INTERNALLY, STABILIZED EARTH RETAINING SYSTEMS WITH DISCARDED TYRES

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ABSTRACT :

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

In the Sri Lankan road network, earth retaining structures made of discarded motor vehicle tyres were used at number of locations to rehabilitate slope failures and for widening of roads. This paper presents the results of the model studies done on them. Different modes of loads were applied and the resulting deformations were measured.

Model tests on the said structures revealed that they are capable of withstanding very high vertical loading intensities with limited deformations while possessing very high safety margins against ultimate failure.

INTRODUCTION

Internally stabilized earth retaining systems in use today can be separated into three basic categories as: Reinforced Earth, Anchored Earth and Soil Nailing depending on their major method of load transfer and method of construction. The basic components in these internally stabilized earth retaining system are; facing elements, reinforcing elements and the soil. In the reinforced earth construction horizontal layers of reinforcements such as metallic strips, metallic or polymeric mesh , polymeric grids or geotextiles placed at designed vertical spacing are connected to a facing. Facing elements may be formed from metals, precast concrete, brickwork, gabions or geotextiles.

In anchored earth constructions facing elements of an appropriate form are connected by strips or ropes to an anchor element placed at a sufficient distance away from the potential failure zone. Both the reinforced earth and anchored earth constructions are carried out incrementally from bottom up.

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. Reinforcing elements should have a sufficient tensile strength to withstand these forces. Similarly, pulling out of the reinforcements should be prevented by embedding them over a sufficient length in the resistant zone (Figure 1 (a)) . The closely spaced reinforcements and the soil behaves as one structural unit. A facing is used simply to prevent local ravelling, erosion and deterioration. It does not carry any significant structural load.

In anchored earth retaining systems (Figure 1 (b)), forces exerted on the facing elements by the outward moving soils are transferred to the anchor elements through the connecting strip or rod. Stability of the system depends on the pullout resistance of the anchor blocks and/or the tensile strength of the connecting wire/rod. The pullout resistance of an anchor block will depend on its shape, overburden stress and the shear strength parameters of the fill and is developed mainly through the formation of a plastic failure mechanism in front of the anchor element. The resistance developing via interface friction of the strip and top and bottom surfaces of the anchor is much smaller in magnitude. Anchored earth has an advantage over the reinforced earth in relation to the location of the anchor block. In reinforced earth constructions the reinforcing strip should be continued to a sufficient distance beyond the potential failure zone to develop the necessary pullout resistance. However, with anchored earth constructions anchors can be placed just outside the failure zone leaving space for the formation of the plastic collapse mechanism. Thus the necessary width of the structure will be somewhat reduced. Also the higher passive resistance values permit the use of a lesser quality material as fill.

In the 1980's techniques of using anchored earth form of structures evolved simultaneously in Europe, Japan, USA and Sri Lanka. Loop anchored wall with concrete facing and concrete anchor blocks connected by polymeric ties in the form of a loop (Figure 2 –(a)) – Brandl and Dalmatiner – Austria, wall with concrete facing units and steel anchor bars bent to form triangular wedge shaped anchor developed at Transport and Road Research Laboratory - UK. (Figure 2 -(b)) are some examples.

The key aspect of an internally stabilized system is its incremental form of construction. In effect the soil mass is partitioned so that each portion receives support from a locally inserted reinforcing element. Internally stabilized earth retaining structures are flexible and can tolerate large differential settlements and lateral movements. Hence good foundation conditions or special preparation of founding soils is not essential. They can be constructed quite quickly and are operational as soon as constructed. The construction process is quite simple and does not require any special machinery. The cost saving can be up to 50%. The cost saving associated with rapid completion of the structure should also be added.

One of the largest applications of internally stabilized earth retaining system is in the construction of highway and bridge abutments. The speed of construction is a very special advantage specially in the case of repair of highways affected by landslides and in the case of widening of existing highway embankments.

Internally stabilized forms of earth retaining structures are very effectively used in active seismic zones. Many reinforced earth structures remained undamaged in the recent Kobe earthquake (1994) in Japan. In Turkey there is an example of a 3 tier reinforced soil wall road embankment retaining a height of 50 m from foundation to road in an active seismic zone.

For developing countries further advantages could be gained by incorporating locally available inexpensive material. Number of anchored earth retaining structures were constructed at several locations in the Sri Lankan road network, using discarded motor vehicle tyres. Similarly, structures with a tyre facing and bamboo reinforcement meshes were used at some other locations. These structures have performed satisfactorily over 10 years and the research reported in this paper was carried out to study their behaviour and to develop efficient design procedures.

