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Chairman's report: Wall structures

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ABSTRACT: For technical session (2) „Wall Structures" a total of 48 papers (including the poster session) were submitted. Twelve papers were selected for oral presentation. The topics of the papers were: model tests, field tests, case histories, analysis, and dimensioning. The session was lead by L. E. Wichter (Germany), co-chairman T.W. Cousens (United Kingdom), discussion leader K.C. Yeo (Hong Kong), and secretary R. Kitamura (Japan). This report gives a summary of the contributions.

1. *Design and Dimensioning*

Anderson, Boyd, Segrestin and Worrall (The Reinforced Earth Company) show in their paper that it is necessary to have more logical consistency and compatibility between national standards. Safety factors and design philosophies should be based on consistent mechanical models.

Zhang Yemin et al. proposed a design method for the construction of reinforced slopes for agriculture storage rooms.

Greenwood and Yeo presented a report on the assessment of geogrids for soil reinforcement in Hong Kong. The use of partial safety factors based on statistical values, and representing the levels of risk and uncertainty for the different influences, seems them to be the best way of dimensioning.

Lesniewska proposes a general classification system of reinforced soil retaining walls regarding the possible failure mechanisms.

Mak and Lo presented a paper on a limit state design specification for reinforced soil walls, using partial safety factors. They set off the potential problems of using a statistical definition of characteristical values.

Pun and Man describe the use of reinforced fill structures in Hong Kong. They give an interesting overview on the design and construction standards, the geotechnical control, performance, research, and development undertaken by the Hong Kong Geotechnical Engineering Office (GEO).

Xueqiang and Zude presented a paper about the designing methods for reinforced vertical slopes using the theories of soil plasticity and limit state analysis

2. *Case histories*

A paper about a 7 km long reinforced earth seawall for a new runway of Sidney airport was presented by M. Boyd. The author describes the construction of the 5 m high sea walls and gives some informations about the considerations on durability of the steel reinforcing strips in aggressive seawater environment, and on corrosion monitoring.

Raybould, Hadley, and Boyd describe the design, construction and performance of a 40 m high and 210 m long reinforced fill wall in Hong Kong. The wall became necessary, together with many other earthworks, to construct the Route 3 expressway linking Hong Kong Island to the chinese border. The construction was equipped with numerous monitoring devices such as inclinometers, piezometers, etc.. During construction time (16 months) a washout failure of a section of the wall occurred showing the importance of temporary drainages for structures built across valleys in areas subjected to heavy rainfalls.

Frankenberger et al. presented a report on the experiences with reinforced earth walls during Northridge (California) earthquake in 1994. Within the affected area a number of 23 reinforced earth structures withstood the earthquake without damage though in the neighbourhood many collapses of highways and commercial structures occurred.

Guo's and Luo's report deals with the application of reinforced earth technologies in the loess areas of China. The authors give an overview of the facing and reinforcing materials. It is very interesting that, even for very high retaining structures (≥ 20 m) polypropylene plastic strips are used successfully, together with loess as backfill material. In a second report they describe in detail the construction of a 50 m high wall using these materials.

Rao et al. describe the construction of a panel-faced reinforced soil wall near the city of New Delhi. The use of fly ash as fill material makes this report very interesting in an environmental aspect.

Another very important contribution was presented by Kobayashi, Tabata and Boyd. They studied the behaviour of reinforced earth structures in the vicinity of Kobe during the Great Hanshin Earthquake in 1995. More than 120 reinforced earth structures were inspected after the earthquake, and they showed only minimal damages. No structure failed. Pseudo-static analyses of some selected structures indicated that present design methods may be very conservative, and the structure's bearing capacities are considerably higher than estimated.

The findings of Kobayashi et al. were confirmed by the observations of Nishimura et al., who investigated ten geogrid-reinforced soil walls in the area of the Southern Hyogo earthquake which happened in 1995. Though having undergone seismic activities of 6 to 7, these structures were not destroyed or even damaged seriously. The stability of the walls was, in all cases, higher than the results of calculations using the conventional design methods.

