Comparison of various types of MSE wall facings

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ABSTRACT: Currently, there are three popular types of facing for Mechanically Stabilized Earth (MSE) Walls: the full-height concrete facing (i.e., Japanese RRR), the segmental/articulated/discrete precast panel (i.e., Reinforced Earth, keystone, etc.) and the wrap around facing. This paper compares these wall facings by using of various criteria: cost, appearance, safety related to facing, construction time, durability, ecology (possibility of vegetation) and CO_2 emission during the life cycles of walls.
Each type of facing has pros and cons in performances based on the above criteria. In this study, the wrap around facing turns out to be the most economical, easy for construction, ecological and least carbon emission. It is particularly suitable for humid areas and rural environment. The segmental/articular panel facing is superior in appearance, and suitable for dry areas and cities. However, it should be noted that some failures were found recently related to discrete panels and connections between panels and reinforced backfills. The full-height concrete facing is the most reliable one in terms of durability and safety.

Keywords: Mechanically Stabilized Earth wall, Full-height concrete facing, segmental precast panel, wrap around facing, comparison of MSE facings, MSE wall failure

1 INTRODUCTION

Many different types of Mechanically Stabilized Earth (MSE) wall facings have been developed in the world. Three of them are frequently used: the full high concrete panel (i.e., Japanese RRR facing), the segmental/articular/discrete panel or block (i.e., Keystone, Reinforced Earth panels, etc.), and the wrap around facings. Figure 1 shows photos of these types of MSE wall facings.

In Japan, the MSE walls with full height panels (called RRR) have been successfully used for railway embankments and bridge abutments. In the USA and other countries, small and large segmental facings with different shapes of wall panels are very popular. The slope angle of these two types of wall varies from 70 to 90 degrees. The wrap around facing extends the reinforcement material (usually geogrid) about 2 m to wrap around the front bags. No concrete nor other solid material is used in the wrap-around facing, except vegetation. The slope angle may vary from 45 to 90 degrees. Economical and easy for construction, the wrap around facing is popular in Taiwan and other humid countries due to its applicability of planting.
Table 1 lists some main features of these MSE wall facings.

Full-height concrete facing(i.e., RRR, etc.)

Wrap around facing

Small segmental precast panel (Keystone, etc.)

Large segmental precast panel (Reinforced Earth, etc.)

Figure 1. Popular MSE wall facings

Table 1. Main features of various types of MSE walls

Type	Full-Height Concrete Facing	Segmental Precast Panel (Keystone, Reinforced Earth facings, etc.)	Wrap Around Facing
Facing feature	Cast-in-place concrete facing is erected after the geogrid and the backfill are installed	Erection methods of precast facing are based on the geometry shapes and connection of these panels	Geogrid is wrapped around the front bags and then vegetated
Slope angle	Close to vertical	Normally between 70° and 90°	Normally between 45° and 90°
Precautions	➢ Concrete facing should be installed after backfill settlement is essentially completed	➢ Connection between facing panel and geogrid is weak spot ➢ Compaction should be carefully near the facings ➢ Internal and external drainages should be properly installed	➢ Wrapped geogrids should be pre-tensioned ➢ Internal and external drainages should be properly installed

2 EVALUATION OF MSE WALL FACINGS

The authors conducted a questionnaire at the 2017 Annual Conferences of Chinese (Taiwan) Geosynthetics Association to collect opinions from local experts. A total of 30 questionnaires were received to evaluate different types of MSE walls. Taking it into consideration, the authors evaluated the facings according to seven criteria, as following table.