ANCHORED TYRE EARTH RETAINING STRUCTURES IN THE SRI LANKAN ROAD NETWORK

Anchored tyre earth retaining structures can be constructed under any ground conditions if the necessary width is available. As the structure is flexible sound founding conditions are not essential. Facing tyres are placed on the founding soil along the desired alignment, with each tyre being connected to its neighbour using nylon wires of diameter 8 to 10 mm. Alternate facing tyres are then tied to anchor tyres kept at a sufficient distance away from the facing. Maximum of four facing tyres are connected to one anchor tyre. Facing tyres that are not connected to the anchor tyres are kept slightly behind the connected ones to have an interlocking effect. The anchor tyres are kept in the resistant zone and this is ensured by keeping them behind the 45 deg line. Therefore, at a height H from the base, the anchor tyre is kept at a distance of H+1 m from the facing (Figure 3 (a)).

After placement of a layer of facing an anchor tyres the tube face inside the tyres are filled with laterietic fill and is well compacted manually with hand rammers. If the structure is facing a stream or a waterway the tube spacing in the facing tyres are filled with a well graded gravelly material. The anchor tyre is pulled back to ensure that the ropes are well stretched and the fill is compacted to a density greater than 95% of standard Proctor. Once the compaction of a layer is completed a new layer of anchor tyres and facing tyres were placed and the procedure is repeated till the desired wall height is achieved. Although it is not essential. A back batter of 1 :12 is maintained in the structure.

Detailed procedure of the construction of anchored tyre earth retaining structures and details of some of the major structures including cost comparisons with alternate gravity form of structures is given in Sumanarathna et al (1997). Anchored tyre earth retaining structure at Ranwala along Colombo – Kandy road is shown in Figure 3 (b).

STABILITY CONSIDERATIONS

An internally stabilized earth retaining structure should be stable both internally and externally. Internally, it should be stable against pull out of anchor or reinforcing elements and tensile failure of these members. Externally the reinforced block should be stable against sliding, overturning or bearing failure just as in the case of a gravity retaining structure. Internal stability can be evaluated through a tie back wedge analysis done at different levels of the structure. At any given level of the structure the potential failure surface can be considered to be of the shape of a wedge (Figure 4 (a)). A trial wedge considered will be in equilibrium under the forces W, T , S and T eqm. The force T eqm is provided by the anchors / reinforcements intercepted by the wedge through their pullout resistance and tensile strength. An equilibrium analysis will enable the computation of the maximum value of T eqm for a given level. The capacity of the anchors T sum is the lower value of the summation of pullout resistances of the anchors / reinforcements and the summation of the tensile strengths of the anchor wires / reinforcements.

The factor of safety on internal stability can be expressed as FOS = Tsum / T eqm. If the summation of the pullout resistances is less than T eqm, the structure will fail by pullout of the anchors or reinforcements. If the summation of the tensile strengths is less than the T eqm the structure will fail due to the tensile failure of elements. An internally stabilised earth retaining structure should have a sufficiently large factor of safety on internal stability.

External stability is evaluated by considering the anchored/reinforced block as a gravity wall (Figure 4(b)). Factor of safety expressions can be derived against failure by overturning, sliding or for the bearing capacity failure. Detailed computations of stability of anchored tyre earth retaining walls together with a spread sheet program is given in Kulathilaka (1998).

BASIS FOR THE MODEL STUDIES ON THE STRUCTURES

A study on the behaviour of the internally stabilized earth retaining systems would require loading of the structure and measurement of deformations. The outward movements of the facing, the internal strains (and therefore stresses) in the wires and outward movement of the anchors etc. would have to be measured in a study. It will also be necessary to load the structure until failure to identify possible failure mechanisms. The difficulties in attaching strain gauges to nylon wires and bamboos and likely experimental errors, and imposing the large surcharge loads on the real size structures were recognized. Hence it was decided to carry out the study through model tests.

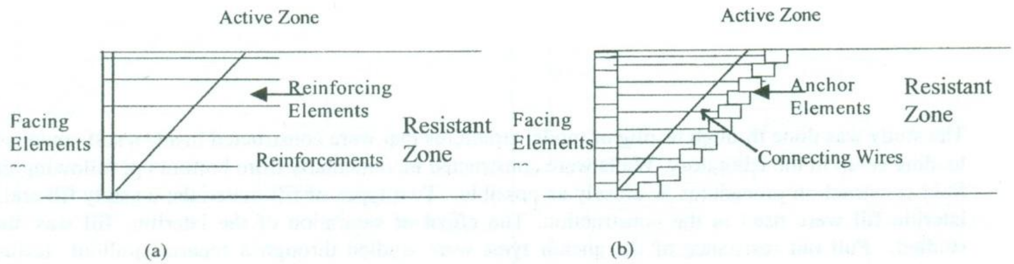
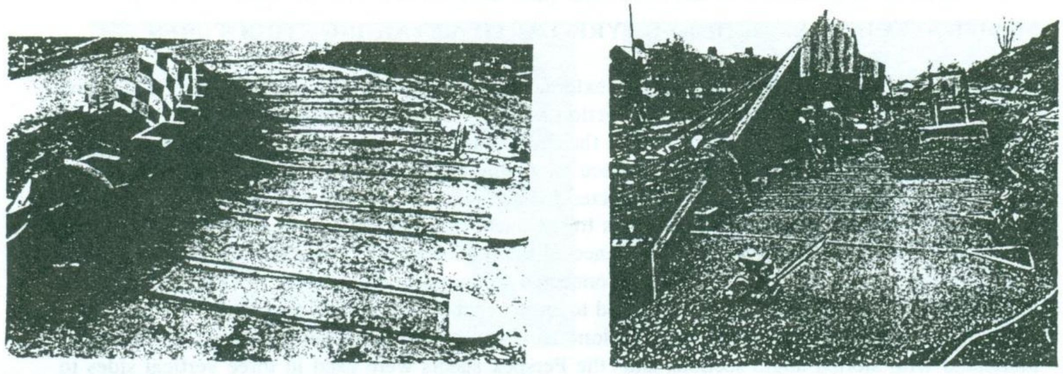


