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Design and performance of three reinforced earth tiered walls

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ABSTRACT: Three tiered Reinforced Earth walls were recently designed and constructed for the Tennessee Department of Transportation. The overall height of the structures range from 17.5m to 30.5m. This paper will discuss the design, construction method and performance of the three tiered structures.

1. INTRODUCTION AND BACKGROUND

1.1 *Owner, location and purpose of project*

In June 1991, the Tennessee Department of Transportation (TDOT) let to contract a project that would relocate and widen U.S. Highway 23 from the town of Erwin in Unicoi County to the North Carolina state line. This work is part of a series of projects which are creating the future extension of Interstate Highway 181 from Johnson City, Tennessee to Asheville, North Carolina.

The US Highway 23 project is located in the rugged terrain of the Great Smokey Mountains, in Eastern Tennessee. As a result, construction of the highway required massive cuts into rock and huge fills. An obvious problem for TDOT was the large amount of highway right-of-way which would have to be purchased to accommodate the large fill slopes.

1.2 *Wall system*

TDOT chose to solve the problem by constructing MSE walls to retain the fills. They selected the Reinforced Earth® technology which they had already used on several major projects, such as the Foothills Parkway project 6 years before.

The Unicoi County project consists of seven locations across steep ravines. Four locations have single walls, the tallest of which is 11m high. For the three other locations, the overall heights of the retaining walls are 17.5m, 28m and 30.5m, not including the slopes on top. Each of the structures supports a sloped embankment (2 horizontal over 1 vertical) up to 38m high, upon which the highway is constructed. For these high and heavily surcharged structures, TDOT decided to utilize tiered structures, with relatively wide intermediate terraces

1.3 *Size of contract and records beaten*

Altogether, the contract included 6,800 square meters of Reinforced Earth concrete facing panels and 138.6 kilometers of high adherence 50x4mm galvanized steel reinforcing strips. The total volume of Reinforced Earth is about 69,500 cubic meters. The construction of the walls began in July 1993 and was completed in September 1994.

The tallest tiered structure of the Unicoi County project is to date also the highest MSE wall ever built in the USA, and one of the six highest Reinforced Earth walls in the world.

2 DESCRIPTION OF THE PROJECT

2.1 *Geometry*

Table 1 summarizes the main data regarding the geometry and configuration of the three tiered walls.

The highest structure, Wall 2, even includes another 11.0m high Reinforced Earth retaining wall, at the

Table 1. Description of the tiered structures.

Structure	Founded on	Maximum height	Set back from previous tier	Length of strips	Area of facing
		m	m	m	m²
WALL 2					
Tier 1 (bottom tier)	Bedrock	12.0	--	14.6	742
Tier 2	RE mass & rockfill below	10.0	11.0	14.6	1041
Tier 3 (upper tier)	RE mass & rockfill below	10.0	11.0	7.3	1287
Sloped embankment	RE mass & rockfill below	38.0	--	--	--
Tier 4 (top of slope)	Fill slope	11.0	48.0	8.0	496
Total		67.7	--	--	3566
WALL 4					
Tier 1 (bottom tier)	Bedrock	9.0	--	10.4	418
Tier 2 (upper tier)	RE mass & rockfill below	10.0	11.0	9.0	668
Sloped embankment	RE mass & rockfill below	4.6	--	--	--
Total		22.3	--	--	1086
WALL 6					
Tier 1 (bottom tier)	Bedrock	10.0	--	11.6	385
Tier 2	RE mass & rockfill below	10.0	11.0	14.6	595
Tier 3 (upper tier)	RE mass & rockfill below	10.0	11.0	9.8	646
Sloped embankment	RE mass & rockfill below	4.2	--	--	--
Total		31.9	--	--	1626

very top of the high sloped embankment right under the highway. Since it is located at one end of the structure and not in the middle, it does not add to the total maximum height. Figure 1 shows the cross section of Wall 2 where this tiered wall is highest. Photos 1 and 2 give overall views of the same structure.

2.2 *Set-back and terraces*

The 11.0m set-back between the different tiers is quite large. The Owner chose to have this space left flat and practically horizontal, for easier maintenance and in order to let rain water uniformly spread out and filter through. As a matter of fact, these terraces are made of the same very coarse and extremely draining material selected for the Reinforced Earth backfill. These terraces are, however, softly graded along the wall.

