m}] = \text{strength } F\ [\mathrm{kN/m}]\ /\text{strain } \varepsilon\ [\%] \qquad \text{(eq. 1)}$$

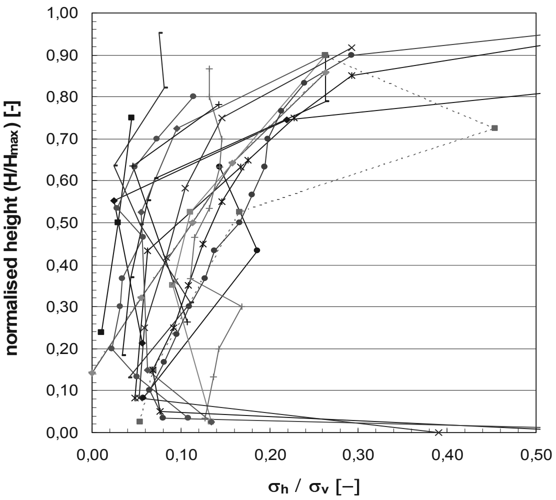

Figure 1. Compiled data of lateral stress to facing, presented at normalized height and relationship between normal load σ_h and lateral pressure σ_v.

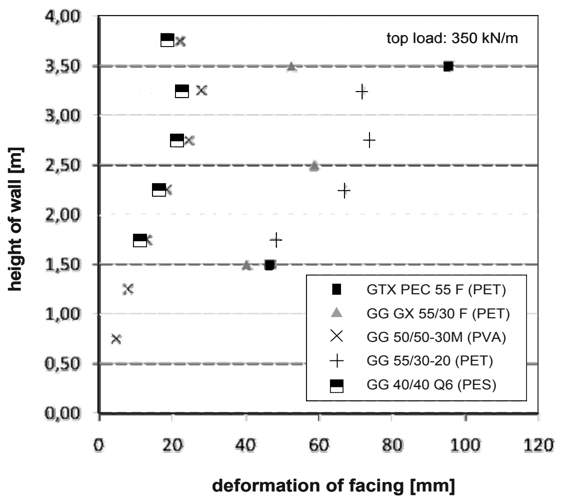

Figure 2. Deformation of full scale walls with semi-flexible facing, depending on the product (Pachomow & Herold, 2009).

Figure 2 shows preliminary results of a 4.0 m high construction using a weak facing system and a load beam 1.0 m behind the wall surface, applying a top load of up to 350 kPa. The deformation varies significantly depending on the type of product. All products performed satisfactory in an acceptable range, while some products allow for higher loads and show an enhanced performance in terms of serviceability.

4 EUROPEAN DESIGN CODES

Exemplarily the mostly used design codes in Europe, BS 8006 and EBGEO 2010, dealing with reinforced earth will be discussed in the following.

Following the basic principles of designing reinforced soil, based on the results shown in Chapter 3, EBGEO allows further for a reduction of the lateral stress as compared to the Rankine´s active earth pressure. The well-known coefficient for the lateral active earth pressure k_{ak} is just used as basic parameter (eq. 2), taking the inclination of the wall as well as the soil parameters (e.g. angle of internal friction φ´) into consideration. The correction factor η_G as per Figure 3 is then applied, knowing well that using the lateral active earth pressure k_{ak} as basic parameter is just an interim solution up to full understanding and modeling of reinforced earth. In the upper part of the construction respectively on the actual construction level, the earth pressure due to compaction (not shown in Figure 3, typically up to 25 kPa) becomes decisive, but is going to be superimposed by the earth pressure resulting from the self-weight of the construction.

$$E_{Facing} = (\eta_g * ka_{gh,k} * \gamma_k * H_i * \gamma_G + \eta_q * k_{aqh,k} * q * \gamma_Q) * l_v \qquad \text{(eq. 2)}$$

with

E_{Facing}	Earth pressure on facing [kN/m]
η_g, η_q	Matching coefficient [-]
$k_{agh,k}$, $k_{aqh,k}$	Coefficient active earth pressure [-]
γ_k	Weight of the soil [kN/m³]
H_i	Covering [m]
q	Traffic load [kN/m²]
γ_G, γ_Q	Partial safety factor DIN 1054 [-]
l_v	Vertical space between layers [m]

