Development of internally stabilized earth retaining structures with local materials

Dévelopment d'une structure retenant la terre intérieurement stabilisée avec les matérieux locaux

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ABSTRACT: Internally stabilized earth retaining systems became popular and came into extensive usage over the last two decades due to many advantages inherited in them. Different forms of internally stabilized earth retaining systems had been developed in various parts of the world. For a developing country further advantages could be gained by incorporating locally available material.

In the Sri Lankan road network anchored earth retaining structures made with discarded motor vehicle tyres and reinforced earth structures with a tyre facing and bamboo reinforcement mesh were used at number of locations to rehabilitate slope failures and for widening of roads. The paper describes the model studies done to study their behaviour and the development of design procedures. The results indicated that these structures possess very high safety margins while being extremely inexpensive.

RESUME : Les sysfémes retenant la terre intérieurement stabilisée sont devenus. Populaire et beadcoup utilizes pendant les deu derniéres décenniès due aux pluseurs avantagess. Différentes formes de ce systéme de retenant la terre intérieurement stabilisée ont été développées dans les regions différentes du monde. Pour un pays en voie de development plus d'avantages penvent être gagner en utiusomt les matérieux locaux.

Dans les réseanx des routes au Sri Lanka, les structures retenant la terre a sont faites utilisant les pneus a Jester en renforcant la erre avu bamboo dans ure forme d'ua grillage pour éviter les défants aux points des pentes et dans l'élargissemnts des routes cet article. Décrive l'étude d'un modéle pour analyzer lear comportemments et les développements poor aider la conception. Les résultats montrent que ces structures donnent les conditions hors risques an même temps ayant un coût trés bas.

1. BACKGROUND

Different forms of earth retaining systems used at present can be separated into two broad categories as, externally stabilized systems and internally stabilized systems (Jones et al 1985). An externally stabilized system uses an external structural wall against which stabilizing and disturbing forces are mobilized. All the traditional retaining wall can be considered as externally stabilized systems. Their supportive action could have been derived from their weight, flexural rigidity or a combination of the both.

In internally stabilized systems, the closely spaced reinforcements and the soil behave as one structural unit. A facing is used to provide continuity and to prevent erosion and deterioration. It does not carry a significant load. As the soil mass is partitioned each portion receives support from locally inserted reinforcing elements. Reinforced earth and anchored earth systems are two types of internally stabilized retaining systems where the construction is done incrementally from bottom up.

Internally stabilized earth retaining structures based on reinforced earth or anchored earth principles posses many advantages over the conventional externally stabilized systems.

Their flexible nature and ability to accommodate considerable differential settlements, ability to be constructed quickly without the help of any special machinery, immediate usability upon completion of the construction and relatively lower cost (specially when the height is high) are some of the major advantages.

In reinforced earth constructions, shear stresses mobilized in the system to resist outward soil movements are transferred to the reinforcing elements developing tensile forces in them. The stability is maintained by embedding the reinforcing elements over a sufficient distance in the resistant zone to develop the necessary pullout resistance (Figure 1). In anchored earth systems forces exerted on the facing elements by the outward moving soils are transferred to the anchor elements through the connecting strips or rods. The anchors are placed in the resistant zone leaving a sufficient length to develop the pullout resistance in front. Anchored earth retaining structures have a further advantage due to the smaller width of the resistance zone required. Also, fill materials of lower shear strength parameters could be used.

Number of anchored earth retaining structures were constructed at several locations in the Sri Lankan road network using discarded motor vehicle tyres (Sumanarathna et al 1997). Tyres were used as both the facing elements and the anchor elements. The connection was done through large diameter nylon wires. At some locations, meshes made of treated bamboo strips were used as reinforcements while having a tyre facing. About forty anchored tyre earth retaining structures and bamboo reinforced structures have served the Sri Lankan road network for around ten years without showing any signs of distress. As these structures were constructed based on personal judgment without a specific design procedure it was necessary to study their behaviour and to develop appropriate design guidelines.

