Mechanically stabilized earth (MSE) wall failures due to hydraulic situations

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ABSTRACT: Presently, the authors have collected information and data on 301 failed MSE walls using geosynthetic reinforcement. Of the total, 64% were caused by internal or external hydraulic situations. The most common specific causes of the failures are as follows: Internal Water (37%) **-** drainage pipe leakage, catch basin leakage, pressure pipe breakage, perched water and saturated backfill. External Water (27%) - retained soil seepage, tension crack water pressure, surface infiltration, high phreatic surface and soil erosion at the toe of the wall.
It should be added that 73% of the wall failures used relatively impermeable silt and clay backfill soils in the reinforced soil zone. In the authors' opinion, such fine-grained backfill soils must have front drainage gravel (which is generally provided) and back drainage using a geocomposite drain (which is rarely provided). Obviously, both drainage systems must have suitable outlets thus the need for a base (or blanket) drain. These are all obvious locations where geotextile filters are essential.
The paper will provide statistics of the worldwide situation, along with proper preventative actions, and conclude with suggestions/recommendations for future practice. Hopefully, this paper will set up the remaining papers and presentations to follow in this session on drainage and filtration associated with MSE walls.

Keywords: MSE walls, wall failures, drainage geocomposites, geotextile filters, barrier layers

1 INTRODUCTION AND BACKGROUND

Since 2001, the Geosynthetic Institute has been collecting data on failures of geosynthetic reinforced (geogrids and geotextiles) mechanically stabilized earth (MSE) walls. We presently have accumulated 301 failures of which 94 (31%) are excessive deformation (Figure 1) and 207 (69%) are partial or complete collapses (Figure 2). In 2013 there were 171 failed walls, hence an increase of 130 in four years; see Koerner and Koerner, 2013. This is felt to be quite serious since several forensic experts suspect that 2 to 4% of such walls are problematic and if 100,000 exist worldwide that means approximately 3000 failures! Our data base is certainly meaningful but is only 10% of the total. Thus, the situation is, or should be, considered to be very serious and reflects poorly on regulators, owners, designers, manufacturers, contractors and installers of such retaining wall structures.