Table 2. Comparison of Various Facings

Evaluation Item\Type of Wall	Wrap Around Facing	Segmental Precast Panel		Full-Height Concrete Facing (i.e.,RRR)
		Small panels (Keystone, etc.)	Large panels (Reinforced Earth, etc.)	
1. Safety (failure related to facing)	****	**	**	*****
2.Cost (material & labor costs of facing installation)	*****	***	***	**
3.Appearance	***	*****	****	**
4.Construction Speed and Difficulty	****	****	****	**
5.Durability	***	***	***	*****
6.Vegetation/Ecology	****	*	*	*
7.Reduction of emission of CO_2	*****	**	**	*
Suitability	(1) Humid area (2) Highway, rural development, etc.	(1) Dry area (2) City, commercial development	(1) Dry area (2) Highway	High speed rail and other important transportation facilities

Note: Excellent *****, Very Good ****, Good ***, Fair **, Poor *

Comparison of these facings based on the above evaluation criteria are discussed in detail as follows.

2.1 *Structural safety related to facings*

Several failure modes were recently found in MSE wall segmental facings (Koerner, 2013; Wu & Chou, 2009, Alzamora & Anderson, 2009). The major one is due to discrete panels and weak connections between the facing structure and the reinforcing material. If the backfill contains some cohesive materials and it is fully saturated (due to seepage, scour and pipe/ditch breakage, etc.), the earth/water pressures will be increased and shear strength of reinforced soils will be reduced, which may lead to the discrete panels failure (Fig. 2). Please note that in this case, the failure only happen in the facing panels and the reinforced soil itself was stable. Another possible failure mode is stress concentration in connections due to differential settlement of facing and backfill. The facing structure, usually concrete, is rather rigid comparing to the backfill soil. We also noticed that a failure case during Chi-Chi earthquake (1999, Taiwan), a series of connections of discrete panels were separated, and the inserted pins popped out of their binding holes (Fig. 3).

The concrete facing of the full-height rigid (FHR) wall, commonly known as RRR wall in Japan, is installed after the MSE wall is built. Therefore, it may tolerate additional horizontal pressures induced by traffic, seepage and earthquake, etc. The stage-constructed FHR facings have been constructed as important permanent MSE for a total length of about 160 km in Japan (Tatsuoka, 2016). It is now the Japanese standard retaining wall technology for railways. Besides, the integral bridges and boxes using the FHR and MSE techniques are also developed, and they exhibit essentially zero settlement in the backfill and no structural damage to the facing (Tatsuoka, 2016).

Without any concrete panels or pin connections, the wrap around facing settles with backfill and no stress concentration may occur. Since the MSE wall is internally stable, the pressure on the wrap around wall facing is very little. It can be proved by cases where the wrap around facings were burned (Fig.4) or eliminated (Fig.5), but the stabilities of walls are not affected. Comparing to a vertical MSE wall, a reinforced slope (i.e., less than 70 degrees) with the wrap around facing has less earth pressure against the facing. A slope flatter than the angle of repose of backfill is essentially stable, since there is no earth pressure generated (only the portion steeper than angle of repose may generate earth pressure). If space available, it is a good idea to design a reinforced slope, instead of reinforced vertical wall, to take advantage of and fully utilize the angle of repose. With less earth pressure, the authors believe that some failure modes (i.e., base sliding, internal (between layers) sliding, overturning, pull-out) for a reinforced slope are unlikely, and the failure chances due to reinforcement breakage, global stability, bearing capacity are much less, comparing with a vertical MSE wall.

Although many failures cases of MSE walls with wrap-around facings were reported, almost none is related to facing itself. Unlike concrete facings, the wrap around facing moves along with the backfill without any phase difference during earthquake. Therefore, with proper design of reinforcement length (usually longer than 70% of wall height), wrap around facing can tolerate major earthquake (Ling, Leshchinsky, and Chou, 2001).