A study on the behaviour of these structures require loading of the structure and measurement of deformations. Difficulties were anticipated in attaching strain gauges to the nylon wires used in the systems, and providing large vertical loading to cause failure of the structure. As such, it was decided to carry out the study through the model structures that were constructed inside a self contained loading setup in the laboratory. Walls were constructed incrementally from bottom up, following the field compaction procedures as closely as possible. Two types of fill materials; a sandy fill and a lateritic fill were used in the construction. The effect of saturation of lateritic fill was also studied. Pull out resistance of the anchor tyres and bamboo meshes were also studied through a separate pullout testing arrangement.

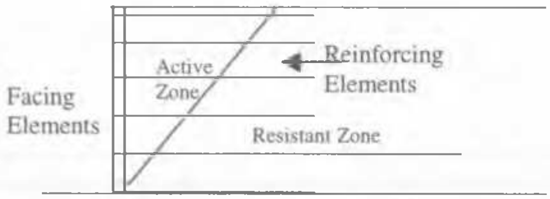

Figure 1 - Active and resistant zones

Two types of loading conditions; a vertical load within the anchor or reinforced zone and a vertical load behind the said zone were applied simulating the different types of loads a prototype structures could be subjected to in its life.

An anchored earth or reinforced earth structure forming a highway abutment where the main load is applied vertically on top is simulated by the application of a vertical load within the anchor or reinforced zone. An anchored earth or reinforced earth structure, constructed at the foot of a slope to provide stability, can be simulated by applying a vertical load behind the anchor zone. The deformations of the structures were measured with the incremental application of the load and failure modes (if any) were noted.

2. STABILITY CONSIDERATIONS

An internally stabilized earth retaining structure should be stable both internally and externally. Internally, it should be stable against pullout of anchor or reinforcement elements and tensile failure of reinforcements or connecting strips. Externally, the reinforced / anchored wall block should be stable against sliding, overturning or bearing failure just as in the case of a gravity retaining structure.

Internal stability of the structure can be studied through tie back wedge analysis performed at various levels in the structure. At a given level, the potential failure mass is in equilibrium under the forces, W, S and T_{eqm} (Figure 2). The force T_{eqm} needed for the equilibrium is provided by the reinforcements or wires connected to the anchors. The value of T_{eqm} can be obtained through the equilibrium wedge analysis. Internal instability of the structure could be caused by a pullout or a tensile failure. The capacity of the anchors/reinforcements is the lower value of the "summation of pullout resistances of the intercepted anchors/reinforcements" and the "summation of the tensile strength of the intercepted anchor wires/reinforcements". This values is denoted by T_{sum}. The factor of safety on internal stability can be expressed as FOS = T_{sum} / T_{eqm}. External stability is evaluated by considering the anchored/reinforced block as a gravity wall.

When the model structure is loaded within the reinforced/anchor zone, tensile stresses are mobilized in them, and they are subjected to a pullout. The applied surcharge also acts to increase the pullout resistance. As such, the structure could fail through tensile failure of the elements or their pullout.

When the model structure is loaded behind the reinforced/anchor zone, the wall unit will behave as a gravity retaining wall and could be subjected to a sliding or overturning mode of failure.

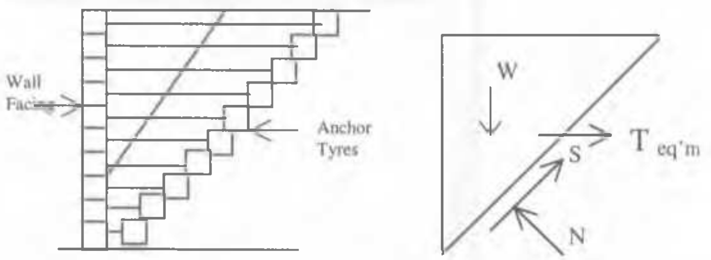

Figure 2 - Equilibrium wedge Analysis

3. PULLOUT RESISTANCE

A specially made reinforced rubber rings of external diameter 55m, internal diameter 35mm and thickness 15mm, were used as model tyres.