	Correction Factor		
	η_g		η_q
	0 < h ≤ 0.4 H	0.4 H < h ≤ H	
rigid ——	1.0	1.0	1.0
semi flexible –·–	1.0	0.7	1.0
flexible – – –	1.0	0.5	1.0

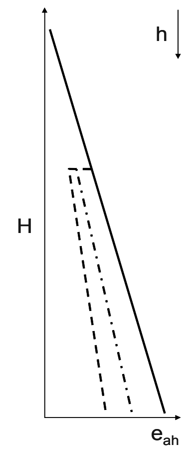

Figure 3. Correction factors applied to k_{ah} according to EBGEO, 2010.

In opposition to EBGEO, the earth pressure following BS 8006 is calculated using the active earth pressure coefficient k_{ah} for the structure, superimposed by k_0 in the upper part. The reduced stress acting on the front of the construction depending on the stiffness of the wall-facings is considered by a reduction of the connection stress, e.g. by 25 % in the upper 60 % of wall height using wrap-around method.

The BS 8006 concept results in having the highest connection stress requirements at the footing of the construction, while research and lessons learned from failures indicate to have the highest stress levels at approx. 1/3 height starting from the bottom of the walls.

Nevertheless, the reduction of the lateral earth pressure of both concepts has a direct influence on the design of reinforced walls and allows for steep walls with a friction connection between e.g. blocks and reinforcement.

5 LARGE-SCALE TEST IN SITU

5.1 *Design and set-up*

In addition to the large scale tests on full height panel walls performed by Pachomow, a full scale trail has been performed by KWS Utrecht, Netherlands, supported by NAUE, Germany. While under laboratory conditions high loads up to 450 kPa could have been applied to the structure, in situ the influence on installation procedure, weathering (changes of moisture-content and temperature) and long term effects caused by the thermoplastic characteristics of the used high strength Polyester geogrid could be investigated. Figure 4 gives the cross section of the test set-up for the in-situ test with geometry comparable to the laboratory test.

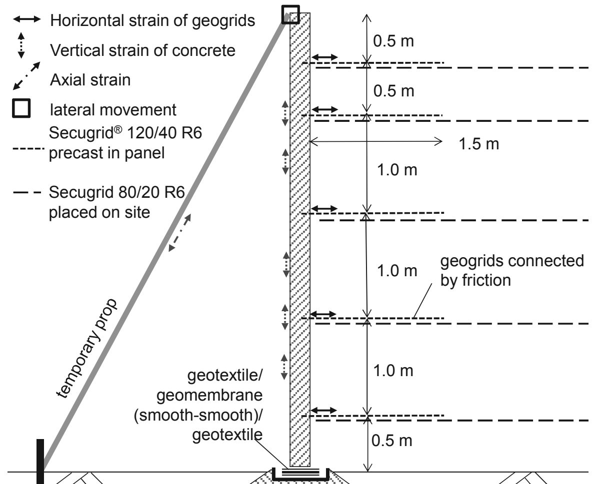

Figure 4. Test setup full height panel wall, KWS Utrecht

To reduce the required amount of structural steel for the construction, the panel has not been designed using conventional design methods, but taking the results from laboratory test explained in Chapter 4 into consideration. Therefore, the design configuration has been optimized, assuming the load distribution given in EBGEO, applying an overall safety to the earth pressure distribution of 1.5 (assumption).

The load distribution has been applied to the panel design, testing several static systems and designs to optimize the amount of required structural steel. At the end, the system could be optimized for transport steel only.

To make the system as easy as possible, only 1.5 m long strips of the reinforcement have been precast to the concrete (Figures 4, 5a). The required length of the reinforcement to fit the overall safety according to EBGEO has been placed on site, just overlapped by friction. For the earth pressure distribution, satisfactory pull-out resistance of the strips from the reinforced backfill has to be ensured.

Several types of instrumentation have been used, taking the static principle of $\Sigma H = 0$ into consideration. The sum of forces acting on the backside of the panel shall be equal to the forces acting on the geogrids, the temporary prop, added by the friction on the toe of the panel.

