New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)
© 2008 Taylor & Francis Group, London, ISBN 978-0-415-45775-0

Design considerations of earth reinforced structures using inextensible reinforcements in heavy load surcharge support capacity

P. Wu & W.J. Brockbank
Reinforced Earth Company Ltd., Mississauga, Ontario, Canada

ABSTRACT: This paper presents the Reinforced Earth® design considerations carried out in using In-Extensible reinforcement in the application of Mechanical Stabilized Earth (MSE) structures in the support of heavily loaded surcharged and high retaining structures. Design methods and considerations, as well as critical performance criteria are demonstrated through actual project case histories in MSE applications in:

1. Mining crusher and dump structures supporting huge trucks in the oil sands operations in Alberta, Canada,
2. MSE Abutment walls loaded with footing pressures of 550 kPa, and
3. Heavily loaded rail structures Cooper E90 load in British Columbia and Ontario, Canada

The load-supporting capacity of in-extensible reinforcement MSE structures is illustrated and discussed against horizontal deflection and movement design criteria, settlement consideration, and post-construction performance and safety requirements.

1 INTRODUCTION

The main difference between MSE walls supporting heavy surcharges and conventional MSE walls is the high stress level to which the walls are exposed. Under this high stress condition there is potential for large deformations to occur unless the components of the wall are sufficiently stiff to resist the high loads. Since high deformations are generally not acceptable in these structures it is necessary to use high modulus materials to control the strains. Vertical consolidation of the fill is generally controlled by the selection of high modulus backfill, consisting of well graded granular material compacted to a high relative density. Horizontal deformations are controlled with the selection of high modulus or inextensible steel soil reinforcement.

Also of great importance in highly loaded MSE walls is the issue of strain compatibility. A clear example of this can be seen in comparing the compression of the MSE backfill with the compression of the facing. In order to not overstress the soil reinforcement's connection to the facing it is necessary to have a compressible facing. This is accomplished in two different ways. The first way is to use a flexible wire mesh facing, which can compress and bend as the backfill behind it consolidates. The second way is to introduce a compressible component into the facing. This is done in the case of precast faced structures by introducing compressible pads in the horizontal joints. By allowing these pads to compress as illustrated in Figure 1, the facing in effect, will consolidate at the same rate as the backfill behind.

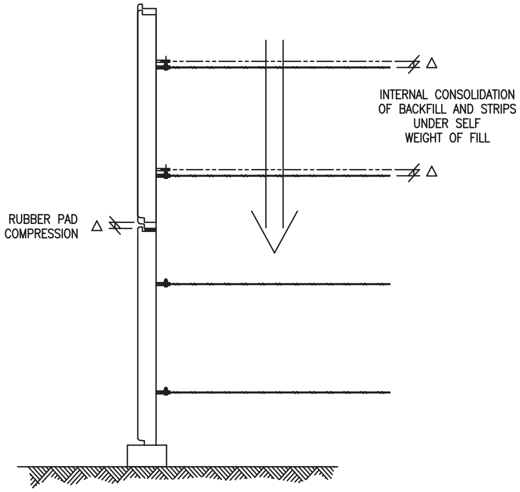

Figure 1. Internal settlement accommodated with compressible pads between precast panels.

2 HISTORY

An early example of an MSE wall supporting a high load is the industrial wall at Dunkirk constructed as early as 1970, where a Reinforced Earth wall supports a Gantry Crane with a wheel load of 1,200,000 kg one to three meters from the face.

Following this in 1988, a test wall was constructed in France by the Reinforced Earth international group to confirm the design theory and failure mode of an MSE load supporting wall. The wall was lightly reinforced with the intention of loading the wall to failure. MSE abutment walls are generally designed to support a surcharge footing pressure on top of the wall of 200 kPa. In the case of this test wall, the load was increased to 800 kPA before conclusion, or four times the normal design pressure. No failure was achieved. The test proved that MSE structures are capable of supporting loads higher than previously imagined. (Reference Bastick, M., et al, 1990)