Pullout resistance of model anchor tyres and bamboo reinforcement meshes were determined in the laboratory. Model tyres / model bamboo meshes were buried within a fill done in a Perspex box. The system was subjected to the required normal loading intensity by jacking up against the self contained loading set up as depicted in Figure 3. An increasing pullout load was applied on the anchor tyre/reinforcement mesh by adding weights to the loading hanger gradually. The outward movement of the anchor tyre/reinforcement relative to a reference frame was measured with each load increment.

In the pullout tests with model tyres, it was connected to the loading hanger through a steel cable. A bamboo mesh of limited width (50 mm) made of only two longitudinal bars and number of cross bars was used and the steel cable was connected to a mild steel bar connected to the longitudinal bars at the front.

The model anchor tyres could not be pullout when they were under a vertical loading intensity of the order of 25 kN/m^2. The connecting wires failed in tension when the applied load exceeded 120 kg. Once the applied surcharge was reduced to less than 6 kN/m^2, tyres could be pulled out. Based on the measured pullout resistances data, an expression was developed to be a lower bound to the observed values.

Similarly, bamboo reinforcement meshes could not be pulled out at vertical loading intensities of the order of 25 kN/m^2. The front bar slipped before the load was increased to necessary levels. As such, some pullout tests were done only under the self weight imposed vertical stresses. The bond coefficient f_b for the bamboo mesh reinforcements found to be more than 0.98.

4. MODEL STUDIES ON ANCHORED TYRE EARTH RETAINING STRUCTURES

The basic unit in the model structure consists of three facing tyres connected to an anchor tyre . Adjacent facing tyres are connected to each other and the two outer tyres are connected to the anchor type. The distance between the facing tyres and the anchor tyre was varied to ensure that the anchor tyre is kept at a sufficient distance behind, in the resistant zone. The construction of the model was done incrementally inside a Perspex-box. The box was fabricated with slotted angle sections and the Perspex sheets were used in three vertical sides to observe the failure patterns. No Perspex sheet was used in the side of the wall facing. The wall was loaded by jacking it against the top beams of the self contained loading setup.

Figure 3 - Pullout Resistance Testing

The outward movement of the wall facing with the increasing load was measured at three vertical sections along the length of the wall. In one vertical section measurements were done at five points at different elevations.

4.1 Model Tests with a Sandy Fill

A well graded sandy soil where particles of sizes greater than 3.35m were removed, was used for the study. Sand was placed in layers at a good workable moisture content of 10% and compacted by a steel roller to have a uniform density throughout. At a given height the basic units corresponding to the particular layer are taken and facing tyres were kept along the desired alignment (Figure 4). The wires connecting the facing tyres to the anchor tyres were stretched by applying a small tension and the sand was filled in between and compacted. Thereafter, sand was placed behind the anchor tyres covering the plan area up to the back wall of the Perspex box and compacted. The sand was compacted to a bulk density of 1740 kg/m^3 and had a friction angle of 34 deg. A competed sand model with the loading arrangement is presented in Figure 5. Alternate sand layers were coloured with a black dye to facilitate the identification of failure surfaces.

The model walls were loaded by jacking up against the self contained loading frame (Figure 5). Number of timber planks were placed on the horizontal surface of the model to ensure a uniform application of the load. Thereafter, two hydraulic jacks were placed on the timber planks, along with the proving rings. The hydraulic jacks were jacked up against the loading frame during the load application. The same load was applied through each jack to ensure a uniform intensity of loading.

4.1.1 Loading of the Models within the Anchor Zone

Initially, tests were done with a smaller model of width 250 mm and height 300 mm, and only one jack was used to load the model within the anchor zone. Loading intensity could be increased to 175 kN/m^2 without any indication of catastrophic failure. The outward wall movements increased gradually as in Figure 6. At this loading intensity the uneven surface settlements cause the loading system to slip and model could not be loaded any further.

Figure 4 – Construction of the Model

When the vertical load is applied on top of the anchors a tensile force is mobilized in the elements and the wall could be subjected to an internal instability either by pullout of the anchors or by tensile failure of the connecting wires. The vertical load applied on top of the anchors will also cause an increase of pullout resistance. As the loading increases the tensile force mobilized in the connecting wires increases. The wires will extend under this tensile force causing an outward movement of the wall facing. A failure by pullout is quite unlikely and if the wires do not fail in tension no catastrophic failure will occur.