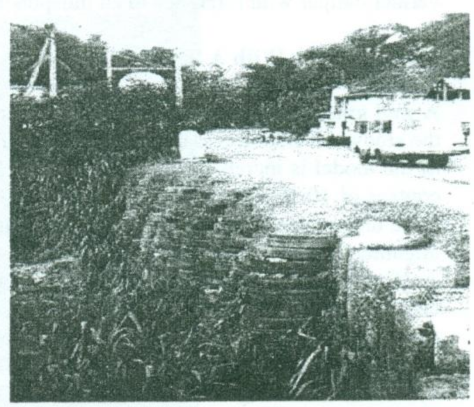
Figure 01-Reinforced Earth and Anchored Earth Concept



Loop Anchored Wall   TRRL – Anchored Wall

Figure 02- Different types of Anchored Earth Structures

(a) Placement of Anchor Tyres and Facing tyres



(b) Completed Anchored Tyre Structure at Ranwala

Figure 03 – Anchored Tyre Earth Retaining Structures in Sri Lanka

The study was done through testing of model structures that were constructed inside a self contained loading setup in the laboratory. Walls were constructed incrementally from bottom up, following the field construction 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 the lateritic fill was also studied. Pull out resistance of the anchor tyres were studied through a separate pullout testing arrangement.

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

MODEL STUDIES ON ANCHORED TYRE EARTH RETAINING STRUCTURES

A model tyre – a reinforced rubber ring of external diameter 55 mm, internal diameter 35 mm and thickness 15 mm, was used in this construction as both facing elements and anchor elements. In the construction of a anchored tyre wall in the field, soil or rubble is filled inside the tube space and well compacted to form a stiff ring. Hence modeling the tyre with a stiff reinforced rubber ring could be justified. Facing tyres were connected to each other by nylon wires and the same type of wires were used to connect the facing tyres to the anchor tyre. The basic unit used in the model structure consisted of three facing tyres connected to an anchor tyre. Adjacent tyres are connected to each other and the two outer ones are connected to the anchor tyre. The distance between the facing tyres and the anchor tyres was varied to ensure that the anchor tyre is kept 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 self contained loading set up. 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 five points were selected and the measurements were done using a vernier caliper with reference to an independent measuring frame.

Model Studies With A Sandy Fill

A well graded sandy soil where particles of sizes greater than 3.35 mm were removed , was used for the study. It was necessary to find a way of ensuring that the sand is placed at a controlled density as the model is incrementally constructed. The sand was found to have a good workable moisture content of 10 % by trial and error. The construction of the model was done layer by layer. The basic units corresponding to a particular layer is taken and facing tyres were kept along the desired alignment. The wire connecting the facing tyres to the anchor tyre was stretched by applying a small tension and the sand was filled in between. Thereafter sand was placed behind the anchor covering the plan area upto the back wall of the perspex box. Moist sand was placed in this manner over the full length of the wall and was compacted by taking a steel roller of weight 2.9 kg, length 190 mm and diameter 50 mm on the sand placed. In order to maintain a uniform density of the structure throughout, the same weight of sand was used for the construction of each layer. Within a layer also sand was placed carefully to ensure a uniform condition. Construction stages of a model retaining structure constructed inside the Perspex box in the self contained loading set up is depicted in Figure 5. The alternate sand layers were coloured in the models to facilitate the identification of failure patterns. The sand had a bulk density of 1740 kg/m^3 and Direct shear tests conducted on sand compacted to the same density yielded shear strength parameters of zero cohesion and $\phi = 34$ deg.

