Stabilization of slopes by anchored type retaining structures
Stabilisation de talus par des structures de soutènement du type ancrage

I. H. D. Sumanarathna – *Road Construction and Development Company, Sri Lanka*
D. P. Mallawarctchie – *Road Development Authority, Sri Lanka*
S. A. S. Kulathilaka – *University of Moratuwa, Sri Lanka*

Abstract

Anchored earth retaining systems constructed using discarded motor vehicle tyres are used in number of locations in the Sri Lankan highway network for restoration of failed slopes and embankments and for widening of roads

These structures are found to be very cost effective making savings of more than 60% from alternate conventional structures. They could be rapidly constructed and have a very high safety margin. Labour intensive construction process does not demand specialised machinery or skilled labour. As such this system is ideally suitable for a developing country like Sri Lanka.

1. Introduction

Number of Earth retaining structures were constructed at around 40 locations in the Highway network of Sri Lanka using discarded motor vehicle tyres. Usually the larger tyres used by lorries, motor coaches and trucks were incorporated. These structures were well distributed in various parts of the country. Large majority of them exist in the central districts of the country where hilly terrain prevails and frequent slope failures were observed. In most instances these structures were deployed to rehabilitate failed slopes and embankments. They were also used for the purpose of widening existing roads.

The concept of Anchored Tyre Earth Retaining Structures was developed by the first author and all the constructions were done by Road Construction and Development Company.

Tyre retaining walls could be erected very rapidly without the use of specialised equipment. Method of construction is generally labour intensive. The cost of the Tyre retaining structures were found to be less than 40% of alternate conventional gravity type structure.

All the structures constructed so far perform satisfactorily without a single record of failure.

2. Working Principle of Tyre Retaining Structures

Tyre retaining structures are essentially a type of anchored earth retaining systems. Therefore they will be referred to here as "Anchored Tyre Earth Retaining Structures". Thus it can be classified as an internally stabilised earth retaining system.

Both the facing elements and the anchor elements of the structure are made of discarded motor vehicle tyres. Several facing tyres are connected to an anchor tyre kept at a sufficient distance behind the facing.

When the soil embankment attempts to move outward it has to take the facing tyres with it. As the facing tyres are connected to the anchor tyres this will generate a tensile force in the connecting rope. If the ropes are strong enough so that they will not fail in tension and if the pullout resistance of the anchor tyre is greater than the developed tensile force, the structure will remain stable.

3. Construction of Anchored Tyre Retaining Structures

3.1 Foundation Conditions

Anchored tyre earth retaining structures are highly flexible and can accomadate considerable differential settlemnts . As such they do not require very sound foundation conditions. They can be erected on generally stable ground . If necessary natural ground may be compacted by several roller passes. If the structure is constructed adjacent to a stream or waterway sufficient precautions must be taken to ensure that no erosion will take place below or behind the facing tyres.

3.2 Placement of Tyres and Compaction of Fill

Placement of Tyres

Facing tyres are placed on the founding soil along the desired alignment. Each tyre is connected to its neighbour with nylon ropes. Ropes of diameter 8 - 10 mm are normally used. Alternate facing tyres are then tied to anchor tyres kept at a sufficient distance away from the facing. (Plate 1). Maximum of four facing tyres are connected to an anchor tyre. Figure 1 depicts a plan view of the arrangement of facing and anchor tyres. Facing tyres that are not connected to the anchor tyres are kept slighly behind the connected ones to have an interlocking effect.

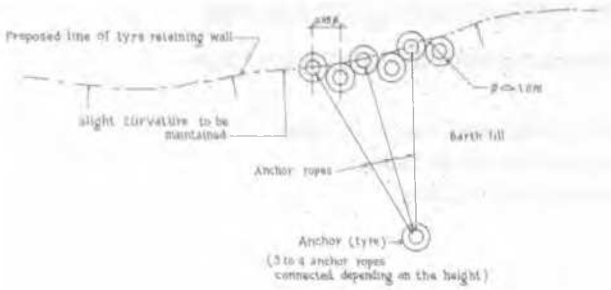

Figure 1 - Plan view of Anchor and Facing Tyre Arrangement

Plate 1 - Placement of Anchor and Facing tyres

Inclination of the critical failure surface to the horizontal (θ) is greater than 45 deg for conventional gravity type structures. Hence the anchor tyres were placed at a location behind a 45 deg line drawn from the base of the wall. At a height H from the base therefore the anchor tyres should be at a distance greater than H from the facing. In practice at a height of H m the anchor tyres were placed at a distance equal to or greater than (H+1.0) m.

Compaction of Fill

Reddish brown lateretic fill material widely used in earth constructions in the country are used as the fill material. Soil with a Plasticity Index lower than 15 and a Proctor dry density greater than 1600 kg/m^3 are recommended for use in these structures.

After placement of a layer of facing and anchor tyres the tube space inside the tyre is filled with lateretic fill and well compacted manually using hand rammers. (Plate 2). If the structure is facing a stream or waterway tube space in the facing tyres are filled with a well graded gravely material.