Another test was done where the facing tyres were connected to anchor tyres with sewing threads. When the loading intensity was increased to 50 kN/m^2 structure failed catastrophically as a result of the tensile failure of connecting threads. The excavation of the failed model and careful identification of the failure points resembled a log spiral shaped failure surface. The factor of safety on internal instability of tensile failure was found to be close to unity.

4.1.2 Loading of the Model behind the Anchor Zone

Another model was subjected to a loading behind the anchor zone by placing the timber planks and the jacks behind the anchor zone (Figure 5). The loading intensity was applied in increments of 5 kN/m^2 and the outward movement of the wall facing was measured. When the vertical loading intensity reached 90 kN/m^2 the wall started to move out at a rapid rate (Figure 7) and the further increase of surcharge was not possible. A wide crack appeared behind the anchors and the wall unit was seen to separate out from the fill as depicted in Figure 8. The stability computation on a rigid wall of similar weight indicated that the wall would have failed by sliding at a loading intensity of 5.7 kN/m^2.

4.2 Model Tests with a Lateritic Fill

The next series of tests were conducted using a lateritic fill material commonly used in filling operations in the country. This type of fill material is quite widely available and less expensive than sand. In fact, all the field anchored tyre earth retaining structures were done with lateritic fill materials. They are a product of insitu weathering of rocks under tropical conditions. The particles greater than 5 mm in size were removed from the original soil considering the smaller size of model tyres. The fines had a liquid limit of 58.0% and a plastic limit of 42.6%. The optimum moisture content was found to be 25% under the standard proctor conditions and the maximum dry density was 1515 kg/m^3.

Figure 5 – A Sand Model Loaded Behind the Anchors

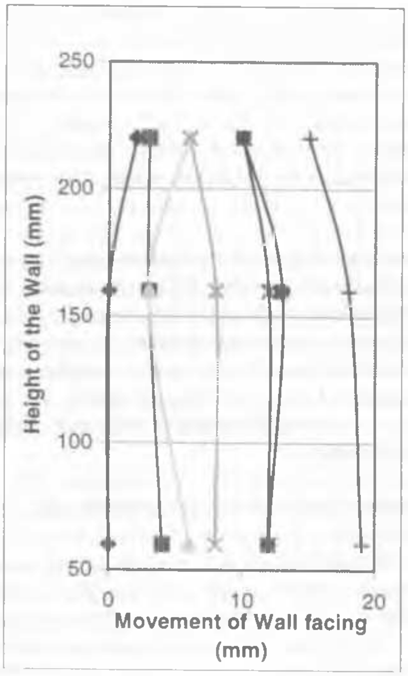

Figure 6 – Outward Movement of the Wall Facing with Loading within the anchor zone

The wall was constructed layer by layer and the lateritic fill material placed at its optimum moisture content was compacted with a specially made drop hammer of weight 6.0 kg falling 0.55 m. A compaction effort equivalent to that in the standard proctor test was given. The compacted fill material is found to have shear strength parameters c = 30.4 kN/m^2 and ϕ = 28.1 deg when tested in the direct shear test setup at a strain rate of 0.29 mm/ min. This high cohesion value obtained was mainly due to matric suction of the unsaturated compacted material.

4.2.1 Model Tests with Loading within the Anchored Zone

In the initial tests done with the smaller models and wires of diameter 6mm, model could be loaded to an intensity of 660 kN/m^2 without any indication of a catastrophic failure. At this point outward wall movements were of the order of 18 mm.

When the diameter of the connecting wires reduced to 3mm, the model could be loaded to an intensity of 176 kN/m^2 at which vertical load slipped due to excessive settlements. The outward wall movements were around 25mm, but still there were no signs of catastrophic failure.

Upon the excavation of model, it was revealed that the maximum outward movement of the anchors were of the order of 1 – 3 mm. Thus the increased movements of the wall facing can be attributed to the extension of the smaller diameter wires.