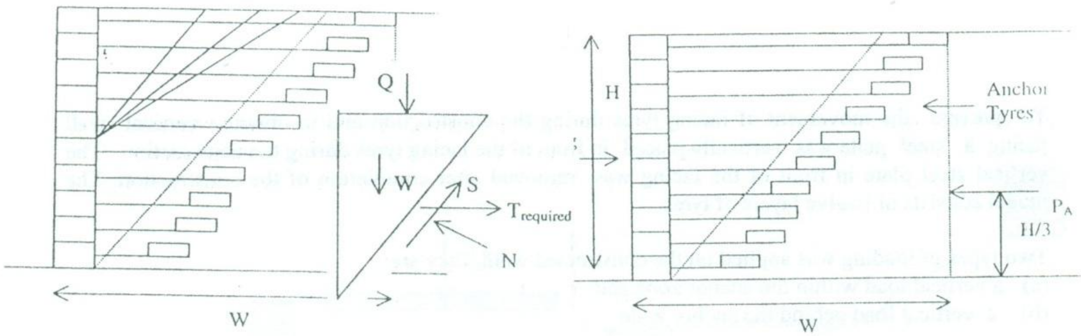
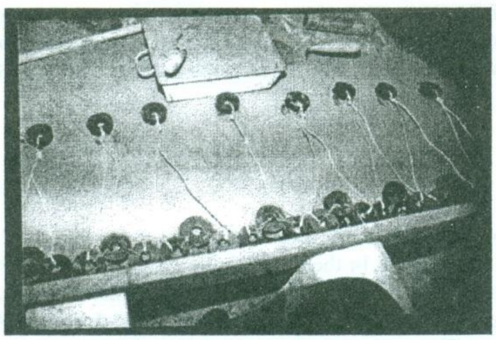
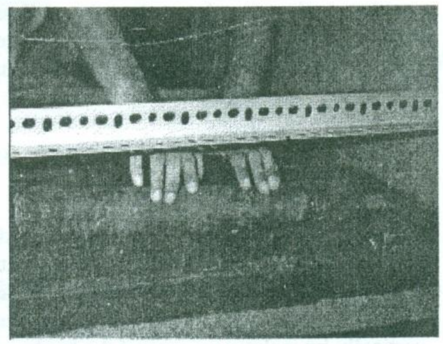


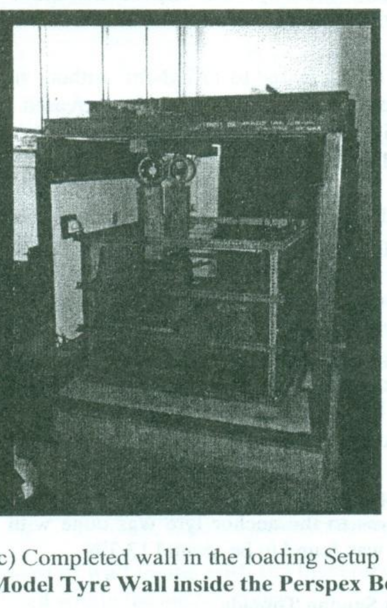
Figure 04 – Stability Criteria for Internally Stabilised Earth Retaining Structures



(a) General Layout of Model Tyres



(b) Compaction Process



(c) Completed wall in the loading Setup

Figure 05 – Construction of Model Tyre Wall inside the Perspex Box under the Loading Frame

To prevent the movement of facing tyres during the construction and to obtain a vertical wall facing a steel plate was vertically placed in front of the facing tyres during the construction. The vertical steel plate in front of the facing was removed after completion of the construction. The model consists of twelve layers of tyres.

Two types of loading was applied on the constructed wall. They are:
(a) a vertical load within the anchor zone and
(b) a vertical load behind the anchor zone.

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 (Figure 6). The deformations of the structure were measured with the incremental application of the load and failure modes (if any) were noted.

<u>Loading of the Model within the Anchor Zone</u>

<u>Model Constructed with Nylon Wires</u>
Initial tests were done with a smaller model of length 300 mm and width (in cross section) 250 mm.Once the wall was constructed to the necessary height in the Perspex box, a number of timber planks were placed on the horizontal surface of the model to ensure an uniform application of the load. Thereafter a hydraulic jack was placed along with a proving ring and the model was loaded vertically by jacking up against the loading frame. The vertical load was applied in increments of 25 kN/m2 and the resulting outward movements of the wall were measured with reference to a measuring frame. Also a close eye was kept on the sides of the Perspex box to identify the possible formation of any failure surface.

Loading intensity could be increased to 175 kN/m^2 without any indication of a catastrophic failure. Increased outward movement of the wall with the increased load is presented in Figure 7. At the loading intensity of 175 kN/m^2 the uneven settlement of the surface caused the loading system to slip and the model could not be loaded any further.