3 ECONOMICAL LOAD SUPPORT

Reinforced Earth walls have been used for many years to support high loads. The reason is these walls can support high loads very efficiently and therefore economically, due to their basic nature. The vertical surcharge loads in an MSE wall are taken entirely by the soil underneath the load, and since soil is relatively inexpensive, compared to steel or concrete, MSE load supporting structures are economical. In the case of an MSE wall, loads are supported by the soil itself, and additional loads do not require any additional vertical structural elements. In contrast to this in the case of a pile supported structure, where the higher the load, more or bigger piles are required to support this load. This results in a direct increase in structure cost with additional vertical load. It is true that with higher loads more horizontal soil reinforcement is required; however, since the horizontal stress in a structure increases at a rate of about 25%, to the rate of the increase of the vertical stress, this means that the cost of structural elements in an MSE wall increases only at this similar rate.

4 DEFORMATIONS UNDER HEAVY LOADS

4.1 *Vertical deformations*

4.1.1 *Foundation settlement*

Compression of the foundation soils under an MSE wall is estimated using well known geotechnical principles by the projects geotechnical consultants and is not described in this paper.

It is noted that external foundation settlement estimate analysis should consider the entire mechanical stabilized embankment, including its bearing eccentricity and not just the facing.

4.1.2 *Internal settlement*

Vertical internal consolidation of the fill in an MSE wall depends on three aspects. First is the vertical stress, second is the volume of backfill influenced by the stress, and third is the property of the fill. It is important to make the point that vertical consolidation is not a function of the density of horizontal reinforcement.

In the case of non-cohesive fills the verticalconsolidation occurs as the load is placed on the structure, and the compression can be controlled with the selection of well graded, easier compactable sands and gravels. In the case of cohesive fills, the consolidation will occur over a period of time and the consolidation of cohesive fills tend to lead to much higher settlement values. The volume and the behavior of backfill influenced depend on the magnitude of pressure, the overall size of the footing being supported, and on the height of the MSE wall.

Although well-compacted sand and gravel is usually much preferred for highly loaded structures, the authors have been involved in the successful construction of highly loaded MSE walls with fine backfills. In the use of these fine backfills a flexible bar meshed facing has been used. By monitoring the walls, constructed with fine lean oil sand fill, it has been found that the internal consolidation of the fill is at least 3%. To accommodate this high level of compression, the bar mesh facing bends and bulges out in the horizontal direction. The bending capacity, durability, the mesh opening dimensions and the structural integrity of these bar mesh facing need careful evaluation in the design. Thin wires are generally not capable of sustaining these demands.

The percentage of fine material in the lean oil sand fill in this case ranges from approximately 40% to 60%. In these types of structures, not only is it necessary to have a strain compatible facing, but it is also necessary to monitor the excess pore pressures that occur in the backfill as the wall height and vertical stress increases. It should be pointed out that extreme caution must be exercised in controlling moisture content and compaction when using fine fill in MSE walls.

Numerous walls referred to as truck dumps have been designed with Reinforced Earth and consist of vertical walls in excess of 20 m in height, where large mining trucks back up to the edge and dump their load into an adjacent hoppers. (see Figures 2 and 3).

For MSE walls with precast facing exposed to high loads, it is necessary to have compressible pads in the horizontal joints between modular precast panels. The smaller the panel height, the more total number of horizontal joints is available to accommodate settlement. Since the precast panels themselves, particularly in rigid big size units, can obviously not compress, it is essential to have highly compressible pads in the

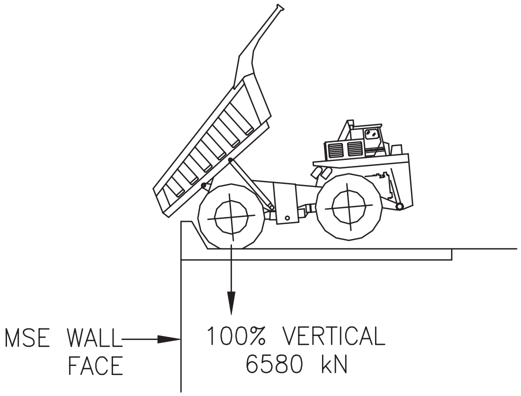

Figure 2. While dumping its ore, the heavy hauler trucks exert a high load near the face of the MSE dump wall.