The large set-back also results in lesser influence of the upper tiers on the lower tiers and in relatively low stresses and low densities of reinforcements, at least for structures of this height.

Because of the width and horizontal set-back of the terraces, the nature of the backfill which keeps any risk of erosion out, and the moderate load at the base of the tiers, the embedment of the individual walls could be limited to a minimum 0.70m.

2.3 *Drainage*

The drainage of the structures and of the embankment, designed by TDOT, essentially consists in the use of a solid rock material. This rockfill is used all over the mass of the backfill behind the tiered walls and up to the benches excavated into the bedrock. The same material extends above, at the interface of the current embankment material and the bedrock. This is completed with a network of perforated drain pipes, ⌀ 20cm, wrapped in filter cloth, and outlet pipes, also ⌀

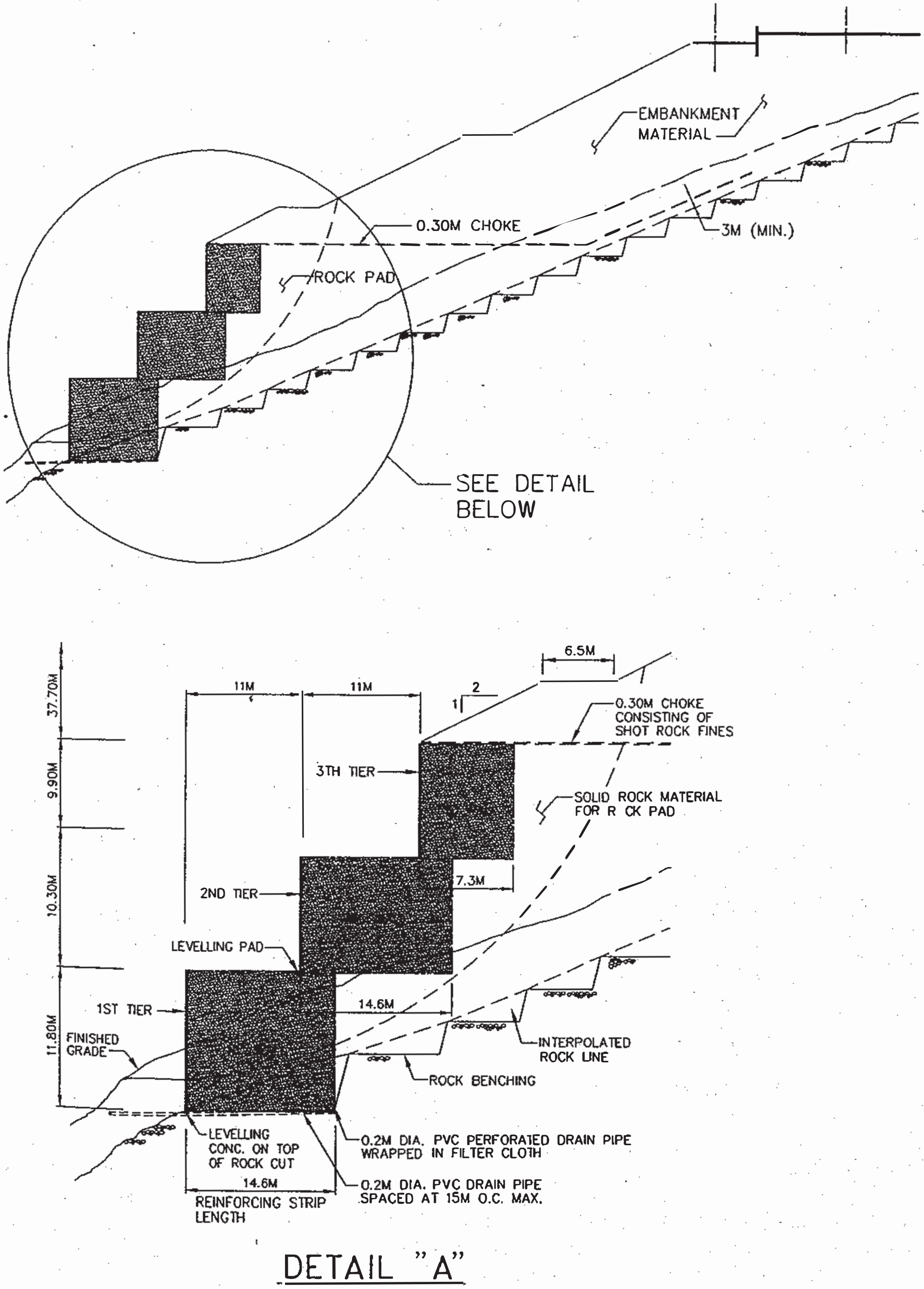
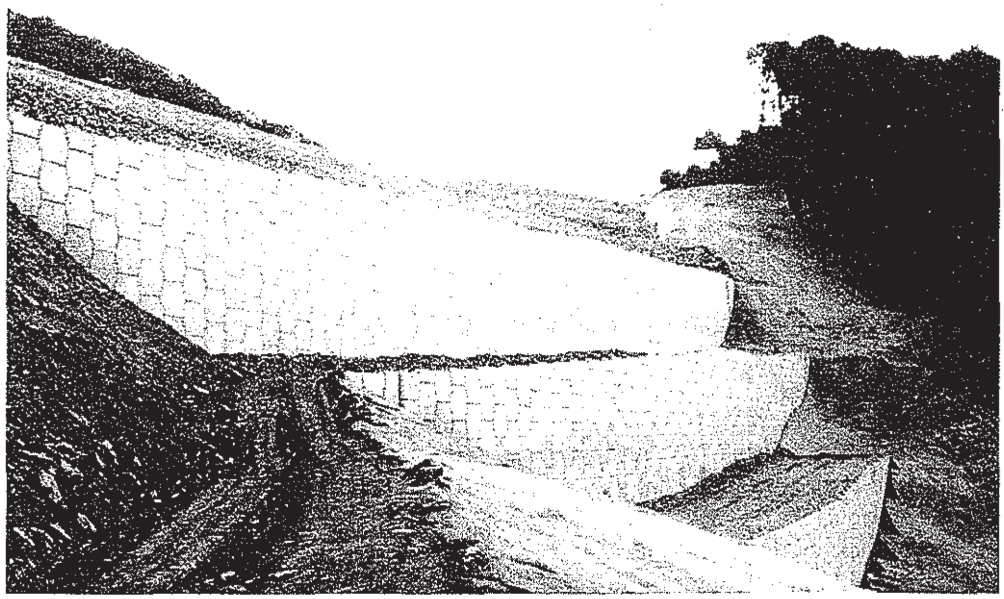
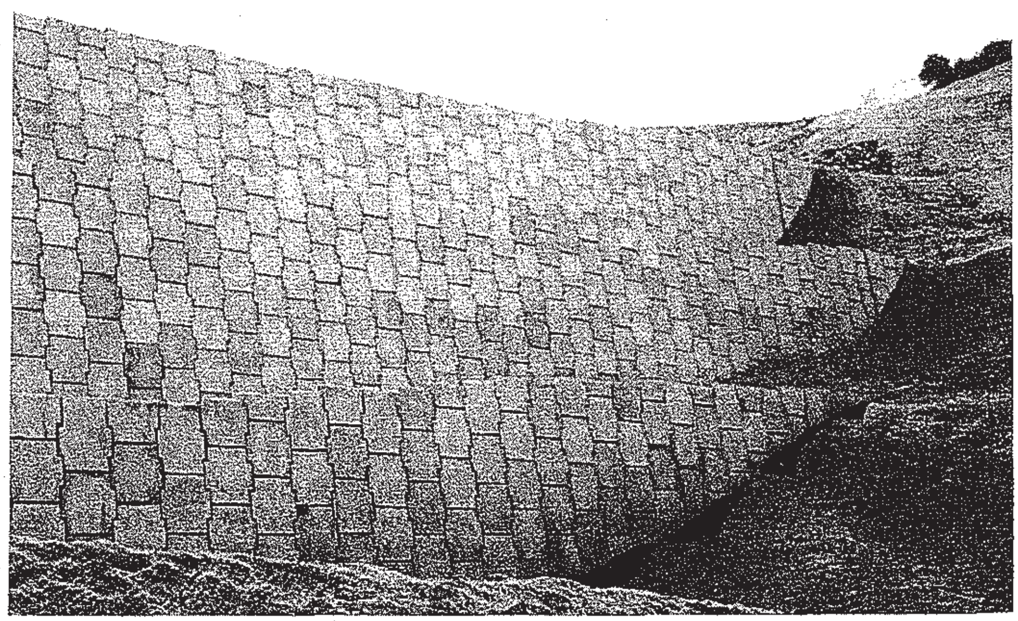


Figure 1 Wall 2 Section at Station 24 + 50



Photograph 1 Side view of three tier structure and sloping embankment atop



Photograph 2 View of three tier structure from roadway in front of it

20cm, at the base of the bottom wall.