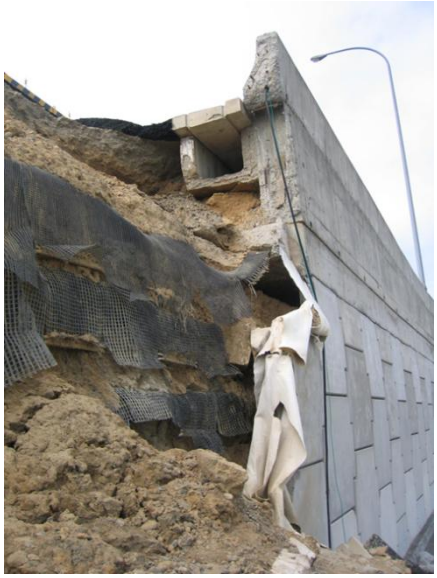


Figure 2. A Reinforced Earth wall facing connections failed due to improper drainage design and cohesive backfill in Taiwan (note: failure only occurred in facing)

Figure 3. A segmental wall connection was separated during Chi-Chi earthquake (1999, Taiwan)

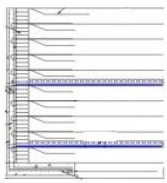
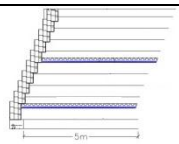
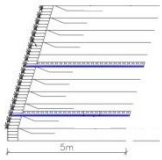
Figure 4. A wrap around facing was burned but remained stable in Taiwan

Figure 5. A wrap around facing was excavated but remains stable for several years in Glenwood Canyon, Colorado

2.2 *Cost*

The authors solicited quotations for building MSE walls with various facings, based on a typical 5m tall wall (Table 3). The quotation was based on the actual costs of building various MSE walls in the Exhibition Center of Green Engineering constructed by Gold-Joint Industry Co., Ltd. (2010). The costs include geogrids, local available backfills, compaction and the facing structures per linear meter (along the alignment). Price of full-height concrete facing wall is the highest, followed by segmental precast panel walls. Wrap around facing wall, without concrete facing, is significantly less in cost. The costs of facing and geogrid (including backfill compaction) per linear meter (along the alignment) and the combined unit price (per linear meter and per square meter of front facing) of these three types are listed in table 3.

Table 3. Cost of various types of MSE walls

Facing Type	Section Shape	Cost of Facing Structure (USD/m)	Cost of geogrid and compaction of backfills (USD /m)	Unit Price (USD)
Full-Height Concrete Facing (RRR)		570	530	1,100 (per linear m) 220 (per sq meter)
Articu-lated Pre-cast Panel (Keystone)		580	420	1,000 (per linear m) 200 (per sq meter)
Wrap Around Facing		130	540	670 (per lin-ear m) 134 (per sq meter)

Note: Tensile strength of reinforcing grid is GG-150 kN/m. Embedded length of reinforcing grid into soil is 5 m.

2.3 *Carbon emission reduction*

To evaluate carbon emissions of these MSE walls, we assumed a 100 m long wall with dimensions as same as the above in section 2.2. We calculated the carbon dioxide emissions of these MSE walls based on Taiwan's standard of carbon dioxide emissions factors (Public Construction Committee, 2012), as shown in figure 6. The results indicated that Carbon dioxide emission of wrap around facing is much lower than the other two types since no concrete facing is used. Besides, O2 generated by vegetation of wrap around facing during the service life may neutralize the CO2 emission during the period of manufacture, transportation and construction. As expected, the footprint of carbon dioxide emission of the full-height concrete facing is highest among the three.