Figure 3. Heavy hauler mining truck dumps into hopper/crusher while supported by bar mesh temporary MSE wall.

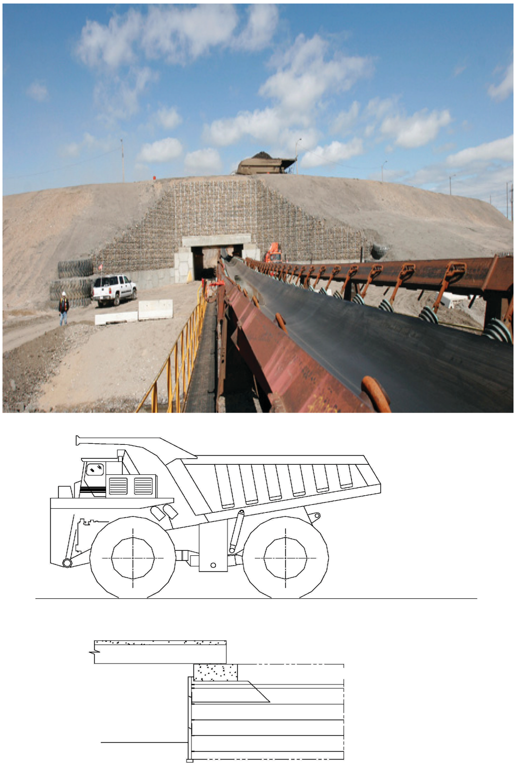

Figure 4. A 700 ton load of truck and ore crosses the bridge and MSE abutment wall over an uninterrupted conveyor. Figure is drawn to scale.

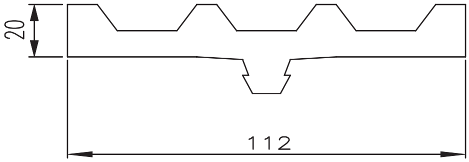

Figure 5. Geometry of a standard compressible joint pad.

horizontal joints so that the overall vertical consolidation of the facing can match that of the backfill behind the facing (strain compatibility). If this is not done and the backfill can settle to a greater degree than the facing, overstressing of the soil reinforcement connection can occur. Particularly when very compressible backfill is used, it will consolidate to such a large extent that the connections to the precast panels shear off and will allow the facing panels to separate from the MSE wall.

Non-standard compressible pads should be carefully designed and tested to accommodate higher than normal backfill compressions, usually accomplished by making the rubber pads thicker.

It has been confirmed that the compressible pads in the horizontal joints compress more under higher loads. This was shown in a survey that the Reinforced Earth Company in Canada performed in March 2007. The compression of rubber pads was measured at 35 different locations under various loading conditions simplified here as low, medium and high vertical load. The corresponding compression of the rubber ribs averaged out to be respectively 30%, 65% and 80%. The 80% rib compression was observed in a true MSE abutment wall where the dead and live loads exerted a 550 kPa footing pressure. (see Figure 4).

The geometry of the standard pads is shown in Figure 5. The top section of the bearing pads are in

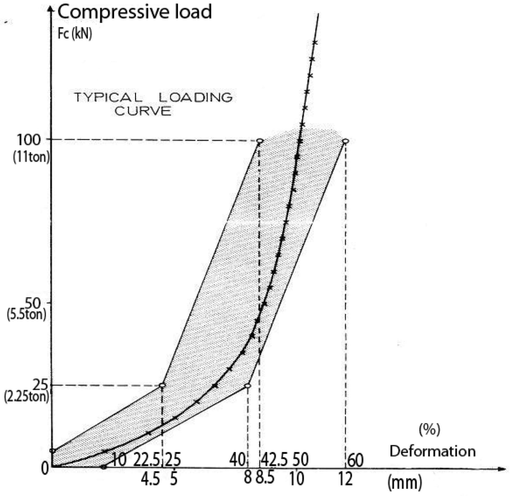

Figure 6. Laboratory results plotted as load versus deformation for compressible joint pads.

the form of 4 nibs to allow easier initial compression. A main solid portion of the rubber pad compresses less easily and prevents the pads from completely squashed, ensuring the panels will not contact each other. Figure 6 shows the compression characteristics of the rubber pads as tested in the laboratory, showing stiffness increasing as a function of increased deformation.