When the vertical load is applied on top of the anchors it could only be subjected to an internal instability either by the pullout of the anchors or by the tensile failure of the connecting wires. The vertical load applied on top of the anchor tyres have increased its pullout resistance preventing that mode of failure. However, this has led to the mobilization of a reasonably high tensile force in the connecting wires. Unfortunately the tensile force on the nylon wires could not be measured due the unavailability of appropriate type of strain gauges. The nylon connecting wires have extended up to a maximum of 20 mm showing an outward movement of the wall facing. Nevertheless, these tensile stresses are not large enough to cause tensile failure of the nylon wire and a catastrophic failure of the model was thus prevented.

Therefore, in an attempt to induce failure another series of tests were carried out where the connection of facing tyres to the anchor tyre was done with threads used in sewing work. The average tensile capacity was found to be around 13.3 N.

<u>Model Constructed with Sewing Threads</u>
The model was constructed in the same manner with the exception that anchor tyres and facing tyres being connected by sewing threads. However the facing tyres were connected with each other

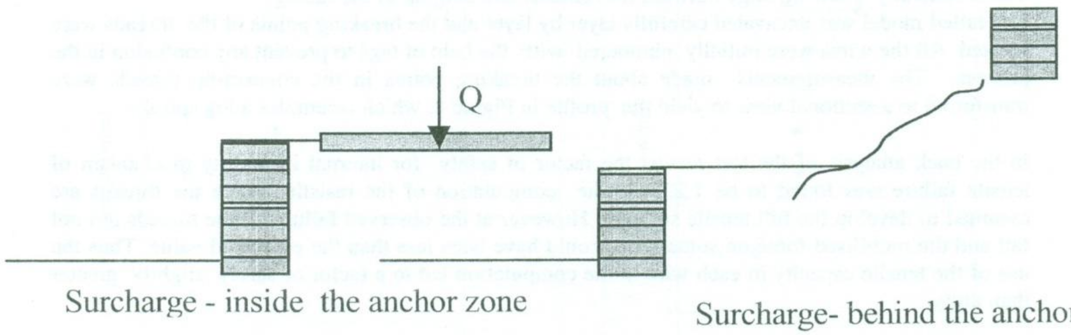


Figure 06- Different types of Loading Conditions

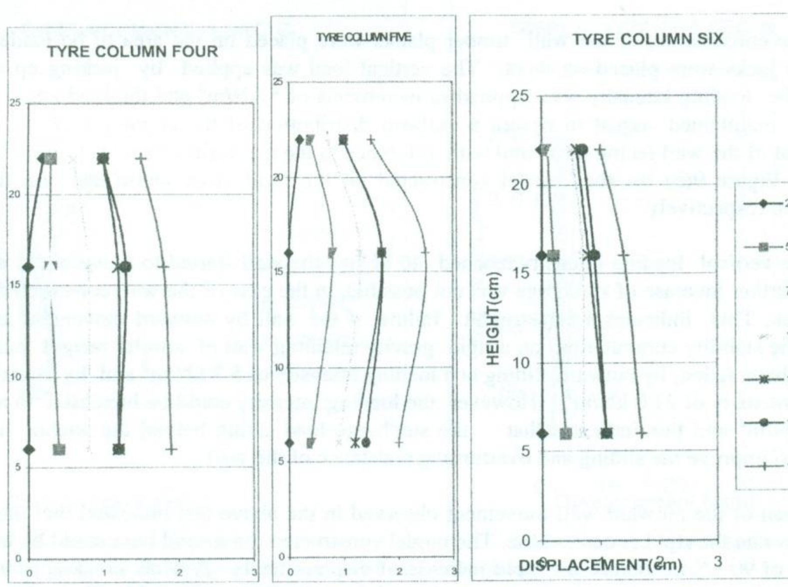


Figure 07– Outward Movement of wall facing with the incremental loading
Small Model – Sandy Fill – Load within the anchor zone

with nylon wires as before. When the loading intensity just exceeded 50 kN/m^2, the structure failed catastrophically showing large outward movements and bulging of the facing.
The failed model was excavated carefully layer by layer and the breaking points of the threads were located. All the wires were initially numbered with the help of tags to prevent any confusion in the process. The measurements made about the breaking points in the connecting threads were transferred to a sectional view to yield the profile in Figure 8, which resembles a log spiral.

In the back analysis of the test results the factor of safety for internal instability mechanism of tensile failure was found to be 1.23. In the computation of the resisting force the threads are assumed to develop the full tensile strength. However at the observed failure all the threads did not fail and the mobilised force on some wires could have been less than the estimated value. Thus the use of the tensile capacity in each wire in the computation led to a factor of safety slightly greater than unity.

Loading of the Model Behind the Anchor Zone

Anchored earth retaining structures may be subjected to a condition of loading where the major load is applied behind the anchor zone as in the case of a wall constructed at the foot of a slope. Under such conditions, the wall behaves effectively as a gravity wall. Thus the external stability criteria were checked by the application of a vertical load behind the anchor zone. Two types of model tests were done, namely ; a wall constructed on a rigid foundation and a wall constructed on compressible soil. The wall on a rigid foundation was simulated by the construction of the model wall directly on the concrete base of the loading setup. A sand fill with same density was placed to a thickness of 200 mm to simulate a compressible base in the other series.