Therefore, the toe of the panel has been designed as plain bearing, using geosynthetic components for sliding purposes with tested and well-known friction parameters for back-analysis of the forces acting at the toe. Temporary wooden wedges, applied during placing the panel, have been removed after the installation of the first 1.5 m of backfill material, so lateral movement of the panel toe was possible but has not been observed.

Further on, it had to be ensured that the material used is applicable to the use in concrete, as it is given here by independent testing and applying a partial reduction factor for environmental influences to the polyester material of 1.18 [-].

To predict stress, strain and lateral movement of the stage construction, finite element (FE) analysis have been worked out using PLAXIS 2D, 2011. These calculations are also usable for comparing the measurements and predictions for the reference times $t_0 \ldots t_5$ charged as indicator for significant changes in the static system with construction stage and time, Figure 5.

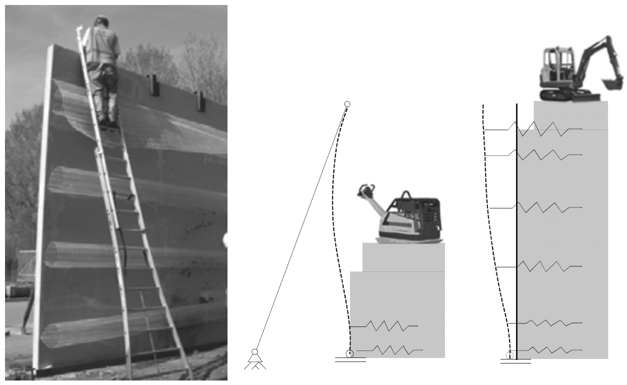

Figure 5a. Installation procedure and expected deformations of wall.

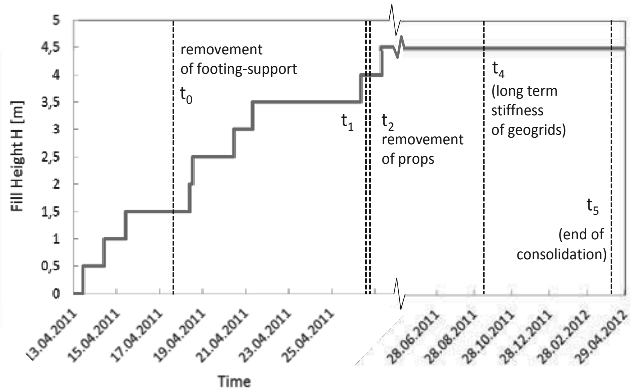

Figure 5b. Time schedule of construction.

5.2 *Measuring strain and back-calculation of stress*

For the back-analysis of horizontal forces from strain recordings, the corresponding stress has to be known. This can be read from isochronous stress-strain curves, as far as they are available. For the used material here, Secugrid® made from polyethylenterephthalat (PET), the curves are given. The back-analysis for representative times t_0, t_1 and t_2 (see Figure 7) has been worked out using the isochronous curve for 1 hour, representative for the situation immediately after compaction of soil. As this gives conservative values of stress, no further differentiation is required.

For the time t_4 and t_5, long term stiffness has been calculated using the isochronous curve for 1000 h, also giving conservative values for stress, as t_4 is approx. at 2880 h and t_5 at 6500 h.

5.3 *Main findings*

Up to the date of printing, the construction is approximately one year in service. Data recording is available continuously during installation and in sequences during the service period. Within the service period, also 24h-measurements have been done to get an impression of temperature changes within the wall. Figure 6 gives the strain recording for the total time, indicating a very low level of strain of less than 1%, as it has to be expected. Nevertheless, only the three layers on the bottom get a significant loading. Two layers of geogrids on the top are up to now not taking any load. As these layers are mainly designed for a top-load of the construction not performed yet, the results fit with the expectations.

Removing the prop (t_1 to t_2) has been expected to increase the strain in the upper layers of the geogrids. Actually, this could not been found on site. The absolute values of strain (and therefore stress) at each layer remained stable.