Another way in which internal consolidation can be accommodated for high walls is by breaking the wall into several tiers with small setback distances. This allows the facing to accommodate additional consolidation over and above that which is available through the compressible pads.

4.2 *Horizontal deformations*

Horizontal deformation of an MSE wall can be broken into two categories.

4.2.1 *External movement*

External movement is caused by the deformation of the foundation soils. Since in the case of highly loaded MSE walls the foundation soils are required to have good bearing capabilities, the horizontal deformation of the soils are generally not that large. This aspect can be ascertained by conventional geotechnical design and is also not described in this paper.

4.2.2 *Internal movement*

The internal deformation of an MSE wall is very much a concern of the MSE wall designers and occurs as a result of two different modes. The first is that which is caused by the slip of the soil reinforcement, or the amount of horizontal movement the soil reinforcement undergoes to mobilize the required fictional resistance. In the case of the types of the structures which this paper is addressing, the soil reinforcement is generally relatively long. When soil reinforcement is long, frictional pull-out and frictional capacity is generally not an issue. What is of much more interest in highly loaded walls is the elastic or plastic elongation of the soil reinforcement under high load. For walls designed for high security, high modulus steel soil reinforcement is selected. Since the design of steel in tension is done only in the elastic range there is no plastic deformation to consider and the elongation is very low. In fact, for a 20 m high wall assuming about 5 m of steel strip reaches approximately 50% of yield only 5 mm of elongation occurs. This predictable and controlled deformation is paramount to highly loaded structures since very strict tolerance is usually required.

Figure 7. MSE wall supports heavy rail load in Vancouver, Canada.

5 SECURITY OF HIGHLY LOADED MSE WALLS

The consequences of failure of a load supporting MSE wall are much greater than a conventional MSE wall, especially for the examples given in this paper, which include walls supporting bridges, walls supporting heavy rail (see Figures 7 and 8) and walls supporting heavy mining trucks. In addition to the potential loss of life, there are in each of these cases potential for millions of dollars worth of damage in equipments and through the loss of income caused by the facility being out of service. In the case of a truck dump wall, the cost of the trucks, and of the hopper, which is situated approximately 300 mm from the face of the wall, is prohibitively high to repair or replace. The loss of income that would result in stoppage or delay of facility operation would be unthinkable. It is obvious then that the owners of these structures must have extreme confidence in the selection of the retaining wall structures, and their designers.

Figure 8. Heavy rail load on MSE wall in Toronto, Canada (Design load of Cooper E90).

Safety of a highly loaded MSE wall depends on the soil reinforcement's resistance against rupture or pullout. For highly loaded MSE walls the most critical internal safety issue is that of the tensile capacity. For the design of these walls, the material of choice has been structural steel. The safety against the rupture or breaking of soil reinforcement is ensured in several ways. The durability of the strip is addressed by disregarding the thickness of the steel which is anticipated to corrode over the life of the structure, which ensures that all of the required factors of safety are met even at the end of the structures design life. Secondly, the uncertainty in loads and material properties are accounted for with the use of limit state load factors and capacity reduction factors. In addition to these two standard design approaches, there is additional safety provided with the use of structural steel. The strength of the structural steel is governed by strict specifications which ensure that the minimum yield strength is guaranteed. This provides a level of security over some other materials which are designed using average tensile test values.

Recently the Finite Difference program FLAC has been used to further the understanding of the direction and magnitude of stresses and strains internal to an MSE wall under high loads. (see Figures 9 and 10). Figure 9 shows the predicted vertical settlements of an MSE wall under 100 kPa train loading. Maximum predicted settlement was 35 mm. Figure 10 shows that the direction of displacements is different between the reinforced and unreinforced zones verifying that the MSE wall behaves as a composite material.