After the construction of the wall timber planks were placed on the area to be loaded and two hydraulic jacks were placed on them. The vertical load was applied by jacking up against the frame. The loading intensity was applied in increments of 5 kN/m^2 and the load applied by each jack was maintained equal to ensure a uniform distribution of the applied load. The outward movement of the wall facing measured with reference to the measuring frame is presented in Figure 9(a) and Figure 9(b) for the model constructed on the rigid foundation and on the flexible foundation respectively.

When the vertical loading intensity reached 40 kN/m^2 the wall started to move out at a rapid rate and the further increase of surcharge was not possible, in the case of the wall constructed on a rigid foundation. This indicates a catastrophic failure of the wall by outward movement as a gravity wall. The stability computation on a rigid gravity retaining wall of similar weight indicated that it would have failed; by outward sliding at a loading intensity of 5.7 kN/m^2 and by overturning at a loading intensity of 21.0 kN/m^2. However the loading intensity could be increased to an intensity of 40 kN/m^2 and this indicates that the surcharge load acting behind the anchor zone is also helpful to improve the sliding and overturning resistance of the wall.

The pattern of the outward wall movement observed in the above test indicated that there is some influence due the rigid concrete base. The model constructed on a sand base could be loaded to an intensity of 90 kN/m^2 before the rapid increase of displacements. A wide crack appeared behind the anchors and wall unit was seen to separate out from the fill as depicted in Figure 10.

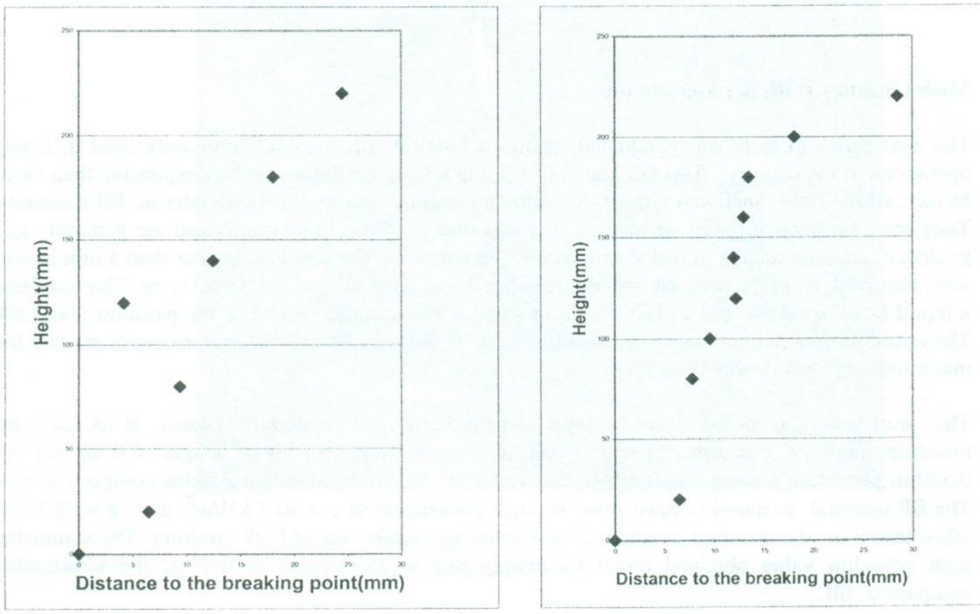
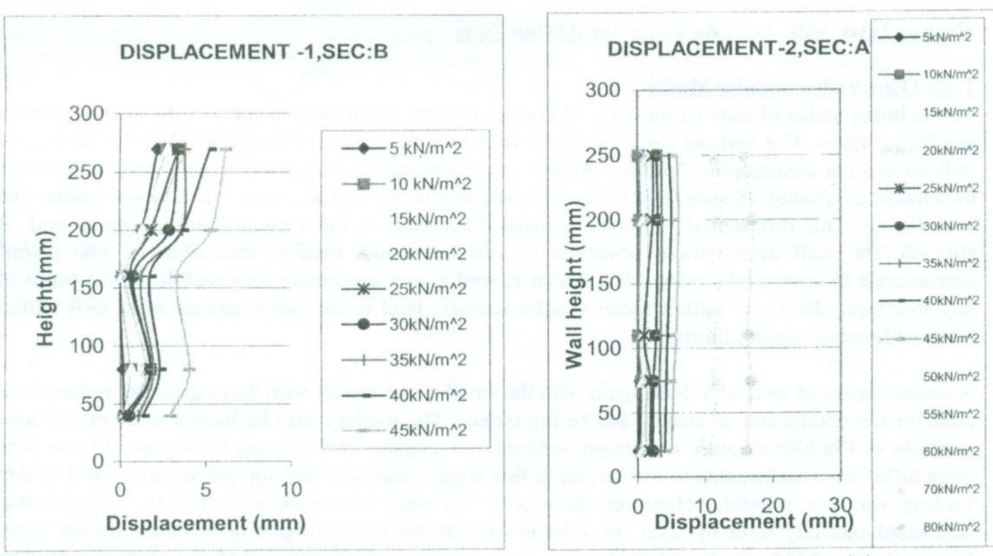