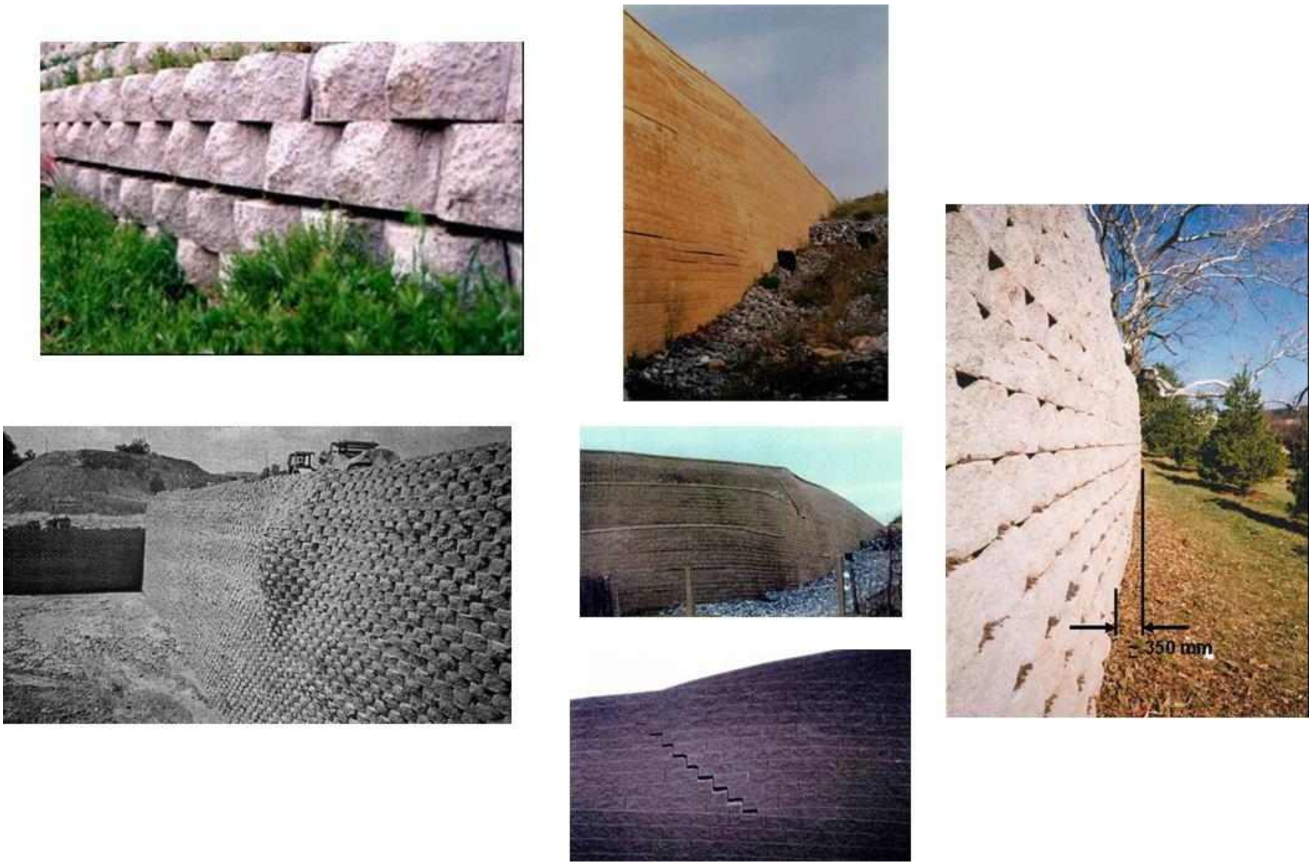


Figure 1. Cases of excessive wall deformations. (Photos by GSI and others)

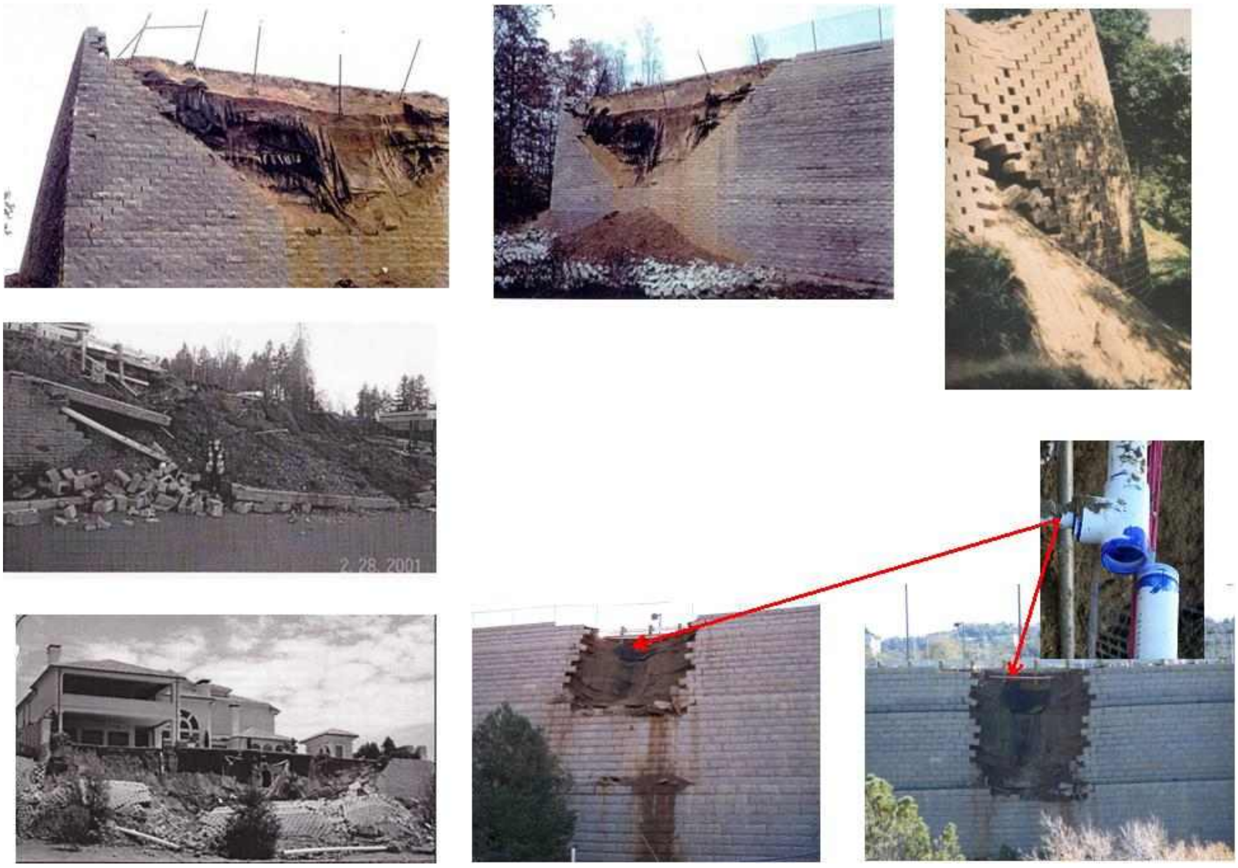


Figure 2. Cases of partial or complete wall collapses. (Photos by GSI and others)

The main statistical findings of the accumulated 301 failures are as follows. Particularly note that 73% of the case histories used fine-grained soil backfills, i.e., silts, clays and mixtures thereof, and 75% had prior moderate compaction.

1. 97% were private walls
2. 75% failed between 1999-2010
3. 79% were in North America
4. 75% were masonry block faced
5. 70% were 4 to 12 m high
6. 94% were geogrid reinforced (the others were geotextiles)
7. 77% failed in less than four years
8. 73% used silt and clay backfill soils
9. 75% had poor or moderate compaction
10. 99% caused by improper design or construction yet none (0%) were geosynthetic manufacturing failures
11. 64% caused by internal or external water (i.e., the remaining 36% were caused by soil related issues)

For the express purpose of this session, however, the realization that 64% of the failures were hydraulically related, insofar as either internal or external water being mobilized is critical. Some of these failures are shown in Figures 3 and 4, respectively. The most common specific causes of failures are as follows:

Internal Water - 111 Cases (37%)

- drainage pipe leakage
- catch basin leakage
- pressure pipe breakage
- perched water
- saturated backfill

External Water - 80 Cases (27%)

- retained soil seepage
- tension crack water pressure
- surface infiltration
- high phreatic surface
- soil erosion at wall toe

Clogged Front Drain

Saturated Backfill

Internal Plumbing

Saturated Backfill

Internal Plumbing

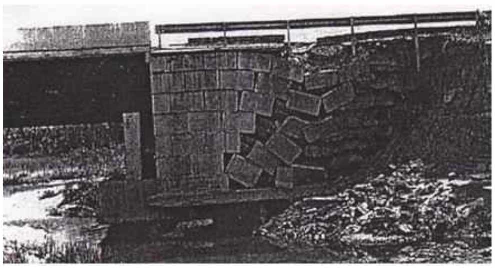
Internal Plumbing

Figure 3. Internal water failures. (Photos by GSI and others)

Tension Crack

Ret. Zone Water

Tension Crack



Adjacent Stream Washout

Tension Crack

High Phreatic Surface

Figure 4. External water failures. (Photos by GSI and others)

2 SPECIFIC HYDRAULIC ISSUES AND LOCATIONS

In light of the 220 (73%) cases that used fine-grained soil backfill (with the large majority having poor-to-moderate compaction) four distinct drainage locations must be designed accordingly. These are addressed individually in the paper, see Figure 5. Of course, use of sand and/or gravel backfill would largely solve the problem from occurring, but cost differences appear to dominate most decisions. It is estimated that cost savings using on-site fine-grained soils, versus quarry purchased granular soils, represents 50 to 75% the cost of a given wall. Thus, there exists the necessity of providing front, back and base drainage as well as a hydraulic barrier at the upper ground surface. These four topics follow.

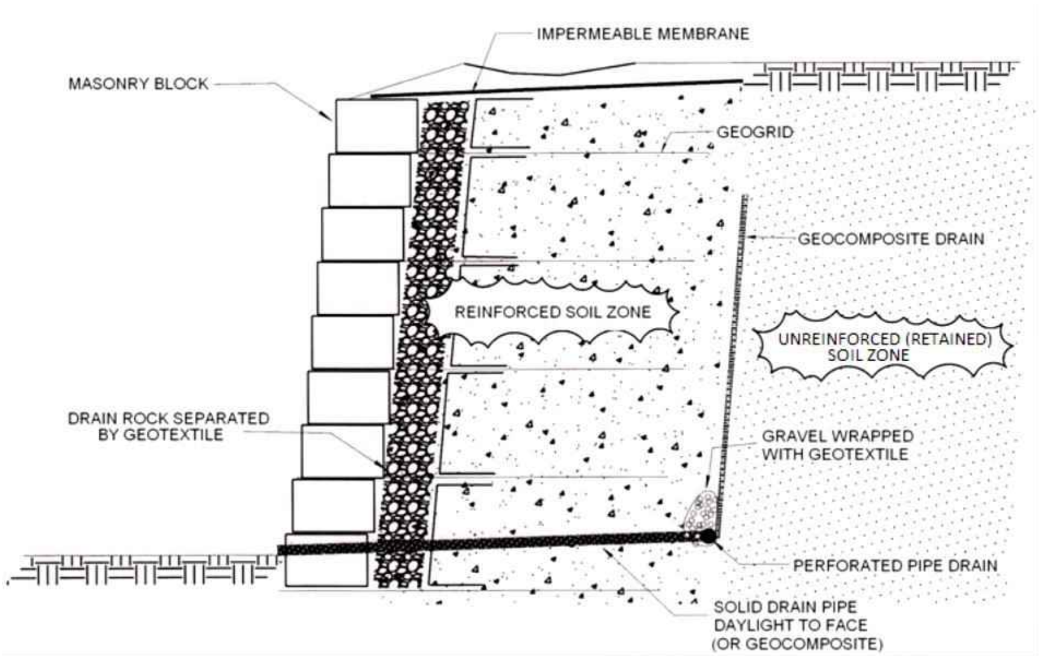


Figure 4. Front, back and base drainage layer locations as well as impermeabilization of the top surface. (Compl. TenCate Geosynthetics, Inc.)

2.1 *Location I - The Front drainage layer*

Located immediately behind the wall facing system is a layer of gravel for the purpose of eliminating water flow through the masonry block, gabion or other wall facing; recall Figure 5. This gravel layer is typically 300 mm thick and actually fills in hollow block voids if they are used. The accumulated water flow is gravitationally transmitted to the toe of the wall and exits either by periodically spaced weep-holes through the toe of the wall, or is collected by a drainage pipe to exit at the ends of the wall. *Absolutely essential is that the gravel layer must be separated from the fine-grained backfill soil with a geotextile filter; see Koerner and Koerner, 2017).* This filter layer must be wrapped around each soil lift between the individual layers of reinforcement. That said, it is generally omitted, not from a cost motivation, but from an construction inconvenience perspective. The obvious reason for such a filter is that individual silt or clay particles coming along with water from the reinforced soil zone will eventually contaminate the lower portion of the front drainage gravel causing toe failures as shown in Figure 6.

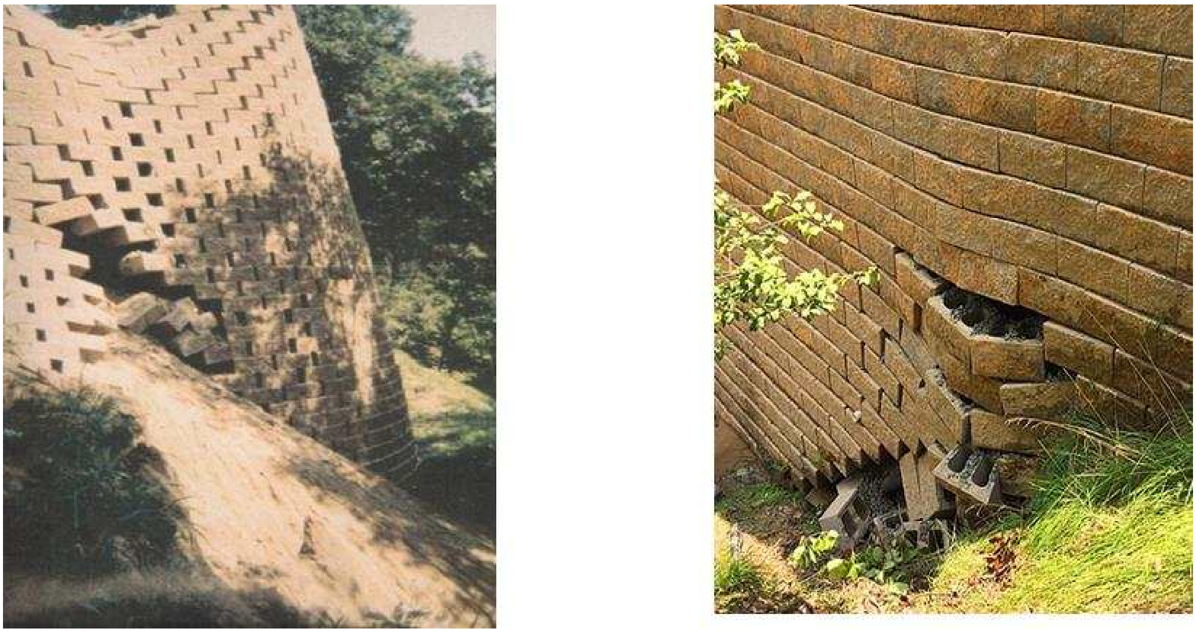


Figure 6. Toe failures of MSE walls caused by hydrostatic pressures. (Compl. Wikipedia and Google)

2.2 *Location 2 - Back drainage layer*

Figure 5 shows the back drainage layer as being a geocomposite drain. The drainage core can be either a geonet or geospacer and the wall designer has many products to consider. See Table 1 for contrasting behavior between these two very different core products.

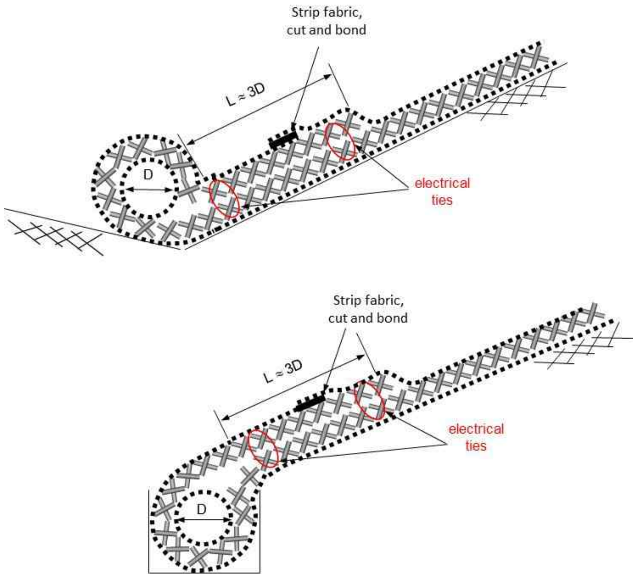
Table 1. Some distinguishing characteristics between geonet and geospacer cores. (ref. Koerner and Koerner, 2018)

Item	Geonets	Geospacers
Type of structure	biplanar/triplanar	3-D mats, channels, protrusions
Resin type	HDPE	PA, PE, PP, PS, etc.
Flow rate	mod/high	low-to-very high
Compressive strength	high/v. high	v. low-to-mod
Joining	cable ties	cable ties or interlocks
Geotextile covering	none, 1-side, 2-side	none, 1-side, 2-side
Geotextile bonding	thermal	thermal, adhesive or tape
Shipping configuration	rolls	rolls or panels

These drainage cores invariably have geotextiles bonded to both surfaces and, as a result, soil contamination from either the reinforced or retained soil zones is not an issue. The drainage core and its bonded geotextiles is referred to as a drainage geocomposite. The location is immediately behind the geosynthetic reinforcement against the retained zone. They can be readily installed along with the backfilling process and geosynthetic reinforcement placement. *In contrast to this situation, the placement of a 300 mm thick granular soil layer as back reinforcement should be dismissed as being both impractical and expensive.* The outlet of this drainage geocomposite back drain is by using a gravel base drain, another drainage geocomposite or transmission pipe all of which are located beneath the reinforced soil zone.

2.3 *Location 3 - The base drain beneath the reinforced soil zone*

Since most facing types of MSE walls have a gravel leveling pad beneath them, a practical design procedure is to simply extend this gravel layer beneath the entire reinforced soil zone so as to "connect" with the back drain. Again recall Figure 5. The geocomposite back drain would be embedded into this gravel base drain for expulsion of the collected water. Obviously, the upper surface of a gravel base layer must be protected using a geotextile filter. If a drainage geocomposite is used for the base drain it is simply a continuation of the back drain but bent into a 90° configuration. Alternatively, the core of the geocomposite back drain can be wrapped around a perforated drainage pipe and the collected water can be transmitted to the ends of the wall, see Figure 7a. Lastly, the geocomposite back drain could be attached to closely spaced transmission pipes beneath the reinforced soil zone. This attachment detail is obviously important, see Figure 7b.



(a) Recommended geocomposite to horizontal drainage pipe connection (ref. Corps of Engrs.)

(b) Specialty product available for pipe outlets. (Compl. of DrainGreat™)

Figure 7. Alternative methods of capturing, transmitting and releasing water from back drain geocomposites.

2.4 *Location 4 - Impermeabilization of Upper Ground Surface*

As again seen in Figure 5, the upper ground surface must be adequately sealed against rainfall and snowmelt such that it cannot enter into either the reinforced soil zone or front drainage layer. The barrier material is sometimes seen as a clay liner but (in the authors opinion) it is not the preferred material. Drying in warm seasons and backfill settlements will cause cracking of the clay which is not reconstituted when moisture returns during wet periods. Far better is to use a geomembrane or geosynthetic clay liner, or even both in the context of a composite barrier.

In this regard, the front edge of the barrier material(s) must be sealed to the facing system as much as possible. The back edge of the liner must extend back to, and a short distance beyond, the retained soil zone. Also, the upper ground surface should be sloped away from the face of the wall so as not to create a "waterfall" over the top of the facing.

3 SUMMARY AND RECOMMENDATIONS

The current situation of mechanically stabilized earth (MSE) wall failures using geosynthetic reinforcement is well in excess of failures in other civil engineering structures. For example, at a current 2% failure rate it far exceeds structural failures (bridges, buildings, tunnels, etc.) which is below 0.01%. These MSE wall failures are often ascribed to the geogrid or geotextile reinforcing materials, yet not one of the 301 failures in our data base has been due to improperly manufactured geogrids or geotextiles. Alternatively, 191 cases (64%) were due to internal or external water pressure which is clearly a design issue having nothing to do with the reinforcement, *i.e., they are all design failures*. Thus it is incumbent to alert MSE wall designers as to taking appropriate measures to avert such failures in the future. This is the specific purpose of this paper.

In this regard, fine-grained silt and clay soils can be used for backfill in the reinforced soil zone but they must be drained and/or protected in so doing. The paper illustrates four distinct locations in this regard; front drainage, back drainage, base drainage and impermeabilization of the gravel surface.

That said, the front and base drainage layers are generally gravel but both locations require geotextiles acting as filter fabrics. Such filtration design is well within the state-of-the-practice as evidenced by hundreds of papers and countless field applications. Conversely, the back drain is an ideal location for a geosynthetic drainage composite using a geonet or geospacer as drainage core with geotextiles bonded to front and back surfaces. The base drain is connected to the back drain and discharges the collected water in front or the ends of the wall system. If the base drain is a gravel layer (as opposed to a pipe removal system) it must be protected by a geotextile filter. Lastly, the upper ground surface of the reinforced soil zone must be impermealized by using a geomembrane, geosynthetic clay liner or geomembrane placed over a geosynthetic clay liner in the form of a composite liner.

With these four locations properly identified, designed and constructed accordingly, the 64% of MSE wall failures caused by hydraulic pressures should be eliminated. This would go a long way toward solving the current situation which is causing many to question and even challenge geosynthetic reinforced MSE walls.

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