Anchor tyre is pulled back to ensure that the ropes are well stretched and then the fill is properly placed. Fill is then compacted using rollers or rammers to a dry density above 95% of the standard Proctor dry density. Heavy compaction equipment were not brought very close to the facing tyres. In the close vicinity of the face hand held rammers or vibrating plates are used. Once the compaction of a layer is completed new layer of anchor and facing tyres were placed and the procedure is repeated till the desired wall height is achieved. As the level of the fill increases the necessary spacing between the facing and anchor tyres must be maintained. Although it is not essential, a batter of 1:12 is maintained in the structures. (Figure 3).

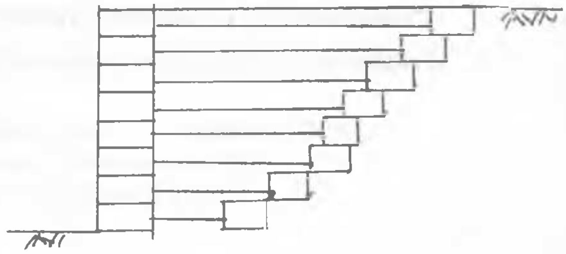

Figure 2 - Anchored Tyre Structure - Cross section

Plate 2 - Compaction of Fill Inside the Tube Space

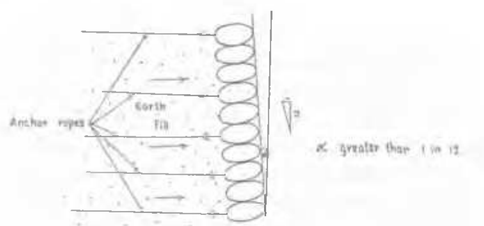

Figure 3 - Batter of the Facing Tyres

3.3 Multi tier Structures (Cascade Structures)

Although there is no limit to the height of the retaining structure that could be built by this method the height of a single structure constructed so far was limited to about 5.5 m. Where it is necessary to have a higher embankment, construction was done in several tiers. At Utuwankanda in the Colombo - Kandy road it was a three tiered structure.

4. List of Constructed Anchor Tyre Retaining Structures

Out of the more than fourty structures constructed to date details of 10 major structures are presented in Table 1. Table provides information such as,locations, length and height, construction period, date of completion, reason for construction, cost of the anchored tyre structure and estimated cost of an alternate conventional structure of random rubble masonry or mass concrete. In all these constructions tyres used were of diameter 1.0 m and nylon ropes used were of diameters 8 mm and 10 mm. Compaction was done with rollers and rammers.

Most of the constructions were done by the Rathnapura and Kegalla district branches of the Road Construction and Development Company in association with relevant district officers of Road Development Authority.

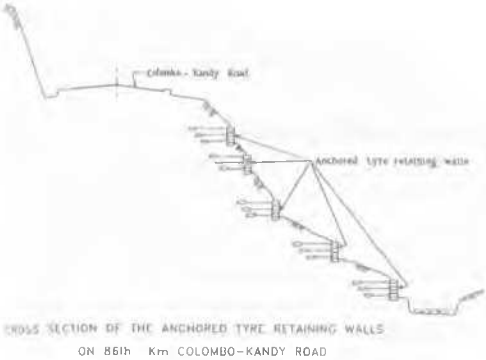

Figure 4 - **Multi - tier (Cascade Type) Stucture**

Plate 3 - Completed Anchored Tyre Stucture at Ranwala

Plate 3 provides a view of the completed structure at Ranwala in the Colombo - Kandy road and Plate 4 presents a view of the cascade type structure at Utuwankanda in the Colombo - Kandy road.

5. Factor of Safety Expression

As outlined already in section 2 of the paper the outward movement of the fill retained will generate a tensile force in the rope connecting facing tyres to the anchor tyres. Failure of a anchored tyre structure can happen either by;

- Failure of connecting rope in tension or
- Pulling out of the anchor tyre

Pull out resistance of an anchor tyre depends on the overburden stress at the level of the anchor and shear strength parameters of the compacted fill. Different pullout failure modes can be assumed for the derivation of pullout resistance. If the structure consist of n level of tyres, the pull out resistance available at each level can be computed and the

Plate 4 - Completed Anchored Tyre Structure at Utuwandanda

Total pullout resistance can be expressed as $T_{pullout}$, where $T_{pullout} = \Sigma T_{i,pullout}$. If the tensile strength of the wire if $T_{i,tensile}$ the capacity of anchor force due to tensile strength can be expressed as $T_{tensile} = \Sigma T_{i,tensile}$. The ultimate anchor force that can be provided by system is the lower value of the $T_{pullout}$ and $T_{tensile}$.