Otani, Mega and Matsui made the same observations on steel-reinforced earth structures after the 1995 Hyogoken-Nambu earthquake. They checked about 40 such structures after the earthquake and found, that reinforcement protected them from severely being damaged. They found that reinforcement also increased the resistance against failures of the natural slopes in the earthquake area.

Lin Xin describes the performance of a reinforced embankment based on a pile construction. The piles were necessary to stabilize the embankment against sliding on a deeper slip plane.

Marchal, Bastick and Belblidia presented a report on a 24 m high Terre Armee wall near Pont de Normandie in France. Great attention was payed to a good design of the facing which forms a part of the landscape in the neighbourhood of characteristic chalk cliffs.

Nakajima et al. describe the construction of a 8 m high reinforced soil wall with a concrete block facing. They observed a maximum reinforcement strain of about 1 % and a horizontal displacement of the facing of 6.5 cm, both measured at the time of completion of construction, and no further increase.

Sakajo et al. describe the performance of a steel strip reinforced wall of 60 m length and 12 m maximum height. They observed a wall base settlement of 100 mm and a lateral displacement of 15 mm at the top of the wall after the end of the measures. Maximum tension force in the reinforcement strips was measured near the wall facing, but no clear distinction between active and passive zone in the reinforced soil mass was found.

Singh et al. analysed the failure of a fully anchored conventionally designed breast wall constructed in an unstable slope area. The construction became unstable after a period of heavy monsoon rainfalls. The authors make a proposal for a better „combined system", with the generous provision of chimney and slot drains to ensure good drainage conditions.

Smith describes the design and construction of the very impressive Terratrel Ro-Ro ramp for second Severn Crossing. The 21.000 kN caissons for the foundation of the construction piers were transported from the precast yard on a 5.000 kN transporter, so that the overall weight of the transport was 26.000 kN. The transports used a 13 m high reinforced embankment in difficult marine environment.

Stewart, Truong and Segrestin describe another three very high reinforced earth constructions in Tennessee, USA. The overall height of their structures ranged from 17.5 to 30.5 m, and they were carried out without the slightest problem. No post construction movement or settlement was observed.

Sumanaratne and Mallawaratchie presented a paper on the use of treated bamboo strips as reinforcement and used tyres as facings in Sri Lanka. They remark that these construction methods could be adopted ideally in countries like Sri Lanka were advanced technologies and, above all, capital intensive equipment is lacking.

Won, Hull and De Ambrosis described the performance of a geosynthetic-reinforced segmental block wall structure in New South Wales, Australia. They found that geogrid strain data and numerical modelling had suggested that load bolts may overestimate geogrid tension in this type of construction.

3. *Model Tests*

M. Hyodo et al. presented a paper on model tests in a pull-out aparatus. They used rubber strips and PEHD strips embedded in Aio sand. The strips of different tensile stiffnesses were equipped with strain gauges. The authors found that walls reinforced with strips of high stiffness need only small displacements to activate the tensile forces along the whole lengths of the strips, while along strips of lower stiffness the friction predominates near the front of the wall and decreases rapidly with increasing distance from the wall facing.

Yogarajah and Saad describe the performance of two large scale tests to determine the behaviour of polymeric-reinforced single and multi segmented walls. They found significant differences between these wall types when considering the horizontal earth pressures and strain distributions along the reinforcement layers.

C.C. Huang and B. Huang performed an infiltration test on the crest of a wrap-around model wall. The 2.77 m high, 6 m wide and 3 m long reinforced construction consisted of an alluvial clay and was exposed to water infiltration over a period of 50 days. The long-term percolation had some influence on the outward deformation of the wall facing. The test shall be used to evaluate the feasability of using clay as backfill material, and is not finished.

Tsukamoto et al. presented a report on a large-scale model test to study the lateral earth pressures on a rigid facing reinforced retaining wall. They used granular backfill material and found, that in their tests neither collapse states nor fully mobilized states for active earth pressure could be observed under the surcharge pressures they used.

Uchimura et al. describe the performance of preloaded and prestressed geosynthetic-reinforced soil. They found that the rigidity of a reinforced soil mass can be increased largely by proper preloading and prestressing.