The larger models could be loaded to intensity of around 300 kN/m^2 without any indication of failure. Even after the saturation of the soil, model wall did not fail. But the outward wall movements were somewhat increased.

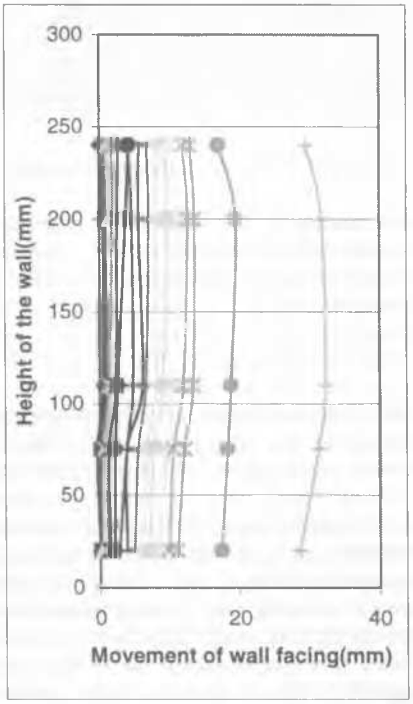

Figure 7 – Outward Movement of the Wall Facing Loading Behind the Anchor Zone

4.2.2 Model Tests with Loading behind the Anchored Zone

When the model was loaded behind the anchor zone, loading intensity could be increased to a value of 280 kN/m^2, before the loading system slipped. The observed outward wall movements were less than 3mm.

5. MODEL STUDIES ON BAMBOO REINFORCED EARTH RETAINING STRCTURES

Model bamboo structures were constructed using 10 mm diameter bamboo rods. Bamboo rods were placed in a 50 mm grid in both directions. Meshes were placed at a vertical spacing of 75 mm. An Aluminum foil used in ventilation work was taken as the facing material. Aluminum foil was used instead of model tyres due to the connection difficulties. Each layer of Aluminum foil was folded back by 50 mm and tied to the bamboo reinforcements. Model studies were done both with the sandy fill and the lateritic fill. The construction stages of a bamboo reinforced model is depicted in Figure 9.

Figure 8 – Separation of the Wall Unit

5.1 Model Tests with a Sandy Fill

5.1.1 Loading within the Reinforced Zone

Initially, smaller models were tested and the models could be loaded to a loading intensity of 300 kN/m^2 without any indication of failure.

Next, a larger model of height 500 mm, length 1150 mm and cross sectional width 400 mm was constructed inside the large Perspex box. The model consisted of six bamboo mesh reinforcement layers. Displacements of the wall facing were measured at load increments of 20 kN/m^2. The arrangement is shown in Figure 10. The vertical surcharge could be increased to an intensity of 260 kN/m^2 without any indication of failure.

Figure 9 – Construction of Bamboo Reinforced Walls

5.1.2 Loading Behind the Reinforced Zone

Another model was loaded behind the reinforced zone in increments of 5 kN/m^2. When the vertical surcharge was 45 kN/m^2, a thin vertical crack appeared at the edge of the loading plate. The crack propagated downward with the increasing loading intensity and at a loading intensity of 90 kN/m^2, wall was moving outward at a rapid rate and further loading us not possible. Thus, the wall is deemed to have failed at the loading intensity of 90 kN/m^2.

A back calculation indicated that if the wall has behaved as a gravity wall of same weight it should have failed by sliding at a load of 29 kN/m^2.

5.2 Model Tests with a Lateritic Fill

Next series of tests were done with a lateritic fill of same properties as used in the tests with anchored tyre retaining structures. The soil preparation and compaction procedures were same as that for the anchored tyre model walls.

5.2.1 Loading of the Model within the Reinforcement Zone

The wall could be loaded to an intensity of 300 kN/m^2. The outward movements of the wall facing were less than 4 mm. The loading was stopped at this stage due to excessive bulging of the Perspex box.

When the fill material is saturated the outward wall movements were around to 8 mm when the load was increased to 160 kN/m^2. But, there were no signs of catastrophic failure.