For Simplicity by assuming a wedge shaped failure zone (Figure 5) the anchor force T that is required for equilibrium $T_{eq'm}$ can be obtained. This depends on the assumed wedge angle θ and the critical $T_{eq'm}$ can be found. The Factor of safety of the structure can be defined as;

$$FOS = \frac{Anchor\ Force\ Available}{Anchor\ Force\ Required\ for\ Equilibrium}$$

$$FOS = \frac{Lower\ value\ of\ T_{pullout}\ and\ T_{tensile}}{T_{eq'm}}$$

Factor of safety of the anchored tyre retaining structure at Ranwala in Kegalle district was found to be 20.0.

6. Model Studies on Anchored Tyre Structures

Anchored tyre retaining structures are found to be a very cost effective alternative to the conventional type structures. As there is a need to understand the behaviour of these structures more closely a program of model studies is now being conducted at the University of Moratuwa. A model retaining wall is constructed with model tyres building up the structure in layers closely simulating the field procedures. The model structure is then loaded vertically and deformations and failure modes of the structure were monitored. Studies are also being carried out about the pullout resistance of the anchor tyres. Results obtained to date are very encouraging and indicate that there is a very high safety margin with these structures.

7. Conclusions

Large number of retaining structures were constructed in the Sri Lankan road network using discarded motor vehicle tyres. They are based on the anchored earth principle and all structures perform satisfactorily to date without the record of a single failure.

This is a very cost effective alternative to the conventional

Table 1 - Major Anchored Tyre Retaining Structures

Details of Some Major Anchored Tyre Earth Retaining Structures							
Location	Length (ft)	Height (ft)	Duration of Construction	Date of Completion	Cost of the structure	Approximate Cost of alt. str.	Reason for construction and special features
CRW Road - 170 km	80	17	2 months	Apr. 1990	Rs. 400,000/=	Rs. 1,500,000/=	To restore failed embankment
CRW Road - 169 km	100	10	2 months	Aug 1993	Rs. 300,000/=	-	Conventional wall not possible
CRW Road - 163 km	60	25	4 months	Aug 1996	Rs. 600,000/=	Rs. 2,500,000/=	Gravel filter provided
CRW Road - 164 km	20	15	1 month	Aug 1996	Rs. 100,000/=	Rs. 300,000/=	Extension of bridge abutment
CRW Road - 145 Km	50	13	2 months	Dec 1992	Rs. 60,000/=	Rs. 150,000/=	Restore failed embankment
CRW Road - 100 km	40	15	1 month	Dec 1994	Rs. 120,000/=	Rs. 300,000/=	To widen the existing road
Kahawatta	90	12	1 month	June 1992	Rs. 150,000/=	Rs. 300,000/=	To widen the existi ; Road Gravel packing is used.
Kalawana	150	15	3 months	June 1994	Rs. 350,000/=	Rs.1,000,000/=	Fd'n not suitble for other walls.
Utuwandanda	150	60	9 months	Dec 1990	Rs. 2,400,000/=	Rs. 6,000,000/=	Restore slope - Cascade structure
Ranwala	80	18	4 months	Apr. 1991	Rs. 600,000/=	Rs. 2,000,000/=	Gravel packing used in tyres

Remarks :
CRW Road - Colombo Rathnapura Wellawaya Road
Utuwankanda and Ranwala are in the Colombo - Kandy Road

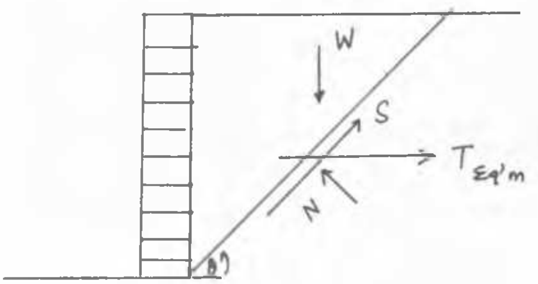

Figure 5 - Stability Analysis of Anchored Tyre Structures

type structures. As it is a highly flexible structure good foundation conditions are not essential. Also it is a permeable structure and water in the backfill will be drained easily. Method of construction does not demand any special machinery and is labour intensive. Hence it is ideally suitable for a developing country like Sri Lanka. These structure can be constructed very rapidly and are operational soon after the completion. Hence it is an ideal method for rehabilitating failed embankments. Once the structure is completed trees or grass that are indeginous to the respective locations were planted on the facing. This will make the structure blend harmoniously with the environment.

Nevertheless as the anchor tyres should be kept at a sufficient distance away from the facing, it should be possible to provide the necessary width. Construction activity such as removal of material that would be required to obtain the necessary width should not cause futher failures. That is the major limitation in this system.

8. Acknowledgements

The authors are indebted to Mr. M. B. S. Fernando, Chairman RDA/RC&DC and Mr. Densil Senanayaka former General Manager RDA for their inspiration direction and continued interest in the project. The whole hearted co-operation extended by Mr. S Mahendran Privincial Director is also acknowledged. The assistance rededered by the Engineers Mr. Dammika Karunasena, Mr. M. M. Thevarajah, and Mr. W. Wimalasiri in the construction is highly appreciated.