For the sum of horizontal loads, compiled for the representative time t_0 to t_5, measured forces as well as forces from FE-calculation and analytical approach by classical earth pressure theory can be compared. Friction at the toe of the wall, forces on the temporary prop as well as forces at the geogrids, measured right behind the wall, have to be compiled.

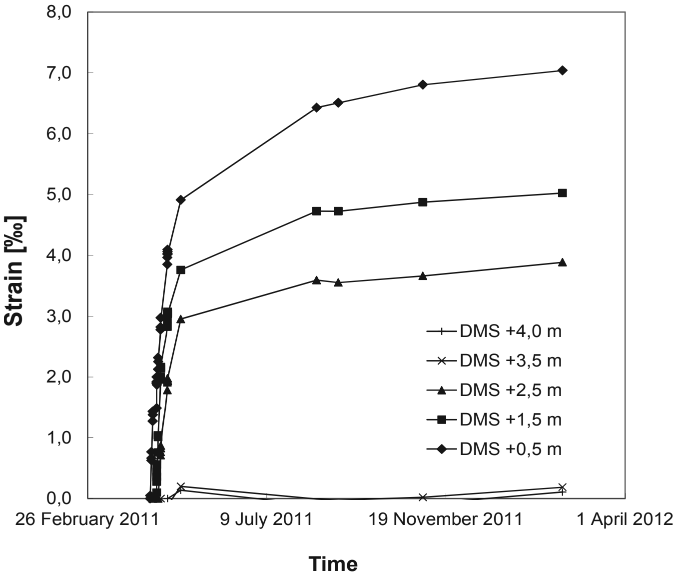

Figure 6. Entire strain recordings of the geogrids (DMS: strain gauge applied to geogrid).

For time t_0 to t_4, the results gained by PLAXIS come quite close to the results gained from measurements in situ, Figure 7. Taking the rotation backwards due to settlements into consideration (time t_5), PLAXIS gives a significant increase in stress, not be found on site.

In comparison to the measurements, results given by classical earth pressure have not been found to represent the reality for this combination of reinforcement and facing, neither the laboratory one nor the in-situ one. The difference is at least between 30% and 40% and therefore in line with the current status of research on reinforced soils. Compared to the design situation according to EBGEO, a reduction of lateral stress for the load case "unit weight of structure" and therefore a correction factor $\eta_g \geq 0.7$ would be acceptable from the author's point of view.

6 SUMMARY

Full scale laboratory tests have been performed for a full height panel wall, combined with a geogrid-reinforced soil structure. Tests are performed at loads up to 450 kPa according to bridge abutments as well as at dynamic loadings.

A comparable setup of a full scale panel wall has also been tested in situ. Monitoring of the reinforced wall allows for satisfactory back-analysis of the constructions steps.

The measured stress conditions fit with the expected low stress approach for the combined structure, given by FE-analysis. The findings combine the current results of international research and updated design approaches (EBGEO) also for full height panel walls. They allow for the consideration of a reduced earth pressure distribution in design as well as for simplified construction.

Due to limitations, the setup and results cannot be transferred to all combinations of reinforcement, soil and panel-systems, but allow for further analysis by FE calculations.

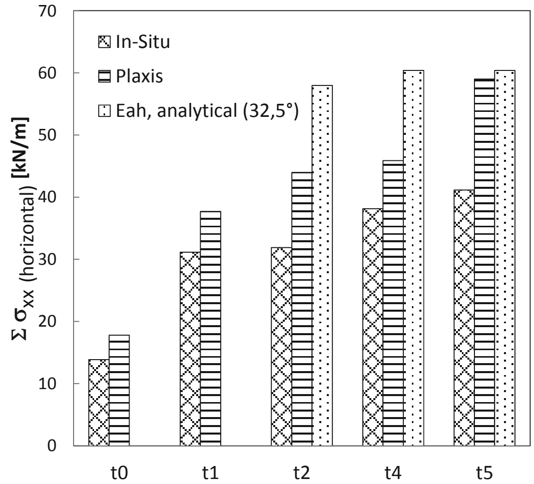

Figure 7. Comparison of measured lateral stress in situ, prediction by FE-analysis and prediction by classical earth pressure theory

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