5.2.2 Loading of the Model behind the Reinforced Zone

The wall could be loaded to an intensity of 280 kN/m^2, before the loading system slipped. The outward wall movements were less than 3mm at this stage and there were no signs of separation of the wall unit as in the case of the wall made with a sandy fill.

When a saturated model was tested a crack appeared at the end of the reinforcement zone at a loading intensity of 200 kN/m^2. When the loading intensity increased to 220 kN/m^2 the crack has propagated to the full depth of the wall and further loading was not possible (Figure 11). This is an indication that wall has failed.

Figure 10 – Loading the Bamboo Reinforced Model Wall

6. CONCLUSION

The model studies on the anchored tyre earth retaining structures reveled that the anchor tyre has a very high pullout resistance and when loaded within the anchor zone it can support very high loading intensities. The applied surcharge itself will increase the pullout resistance and catastrophic failure can be seen only if the connecting wires fail in tension. If wires of smaller stiffness were used the tensile stresses mobilized in them will cause greater extensions which in turn will lead to larger outward movement of the wall. As such, the use of wires of larger stiffness (larger diameter and elastic modulus) will be effective in minimizing the wall deformations.

Figure 11 – Failure of the saturated Bamboo Reinforced Model Wall Loading Behind the reinforced zone

Model walls constructed with lateritic fill showed lesser deformations compared with the models constructed with sandy soils. Even after the saturation of the model, a catastrophic failure could not be induced in the model anchor tyre walls constructed with lateritic fill.

When the load is applied behind the reinforced zone, there was more resistance to overturning or sliding than in the case of an equivalent gravity retaining wall of same weight with both type of fill.

Motor car tyres and nylon wires have a long life and there would not be any problem arising from deteriorating strength. A design procedure was developed for the anchored tyre earth retaining structures (Kulathilaka 1998) by application of the findings of the pullout resistance observed in this research. It was revealed that the field retaining structures of this form has safety factors on internal stability over 6.0.

The model studies on bamboo reinforced earth retaining structures reveled that the bamboo meshes have bond coefficients of the order of 0.9 to 1.0. The bamboo reinforced earth retaining structures could also be loaded to very high loading intensities within the reinforced zone without any indication of failure.

The deformations seen in the bamboo reinforced earth structures were smaller than that seen in anchored earth structure under similar loading conditions. As in the case of anchored tyre earth retaining structures, model reinforced earth walls had more resistance to overturning or sliding than an equivalent gravity wall.

Tensile strength tests conducted on bamboo material showed that they posses tensile strengths greater than 300 MN/m^2, when they are fresh.

A design procedure was developed for the bamboo reinforced earth retaining structures (Kulathilaka 2000) based on applications of the findings of this research. It revealed that the field retaining structures of this form have safety factors on internal stability of the order of 7..

The questionable aspect of the bamboo reinforced earth structures is the deterioration with time. At present studies are been carried out to study the effect of chemicals such as Copper Sulphate, Potassium Dichromate and Coar tar in preserving the strength of bamboos. Bamboos treated with above chemicals are buried in an embankment and their state will be evaluated at different time periods spanning over more than ten years.
The research findings reported in this paper has shown that Anchored Tyre Earth Retaining Structures and Bamboo Reinforced Earth Retaining Structures are not only less expensive, but also are superior on stability aspects when compared with the conventional forms of earth retaining structures.

REFEENCES

1. *Jones C J F P,* (1986) – Earth Reinforcements and Soil Structures – Thomas Telford

2. *Kulathilaka S A S* (1998) – Model Studies on Anchored Earth Retaining Systems and Development of a Design Method – Conference on Earth Retaining Structures – Sri Lankan Geotechnical Society.

3. *Kulathilaka S A S* (2000) – A Study on Bamboo Reinforced Earth Retaining Structures –Research Report University of Moratuwa.

4. *Sumanarathna I H D, Mallawarachchi D P and Kulathilaka S A S* (1997) – Stabilization of Slopes by Anchored Tyre Retaining Structures - Published in the XIV th International Conference of ISSMGE in Germany.