Figure 08 - Failure Profiles of Connecting Sewing Threads



(a) Model on Rigid Foundation (b) Model on Compressible Foundation

Figure 09 -Outward Movement of Wall Facing- Sandy Fill

Loading Behind the Anchor Zone

Model Studies With A Lateretic Fill

The next series of tests was conducted using a lateritic fill material commonly used in filling operations in the country. This 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 and are generally gap graded, containing mainly gravel size and clay size particles. The particles greater than 5 mm in size were removed from the original soil considering the smaller size of the model tyres. The fines had a liquid limit of 58.0% and a plastic limit of 42.6%. The specific gravity of the particles was 2.60. The optimum moisture content was found to be 25.0 % under Standard Proctor conditions and the maximum dry density was 1515 kg/m^3.

The wall was constructed layer by layer and the latritic fill material placed at its optimum moisture content and compacted with a specially made drop hammer of weight 6.0 kg and fall 0.550 m providing a compaction effort equivalent to that in the standard Proctor compaction test. The fill material is found to have shear strength parameters of c = 30.4 kN/m^2 and ϕ = 28.1 deg when tested in the standard direct shear test setup at a strain rate of 0.29 mm/min. The somewhat high cohesion value obtained could be mainly due to the matric suction of the unsaturated compacted fill.

Initial tests were done with a smaller model of height 250 mm (13 layers of tyres), and width 200 mm and the later tests were performed with larger models of height 375 mm (20 layers of tyre) and width 1120 mm.

Results Tests with Loading within the Anchor Zone

Tests Done with a Smaller Model

In the initial series of tests nylon wires of diameter 6 mm were used to connect the anchor tyres to the facing tyres. The vertical load could be increased to an intensity of 660 kN/m^2 without any indication of a catastrophic failure. At this stage the wall facing has experienced an outward movement of around 18 mm. The vertical settlements in the surface were much larger nearer the wall facing. This differential settlement caused difficulties in the vertical loading system and it slipped. The wall deformations observed at the very high loading intensities of 660 kN/m^2 corresponds to strains of around 9.0% which is well above acceptable serviceability limit states of any structure. However within much smaller realistic load levels deformations were well within acceptable serviceability limits.

A second series of tests was done again with the smaller size model with 3mm diameter nylon wires used for the connection of anchor and facing tyres. The model could be loaded to a vertical load intensity of 176 kN/m^2 until maximum outward movements of the facing tyres were 25 mm. The large differential settlements of the surface at this stage caused the loading system to slip and further loading was not possible. However there were no signs of catastrophic failure. Model was excavated carefully layer by layer in order to identify the outward movement of the anchor tyres. Observations made in the top most layer was ignored due to the high level of disturbance caused by surface settlements. The outward movements of the anchor tyres were measured to be 3 mm at level 2, 2 mm at level 3 and around 1 mm at level 4 (Figure 11). No measurable movements were seen in the anchor tyres below this level. Thus the somewhat larger outward movements of the facing can be attributed to the larger extensions in the wires of smaller cross section. The use of wires of larger stiffness will help to minimise the wall deformations.