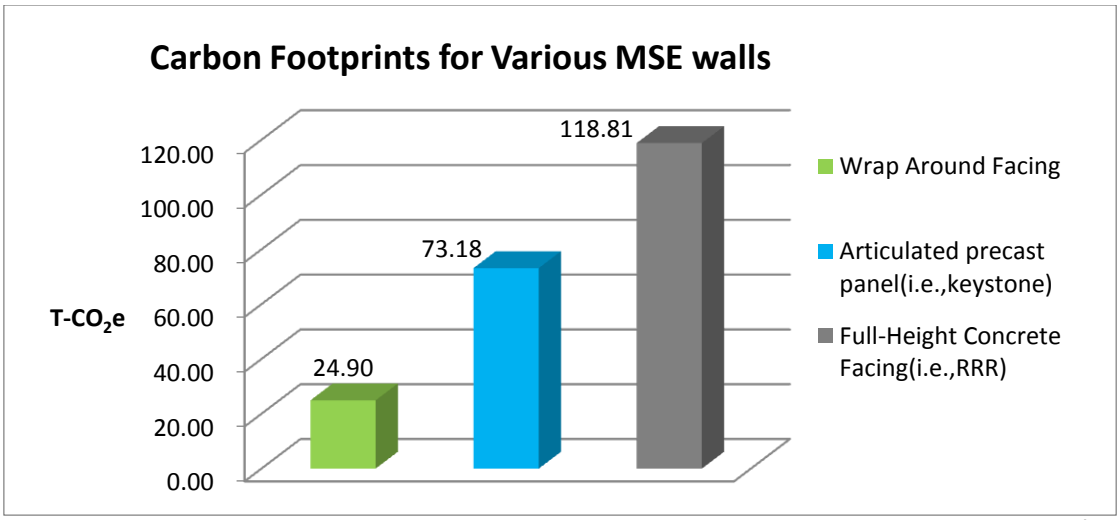


Figure 6. Carbon dioxide emissions of different types of MSE walls (L=100m, H=5m)

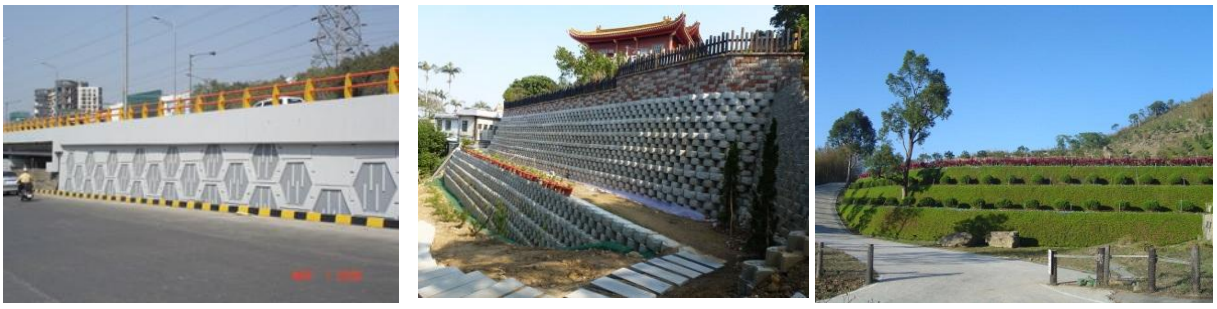
Research showed that footprints of carbon dioxide emission of MSE walls in Germany are only 20% of the counterpart of the traditional RC retaining walls (Heerten, 2009). In Taiwan, similar research also indicated that carbon dioxide emissions of MSE walls are only 12.5~20% of traditional RC retaining walls (NCKU Research and Development Foundation, 2009).

2.4 *Landscape and ecology*

Figure 7 shows appearances of different type of MSE walls. The segmental facings are usually satisfactory in appearance. Although aesthetic, in our opinion, tall segmental facing walls may create a sense of threat or fear to the people around it. To reduce this feeling, it is recommended to terrace the wall and each terrace not more than 3 to 5m high (Figure 7). Another method is to install the segmental panel walls only in the lower part, and build the wrap around facing wall in upper part of slope.

The full-height concrete facing is usually cast-in-place concrete, quite monotonic and not appealing. Unlike other types of MSE walls, the wrap around facing with vegetation and relatively flat slope usually integrates well into surrounding environment, especially in mountainous highway and rural area. However, if it is built in dense population area, the facing requires periodic maintenance work to prevent from overgrowth of weeds.

Among various types of facings, vegetation can only grow in wrap around facing. In humid areas, wrap around facing and reinforced slope (relative flatter than vertical wall) can provide suitable environment for plant roots to grow. In addition, the voids between the geogrids and the sand bags provide perfect environment for variety of small animals and vegetation, and therefore enhance biological diversity (Fig.8). In central Taiwan, an ecological survey indicates 95% of vegetation coverage in wrap-around facing five years after completion of MSE walls. In addition, various wild animals and birds were found in this project. (Observer Ecological Consultant Co., Ltd., 2015)



Large Segmental Facing Small Segmental Facing Wrap Around Facing

Figure 7. Appearances of different type of MSE walls

2.5 *Construction speed and difficulty*

Construction speed is about the same among the various segmental and wrap-around facings. For full height rigid walls, additional concrete facing is installed after the MSE wall was completed and the procedures are more complicated and time consuming.

Only small compaction equipment can be used near the segmental wall facing, and precautious should be taken not to damage the connection. Otherwise it may induce stress concentration in connection. The wrap around facing uses sand bags as temporary as well as permanent facing, and therefore is more efficient in construction.

2.6 *Durability*

Durability of reinforcing geogrid exposed to long-time ultraviolet (UV) radiation has been a concern for years. Since the segmental panels and full-height concrete facing protect the geogrid from being exposed to sunshine, there is no concern in UV radiation. Only the wrap around facing should take this issue into consideration. A serial of in-situ long term sunshine exposure tests, in accordance with ASTM D5970, were performed in ACE plant, Taichung, Taiwan (Table 4 & Fig. 9). The tests are in progress now. Based on some available data, after 3000 hours (about 1year) sunshine exposures, the retained strength of two samples (100 & 160 kN/m) are around 98.5% of the original strength (ACE Geosynthetics, 2017).

In fact, UV damage can be significantly reduced by covering it with vegetation. In relatively humid areas, with proper selection of species, fertilizer and watering, it may take only a few months for vegetation to fully cover the geogrid.

It has been 30 years since the wrap around facing MSE walls were successfully used in Taiwan. Experiences show that the UV radiation is not a concern for wrap around facing wall in humid area. In dry areas, however, since vegetation is relatively difficult, potential damages in geogrid due to UV should be considered. Although the quality of wrap around facing does not influence the stability and overall per-

formance of MSE walls (Figure 4 & 5), it may affect the appearance of the wall. In these cases, segmental panels would be a better choice.

Table 4. Test results of long term sunshine exposure tests in accordance with ASTM D5970

Test method	Tensile test method	Grid type	Exposure time	Exposure place	Retained strength
ASTM D5970	ASTM D6637-01	GG100	3000hr	Taichung	98.5%
ASTM D5970	ASTM D6637-01	GG160	3000hr	Taichung	98.6%

Note: Results in this table are excerpted from ACE plant tests. A series of tests are in progress now.

Figure 8. The voids in wrap-around facing provide a perfect environment for both animal and vegetation

Figure 9. On site ultraviolet radiation tests (ASTM D5970) in ACE plant, Taiwan

3 CONCLUSION

Currently, there are three popular types of facing for MSE Walls: the full-height concrete facing (i.e., Japanese RRR), the segmental/articulated/discrete precast panel (i.e., Reinforced Earth, keystone, etc.) and the wrap around facing. This paper compares these wall facings by various criteria: safety, cost, appearance, construction speed and difficulty, durability, vegetation/ecology and reduction of CO_2 emission during the life cycles of walls.

In recent years, some failures were noted related to segmental facings walls, mainly due to (1) unreliable facing system (discrete panels and connections) which cannot resist earth pressure due to saturation of backfill, seepage and earthquake, and (2) differential settlement (between facing and backfill) induced stress concentration in connection. Contrarily, the full-height concrete facing, such as RRR method, is installed after the primary settlement is completed. Since it is more rigid and durable, and therefore can share some earth pressure with reinforcement. The wrap around facing settle together with the backfill, so neither differential settlement nor stress concentration would occur.

Each type of facing has pros and cons in performances according to different evaluation criteria. In our opinion, the wrap around facing is the most economical, easy for construction and least carbon emission CO_2 emission. During its service life, the wrap around vegetated facing will generate oxygen which may compensate the emission of CO_2 in manufacture of geogrids and installation of MSE walls. The segmental/articular panel facing is superior in appearance. The full-height concrete facing is the most reliable one in terms of durability and safety.

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