6 CONCLUSION

With the careful selection of material properties, including high modulus fills, high modulus soil reinforcement and detailing of facing panels to account for consolidation, MSE walls can be successfully designed and constructed to support extremely high surcharge and pressures.

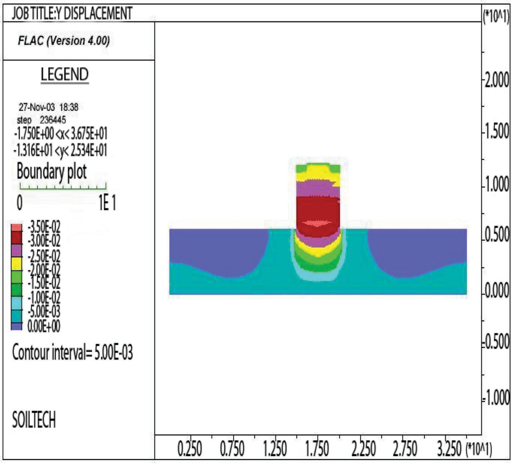

Figure 9. FLAC analysis predicted a maximum settlement of 35 mm under Cooper E90 rail load for the Vancouver MSE wall.

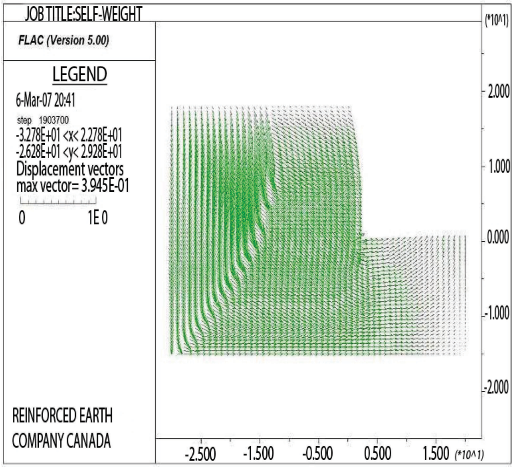

Figure 10. FLAC displacement vectors for a 20 m high truck dump MSE structure.

ACKNOWLEDGMENT

The authors acknowledge the many owners, structural and geotechnical engineers who have put their confidence over several decades in the Reinforced Earth designs of MSE walls to support very high loads.

REFERENCES

Bastick, M., Schlosser, F., Segrestin, P., Amar, S., Canepa, Y. 1990: *Experimental Reinforced Earth Structure of Burron Marlotte: Slender Wall and Abutment Test.* Report TAI.

Brockbank, W.J., Mimura, W. & Scherger, B. 2005. *Case Study: Highly Loaded MSE Bridge Supporting Structure, Syncrude NMAPS Conveyor Overpass, Proceeding, 58th CGS Conference*, Saskatoon:

Brockbank, W.J., Essery, D. & Wu, P. 2003. *Design of Reinforced Earth Wall for Contingent Loading and Longevity, 56th CGS Conference*, Winnipeg:

Brockbank, W.J., Ropret, M. & Wu, P. 2002. *Advanced loading aspects of Reinforced Earth Mechanically Stabilized Earth (MSE) Design. 55th CGS Conference*, Niagara Falls:

Brockbank, W.J., Kalynchuk, G. & Scherger, B. 1992. *Use of Oil Sand for Construction of a Reinforced Earth Dump Wall, Proceeding, 45th Canadian Geotechnical Society Conference*, Toronto:

Brockbank, W.J. & Weinreb, D. 1986. *Construction of Reinforced Earth Abutment Walls at the Harvey Creek Crossing, Proceeding, Second International Ottawa 1986 Conference on Short and Medium Span Bridges, CSCE*, Ottawa:

Segrestin, P. 1987. *Bearing pads in EPDM, Internal report by Terre Armee Internationale*.

Vidal, H. 1969. *The Principle of Reinforced Earth, Highway Research Record, No. 282*.

Wandschneider, H. & Wu, P. 1985, *Reinforced Earth Bridge Supporting Structures, Canadian Transportation Research Forum*, Ottawa: