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Discussion leader's report: Wall structures

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ABSTRACT: This report presents a summary of all the forty-eight papers which are represented by more than seventeen countries, submitted for this technical session. The range of topics is widely spread, and can be categorised into five main groups, namely, Classification/Specification/Standards, Analyses, Laboratory Model Tests, Field Trials/Tests and Case Histories. There is a sharp increase on number of papers by Asian/Pacific Asian countries, which indicates the importance of reinforced soil technology in Asian development. Importance issue as raised in these papers are highlighted by the writer, and in the writer's view, this would be used to gauge the advancement of reinforced soil technology in the future.

1 INTRODUCTION

There are in total forty-eight papers submitted for the technical session on wall structures of IS Kyushu'96 as compared to twenty-two in 1992. A comparison of the breakdown with respect to country/continent is shown in Figure 1. It is noted that there is a marked sharp increase on the number of papers submitted by Asian/Pacific Asian countries.

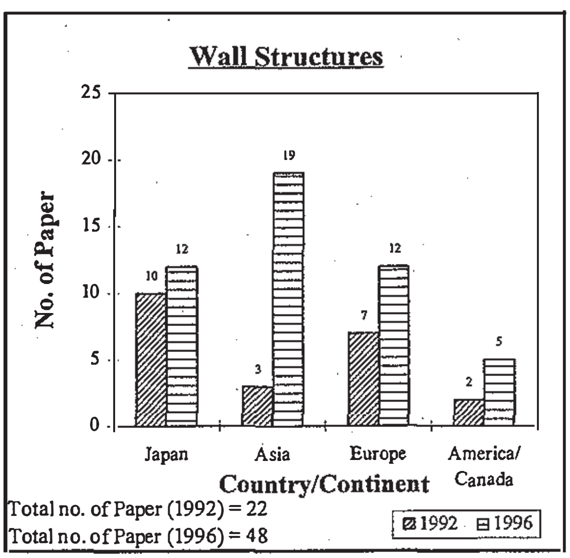

Figure 1 Comparison of Number of Papers Submitted for IS Kyushu' 92 & 96

This indicates the importance on the use of reinforced soil technology in the development of Asia over the next decade.

The submitted papers covered a wide range of topics, and can be categorised into five main groups, namely, Classification/Specification /Standards, Analyses, Laboratory Model Tests, Field Trial/Tests and Case Histories. Table 1 shows the breakdown of the number of papers with respect to each group. The papers included in each group are briefly summarised in the following sections, and readers are drawn attention to important issue as raised in the papers.

Table 1 Number of Papers Submitted for Each Group of Topic(s)

Wall Structures		
Topic		No. of Papers
Classification / Specification / Standards		5
Analyses	Numerical	3
	Others	5
Laboratory Model Tests		11
Field Trials / Tests		9
Case Histories (Case Studies)	Seismic	4
	Others	11
	Total :	48

2 CLASSIFICATION/SPECIFICATION/ STANDARDS

Five papers are included in this section on classification/specification/standards, which also includes some discussion on the issue of partial safety factors.

Leśniewska proposed a classification system of reinforced soil retaining walls taking into account of the internal structure and the most probable failure mode. She concluded that much attention should be paid on the lack of mechanical uniformity of many reinforced soil structures, which is important in deriving the appropriate theoretical description.

Pun & Man and Greenwood & Yeo described the use of an endorsement (pre-approval) system, and outlined the importance of taking the appropriate design conditions when endorsing the system.

Mak & Lo described the development of a limit state design specification based on reliability analysis (calibration) of a limited number of data.

Anderson et al demonstrated the use of different design codes may result in quite different safety factor for the steel/geosynthetics reinforcement, and suggested the need for a rational approach.

In addition, Greenwood & Yeo and Anderson et al proposed that different group of partial factors, i.e. related to reduction of strength, related to uncertainty etc, must be treated differently, to achieve compatibility, effectiveness and consistency in design.

The writer would like to draw attention that as different type of reinforced soil wall, i.e. with /without structural facing, extensible/ inextensible reinforcement etc, may render different behaviour, it is important to classify the structure and to develop appropriate design method for the structure. In addition, it is vital to exercise control over the use and design of reinforced soil structures, e.g. by modified (international)design code, by providing specification or by pre-approval(endorsement) system, to avoid failure that may be caused by inappropriate design method or construction procedure applied. Means of handling the partial factors used in design should be considered carefully to produce compatible and consistent design solution.

3 ANALYSES

Eight papers are included in this section on analyses, which cover a wide range of analytical methods.

Rowe & Ho, based on their previous numerical modelling work using finite element analysis, gave an account on the effect of intermediate layers, interface shear, panel continuity, panel location, facing rigidity, backfill stiffness and foundation stiffness, on the behaviour of a modelled reinforced soil wall.

Cardoso & Lopes used a numerical model, again based on finite element analysis, to study the effect of wall construction technique, i.e. use of a fully propped rigid panel & use of incremental panels.

Boyle & Holtz used (performance) charts developed from two independently calibrated (finite element) numerical models to predict and compare the actual deformation of wall in sixteen case histories.

Bastick & Segrestin compared the use of three limit equilibrium methods of analysis for reinforced soil wall design, namely coherent gravity method, slip circle method and two-part wedge method.

Kim et al carried out internal stability analysis of a reinforced soil structure based on limit equilibrium, using a non-linear hyperbolic load-extension relationship for the reinforcement.

da Silva & Abramento used an analytical model based on shear-lag formation, to verify the loads along the length of the reinforcement at various depth of an instrumented reinforced soil wall.

Yang & Liu employed limit analysis to develop upper bound solutions for vertical reinforced soil slope, taking into account the reinforcement with and without bending stiffness.

Zhang et al developed a design procedure for a tied back to back wall based on limit equilibrium.

The writer would like to draw attention to the feasibility of using a calibrated numerical model to develop design (performance) chart that can be used in limit states design, and the continuous effort of researchers in developing other design methods based on limit equilibrium methods of analysis.

4 LABORATORY MODEL TESTS

Eleven papers are included in this section on various laboratory model tests, i.e. soil nails, geocell, soil anchors, centrifuge, laboratory-scaled reinforced soil walls etc, to study the behaviour of different soil reinforced system for wall structures.

Chang & Milligan carried out small-scaled pullout tests to study the effect of transition zone in a nailed wall. They concluded that under the conditions in which no overall failure is occurring and transition zone are not fully developed, results yielded from pullout- tests conducted may be unsafe for ultimate failure conditions.

Gourvès et al carried out a study on geocell reinforced soil wall using simple shear and compression tests, and carried out full scale and centrifuge model tests with analyses based on two part wedge limit equilibrium and FLAC (finite differences) methods of analysis.

Rajagopal & Sri Hari carried out pullout tests to study the effect of shape and size of anchor plate for a model soil anchored wall.

Cousens & Pinto and Pinto & Cousens studied the effect of compaction and creep behaviour of a modelled fabric reinforced soil wall with brick facing.

Porbaha used centrifuge model tests to study the failure modes of a non-woven geotextile reinforced soil wall with different length of reinforcement using cohesive backfill on firm/rigid foundation.

Hyodo et al studied the effect of reinforcement stiffness on the deformation of geosynthetic-strip modelled reinforced soil walls with single layer of reinforcement. The strip was pull-out with the wall subjected to a rotational movement at toe.

Yogarajah & Saad studied the effect of facing construction on the development of earth pressure and load-strain performance of the geogrid reinforcements.

Sreekantiah & Tito Kishan applied surcharge load to study the wall deformation of a geogrid reinforced wall varying spacing of the reinforcement.

Tsukamoto et al studied the (active) earth pressure development on the front wall, side wall and back wall of the retained geogrid-reinforced soil, using large-scaled model test.

Okabayashi et al carried out centrifuge model test of a steel strip reinforced soil wall varying the facing thickness, length and width of the reinforcement, and verified some of the test results with a 3-D finite element analysis.

The writer would like to draw attention to the continuing effort of using laboratory model test to study the behaviour of different reinforced soil system, and the validity of the these test results in accounting for the effect of construction technique.

5 FIELD TRIALS/TESTS

Nine papers are included in this section on field trials/tests.

Huang & Huang carried out infiltration test on two 2.8m high clay walls, reinforced with a woven & non-woven composite geotextile and a PVC coated polyester fibre geogrid respectively, to study the permeability of compacted clay and the stability of clay reinforced soil structures.

Uchimura et al developed a new construction method to prestress the reinforced soil vertically by metallic tie rod, thus increasing the shear rigidity of the soil, and carried a field trial on a 5m high block. In addition, they also conducted a laboratory experiment to study the relaxation of the pre-stressed reinforced soil.

Won et al carried out a field study on the behaviour of a 9.5m high geogrid reinforced four terraced (tiered) segmental block wall, instrumented to measure strains in the reinforcements, base pressures, settlement and settlement profile of the wall and also lateral deformation of the soils. Numerical analysis based on FLAC (finite difference analysis) calibrated by (back analysed) pull out test was then carried out to assess the performance of the structures.

Tajiri et al carried out full scale failure experiments of three 5m high geogrid reinforced soil walls with different facing, namely expanded polystyrol (EPS) blocks, full height concrete panel & concrete block. Instrumentation was installed to measure earth pressure on the facing of the walls, base pressures, displacement of the facing and strains in the reinforcement.

Nakane et al carried out finite element numerical analysis to model the same experiment, and to study the effect of facing rigidity.

Nakajima et al also carried out field study on the performance of a 8m high geogrid reinforced soil wall of concrete block facing, with instrumentation to measure strains of the reinforcement, earth pressures on the facing of the wall, base pressure distribution, settlement and displacement of the wall.

Benigni et al conducted field study on the construction and performance of a 5m high geocomposite (non-woven polyester sheet with woven polypropylene thread knitted at constant spacing both directions) reinforced soil wall with strong fill and weak reinforcement. Instrumentation was carried out to measure elongation of the geocomposite and the deflection of the wall.

Arab et al carried out finite element analysis to simulate the behaviour of two instrumented 4.5m high reinforced soil walls, one with woven and one with non woven reinforcement. The walls were loaded to failure and instrumentation was installed to measure the load settlement, wall deflection and strains along the reinforcement sheet with respect to increase of load.

Sakajo et al carried out field study of the performance of a 12m high steel strip reinforced wall with numerical modelling based on finite element analysis, with instrumentation data on both the vertical and horizontal displacements of the wall and settlement of the fill.

The writer would like to draw attention to the importance of quality field studies with high quality instrumentation measurement, to be used to calibrate numerical models, to develop design (performance) charts for limit states design.

6 CASE HISTORIES

Fifteen papers are included in this section of case histories.

Four papers are concern with the effect of earthquake on reinforced soil structures. Frankenberger et al gave an account of the behaviour of Reinforced Earth structures (23 number) in Northridge Earthquake in LA, California on 17.1.1994. Kobayashi also reported on the performance of Reinforced Earth structures (124 number) in the Great Hanshin Earthquake, near the vicinity of Kobe on 17.1.1995. Otani et al reported on the performance of 47 steel reinforced soil structures, including Reinforced Earth walls and pile reinforced slopes, during the same earthquake, and carried out some case studies with analysis on factor of safety. On the other hand, Nishimura et al reported on the performance of 10 geogrid reinforced soil structures during the same earthquake, and compare the safety factor obtained based on some existing methods of analysis for design. All the four papers confirmed the effectiveness of reinforced soil structures under seismic impact. The analysis carried out indicated that under the effect of the seismic force recorded, some of the structures would have already failed. However, most of the reported reinforced soil structures suffered either little or no damage during the earthquake.

Marchal et al reported on the use of an innovative facing for a 24m high Reinforced Earth wall near Pont de Normandie in France.

Boyd reported on the use of a 5m high Reinforced Earth seawall at Sydney Airport in Australia.

Stuart et al reported on the construction of 17m to 30m high three tiered Reinforced Earth walls in Eastern Tennessee of the United States of America.

Smith reported on the construction of a 12m high Terratrel (Reinforced Earth structure with wire-mesh facing) temporary jetty ramp for Severn river in Wales of the United Kingdom.

Raybould et al reported on the construction of a 40m high Reinforced Earth wall in Hong Kong.

Lin reported a case of using piles installed at the toe of a reinforced soil wall on soft foundation (which is used to support a road embankment) to prevent a sliding failure, in Chongqing of the PR China.

Guo & Luo presented an account of case histories on reinforced soil structures using loess as backfill, also in the PR China. The reinforcements used include ribbed and plain steel strips, polypropylene strip & reinforced concrete bar.

In addition, Luo & Guo gave an account on the design of a 50m high reinforced soil wall using oil painted ribbed steel strips as reinforcement, in Shan Xi Province of the PR China.

Rao et al described the design, construction and monitoring of a 6-7m high geogrid reinforced soil wall using fly-ash as backfill, in New Delhi of India.

Singh et al described the construction of an anchored earth wall of 3-4 m high using semi-Z shaped mild steel reinforcement with cohesive backfill, in the sub-Himalayan region of India.

Sumanaratne & Mallawaratchie described the use of used Tyre facing with treated bamboo strips as reinforcement, to construct reinforced soil wall of 2m high (which is used to support a 3m high road embankment), in Sri Lanka.

The writer would like to draw attention to the effectiveness of designing and constructing reinforced soil structures in areas proning to earthquake, and the lack of a possible international design code of reinforced soil structures taking into account of the appropriate earthquake impact. It is also important to share international experience on the use of reinforced soil technology, so that technical transfer can be efficiently transmitted to less privileged countries.

7 DISCUSSION

To ensure the development and advancement of the state-of-the-art in a positive direction, it is important to set some milestones to gauge the progress on the use of the technology. The writer would like to suggest five areas for further discussion and consideration as follows:

a. The need for developing Asian countries to exercise control over the use of reinforced soils based on modified code, specification or pre-approval system.

b. The use of reliability analysis and treatment of partial safety factors, to ensure consistency and effectiveness in design.

c. The use of calibrated numerical model with quality field study to develop design (performance) charts for limit states.

d. The boundary conditions should be carefully considered in design for different types of reinforced soil structures. Effect of compaction, method of construction etc, clearly affect the behaviour of the reinforced soil wall.

e. The need of an international design code for reinforced soil wall, taking into account of the appropriate effect of earthquake.

REFERENCES

BSI (1995). *British Standard Code of Practice for Strengthened/Reinforced Fills (BS 8006)*. British Standards Institution, London.