3. DESIGN CRITERIA AND METHODOLOGY

3.1 *Internal stability*

Due to the large offset of 11.0m between the tiers, each tier could be considered as an independent wall and designed according to the current standard design method. Each tier is considered as a rectangular coherent gravity wall submitted to a series of external loads.

Any lower tier, beside the weight of its own mass, withstands the vertical and horizontal forces transferred from the Reinforced Earth wall above, as well as the earth pressure coming from the backfill behind and from the surcharge of soil on top of it. The variation of the earth pressure behind every individual Reinforced Earth wall is derived from a Coulomb failure wedge analysis carried out at the level of each layer of reinforcements, from top to bottom.

In checking the pull-out capacity of the reinforcements, the surcharge of backfill applied at the top and the back of the lower tiers was assumed to spread out within a 2:1 angle, into the reinforced mass.

It can be noted that with much narrower berms between the tiers, the tiered structure would have been considered as a whole. Such steep tiered structures can be somewhat likened to a sloping wall, and designed according to the method developed by Terre Armée Internationale (Segrestin, Fiorentini & Spiti, 1991).

3.2 *Overall stability*

TDOT had performed overall stability analysis for a number of sections, in order to assess the stability of the large road embankments, with various configurations and combinations of backfill materials.

In addition, The Reinforced Earth Company also ran a series of overall stability calculations, limited to the regions of the embankments directly supported by the tiered structures. These studies consisted of some double wedge equilibrium analysis and, mainly, slip circle analysis. The considered slip circle failure lines were allowed to go through the reinforced zones, where the potential contribution of each individual layer of reinforcements was taken into account. Such failure lines can originate for example from far above and behind the upper tier, and end across the reinforcing layers of the bottom tier, as shown on the cross section, Figure 1. This kind of analysis, therefore, pertains altogether to the external and the internal stability of the structure. It constitutes a useful cross checking of the current internal design method for structures of such unusual geometries.

4. CONSTRUCTION METHODS

4.1 *Backfill materials and compaction procedure*

The select granular backfill for these walls was an open graded crushed gneiss. This material was excavated, crushed and screened from the project site by the Contractor. The particle size ranged from 3cm to 15cm. The select fill was placed in even lifts of 37.5cm and was compacted by means of a 10 ton vibratory smooth-drum roller.

Due to the open-graded nature of the material, TDOT was unable to test the in-place density of each lift, so it was decided that three passes with the vibratory roller for each lift of backfill would be adequate.

The random fill behind the select fill was composed of shot rock, mostly granite, which the Contractor also excavated, crushed and screened from this project site. The particle size for this material ranged from 3cm to 30cm.

The parameters of these fill materials are as follows:

	Select RE fill	Random fill
Friction angle	35°	35°
Unit weight (kN/m^3)	20.7	18.0

Table 2. Fill parameters

4.2 *Construction rates*

Construction of the walls was performed by Vecellio & Grogan Inc. Contractors. For the tiered walls the average production rate was about 60 m^2 per day.

5. PERFORMANCE AND CONCLUSION

The construction of the tiered walls was completed in June 1994, without the slightest problem. No post construction movement or settlement of any of the walls, nor bulging of facing panels has been observed.

The overall performance of the walls has been very good; it confirms, once again, that the classical Reinforced Earth technology and design method leads to high performance structures and safe design, even for walls of large size and unusual geometries. The good quality of the backfill material and the way it is placed and compacted, in strict compliance with the specifications, is clearly a key for such achievement.

REFERENCES :

Segrestin, P. Fiorentini, F. & Spiti, F. 1991. Design of sloped retaining structures or slope stabilization with Reinforced Earth. *Italian Building and Construction* 73-82.