Arab, Villard and Gourc presented the results of two large scale loading tests. They used woven and nonwoven geotextile and observed only very small displacements until 2/3 of the failure loads were reached. Finite element analysis gives rise to the assumption that a compaction effect causes this bearing characteristic.

Benigni, Bosco, Cazzuffi and De Col describe the construction of a 5 m high geocomposite-reinforced wall in Northern Italy. The wall was loaded, and measurements showed that the tensile strength of the reinforcement was mobilized only minimally.

Chang and Milligan carried out a series of small-scaled pullout tests on soil nails. They found that pullout tests conducted under conditions in which no overall failure is occurring, and where the active and transition zones are not fully developed, may be unsafe for pullout under ultimate failure conditions.

Okabayashi, Kawamura and Okada carried out two series of centrifugal tests on three-dimensional models of reinforced retaining walls, and verified the test results with three-dimensional FEM analysis. They found that the shape of the reinforcement mainly influenced the stability of the walls under their test conditions.

Centrifuge model tests were also carried out by Porbaha using different foundation conditions, nonwoven fabric, and cohesive soil as backfill. Overturning and rotational sliding were observed as failure modes.

Da Silva and Abramento propose a method for verifying the performance of reinforced soil walls under working conditions, using an analytical model based on shear-lag formulation.

Sreekantiah and Kishan describe geogrid-reinforced earth model retaining walls and found a remarkable decrease in lateral deformation and vertical settlement when increasing the number of reinforcement layers.

Tajiri et al. described a series of very interesting full scale loading tests with different types of facings. They found that the displacement of the wall facings could be reduced by the gravity effect of it's facing, and they have studied the shapes of the failure planes.

4. *Analyses*

Rowe and Ho carried out a FEM study on the influence of some parameters on the deformation behaviour of reinforced walls. The found out that the deformation of walls constructed with wrap-back type facings is smaller when the intermediate layers that form part of the facings are not to far from the anticipated failure plane, because they share the load with the main layers. Location of panel connections and the panel continuity had no significant influence on the force in reinforcement and deformation. The effect of higher backfill soil stiffness on the deformation behaviour was relatively insignificant. Rigid facings on a rigid base lead to a clear decrease in horizontal facing deformation.

M. Bastick and P. Segrestin presented a study on the use of double wedge equilibrium method for reinforced earth structures design. They found that the method is suitable together with the use of partial safety factors for loads and material properties. The attempts to define global factors of safety using double-wedge failure mechanisms lead to meaningless results.

Kim et al. carried out a theoretical study on the stress-strain behaviour of reinforced walls using a nonlinear elastic soil behaviour constitutive law and nonlinear response of the fabric reinforcement.

Boyle and Holtz used sixteen case histories reported in the literature to assess the accuracy of methods for the prediction of wall deformations. They found that the predicted deformations ranged from 40% to 460% of the actual deformations of walls constructed with cohesionless soils.

Cousens and Pinto studied the effect of compaction on model fabric reinforced brick faced earth retaining walls. In order to avoid or minimise unwanted effects of compaction they propose to compact the backfill in the direction towards the wall, and to use only light compacting device within 1 or 2 m from the wall facing. In a second paper the same authors describe the creep behaviour of the model walls. They found that creep does not seem to be a major problem of reinforced earth constructions, which is in agreement with the observations of many other researchers.

Cardoso and Lopes used FEM analysis to perform a numerical study on the influence of the construction method on the behaviour of geosynthetic reinforced walls.

Gourves, Reiffsteck and Vignon presented two different methods of stability analysis which were developed for geocell retaining structures.

Nakane et al. analized three geotextile-reinforced soil walls using a two-dimensional elasto-plastic FE model. The aim was to get some information about the influence of facing rigidity on the deformation behaviour of such walls.

Rajagopal and Sri Hari propose a method of design for anchored retaining walls. Their proposal is based on the results of model tests in a 0.8 x 0.6.0.8 m test box.

5. *Conclusions*

A main result of the observations described in the session is the high resistance of reinforced earth structures against beeing damaged by earthquakes. Another aspect is that there is obviously a lot of work to do in order to come to a better agreement of calculation results and field observations. The contributions have shown that it is possible to construct high and very high reinforced walls safely and, in general, with lower expenditure than conventional retaining walls.