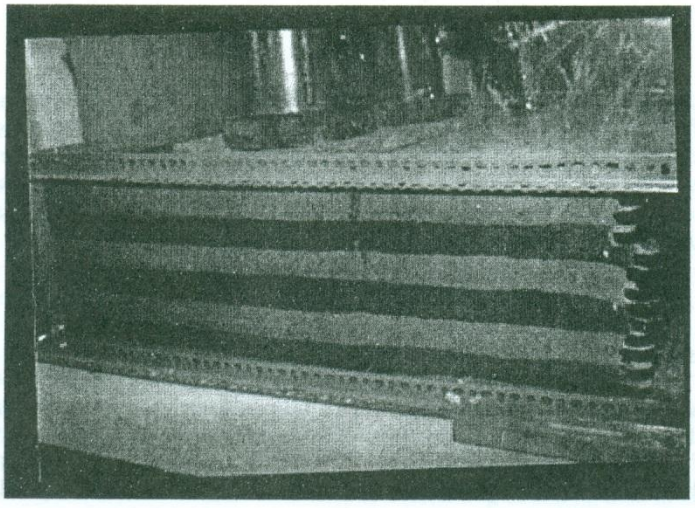


Figure 10 – Separation of the Wall Unit
Loading Behind the Anchor Zone

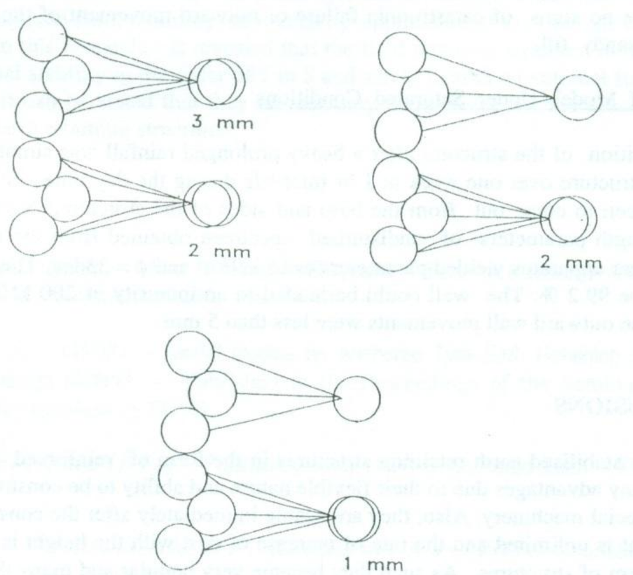


Figure 11 – Outward Movement of Anchor Tyres – Lateretic Fill

The next series of tests were done to simulate the saturation condition that may occur in the field after a heavy prolonged rainfall. The model prepared was kept in a shallow container and was saturated by pouring water frequently on the surface. Subsequently the saturation was found to have reached 100 %. During the application of the vertical load the saturated soggy soil settled by more than 40 mm and outward movements of the order of 40 mm were recorded at a vertical loading intensity of 325 kN/mm^2.

Results of the Larger Model Tests (Loading within the Anchor Zone)

A larger models of height 375 mm, width 1100 mm and sectional width 400 mm were used in the following tests. The construction was done in a similar manner and the loading was applied within the anchor zone incrementally using two jacks. The anchor and facing tyres were tied with nylon wires of diameter 3 mm. The loading intensity was increased to 300 kN/m^2 incrementally without any indication of a catastrophic failure. The load was not increased beyond 300 kN/m^2 due to excessive bulging of the box.

Results of the Model Tests (Loading Behind the Anchor Zone)

A model constructed in the same manner as above in the large Perspex box was loaded from behind using two jacks. The loading intensity was increased to an intensity of 280 kN/m^2 before the loading system slipped. The observed outward wall movements were less than 3 mm at this stage. There were no signs of catastrophic failure or outward movement of the wall unit as seen in the case with sandy fill.

Testing Of Models Under Saturated Conditions

The condition of the structure after a heavy prolonged rainfall was simulated by sprinkling water over the structure over one week at 1 hr intervals during the day time. By this time the sprinkled water is seen to come out from the base and sides of the structure. Subsequent measurement of shear strength parameters of undisturbed specimen obtained from the model, made using the Direct Shear apparatus yielded parameters $c=15$ kN/m^2 and $\phi = 33$deg. The degree of saturation was found to be 99.2 %. The wall could be loaded to an intensity of 200 kN/m^2 without any signs of failure. The outward wall movements were less than 5 mm.

CONCLUSIONS

Internally stabilised earth retaining structures in the form of reinforced earth on anchored earth posses many advantages due to their flexible nature and ability to be constructed quickly without the use of special machinery. Also, they are usable immediately after the construction. The achievable wall height is unlimited and the rate of increase of cost with the height is much lower than for the gravity form of structures. As such they became very popular and many different innovative forms were developed. Most of the retaining structures constructed today to support highway embankments, bridge abutments etc. are of this form. For a developing country further advantages could be gained by the use of locally available material in these constructions.

Models studies reported in the paper were done to study the performance of anchored earth retaining structures made up of discarded motor vehicle tyres. It was also expected to develop rational design procedures. The cost of these structures was as low as 30 - 40 % of an alternate gravity form of structure.

The model studies on the anchored tyre earth retaining structures revealed 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 mobilised in them will cause greater extensions which in turn will lead to larger outward movements of the wall. As such, the use of wires of larger stiffness (larger diameter and elastic modulus) will be effective in minimising the wall deformations.

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 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 types of fill. Motor car tyres and nylon wires have a long life (at least 50 years), and there would not be any problem arising form deteriorating strength.

A design procedure was developed for the anchored tyre earth retaining structures (Kulathilaka 1998) and bamboo reinforced earth retaining structures by application of the findings of the pullout resistances observed in this research. It revealed that the field retaining structure of this form has safety factors on internal stability in the order of 7 to 8 and safety factors on external stability in the order of 3 to 4. Thus it can be stated that they are not only inexpensive but are more stable than alternate gravity type earth retaining structures.

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