Mechanically Stabilized Earth MSE Walls Applications: Review

Haitham H. Muteb¹,a and Mayadah W. Falah²,b*

¹Department of Civil Engineering, University of Babylon, Hillah, Babil, Iraq.
²Building and Construction Techniques Engineering Department, Al-Mustaqbal University College, 51001 Hillah, Babil, Iraq.
aeng.haitham.hassan@uobabylon.edu.iq, bMayadahwaheed@mustaqbal-college.edu.iq
*Corresponding author

Abstract. Internally stabilized walls have entirely transformed the soil preservation mechanism. While such walls have achieved widespread recognition in many areas of the world, such a structure is widely adopted recently. The key explanation might be that such walls are likely to be more costly than traditional externally reinforced walls and that the construction processes included could be too time-consuming. This article provides an overview of the background, styles, advantages, and disadvantages of Mechanically stabilized earth (MSE) wall requirements. For contrast, traditional construction samples of externally and internally supported walls have been given, including metal strip reinforcement walls, reinforcement concrete cantilever retaining wall, geotextile reinforcement walls, and grounded earth walls of various heights.

Keywords: Mechanically stabilized earth (MSE); applications; design; benefits; drawbacks.

1. Introduction

Soil is a natural substance with different properties depending on the form of soil. This is primarily determined by the soil's cohesion, c, and angle of internal friction. It often forms a slope as dry soil flows freely. It is not in a straight vertical face. However, in certain instances, such as on both sides of a highway, it is essential to maintain the soil in a straight vertical face for bridge abutment, sea walls, submerge walls, wing walls, and slope stabilization. It is important to provide vertical support to the soil to keep it vertical. Earth Retaining Structure delivers the service. For several years, retaining frameworks were built of reinforced concrete and engineered as gravity or cantilever walls, which are rigid constructs that cannot accommodate large differential settlements unless backed by deep foundations. The expense of reinforced concrete retaining walls rises exponentially as the height of soil to be maintained rises and the subsoil levels deteriorate. The foundation attempts to overturn due to ground strain [1-5]. Nevertheless, the base soils that are porous or compressible pose major design and building problems. Wall heights typically vary from 10 to 40 feet, with pressures near the wall face varying from 4,000 to 7,000 pounds/foot² (psf), depending on the wall design. Inadequate factors of protection for global stability and bearing capability and unnecessary complete and differential settlement are among the geotechnical problems presented by the rising scale of these walls.

The Mechanically stabilized earth (MSE) Method can be utilized to solve this issue. This arrangement is known as a MSE Wall, where the soil acts as a reinforcing structure and the facing units serve as a supporting system (MSE Wall). Precast concrete tiles, dry cast modular boards, metal sheets and plates, gabions, welded wire mesh, wood lagging and columns, and wrapped sheets of geosynthetics are used to mount the first facing units of the first side. The earth can then be compacted correctly and...
secured with supporting elements such as steel strips or bars, welded wire mats, polymer boards, or geotextile frames. The planet is mechanically stabilized by these reinforcing materials [6]. Retaining walls can be traced back to ancient Egypt. They were designed to keep the Nile River at bay. The Nile will overflow, causing the earth to erode. Egyptians use reeds to build Gabion-style retaining walls. The walls will divert the Nile's flood into ponds while still supplying drainage for the fields. A retention wall consists of big rocks, baskets full of tiny rocks, treated wood, cast-in-place concrete, and concrete blocks. (MSE) walls are made up of a solid composite structure facing elements, soil density, and reinforcement. Some of the first reinforcing approaches, which are still in use today, were developed in the 1960s and have mostly been utilized as retaining walls, berms, seawalls, and bridge abutments since then [7].

Compacted granular soil is reinforced by horizontal layers of steel strips or geosynthetic materials in a standard MSE wall. The use of reinforced components dramatically improves the system's strength. Facing elements are typically made of precast concrete, fastened wire mesh panels, or shotcrete and are relatively thin. Their structural goal is to keep the soil in place between the layers of reinforcement. A facing framework allows for the building of a vertical or even steep MSE wall. Between the stable zone and the ground's natural surface, soil content is often put without reinforcement. The term "retained backfill" refers to this region. MSE walls, usually described as reinforced soil walls, are a kind of earth retaining structure made up of three main components: granular soil as the earth fill, metallic or geosynthetic supports, and facing units. Reinforced soil retention walls could be conceived of as composite structures in which the reinforcements boost the ground fill integrity and capacity to maintain backfill [8]. Tensile–resistant additions have the resilience and containment that granulated earth fill usually lacks. Pressures were transmitted between fill and reinforcement thru interface friction, passive resistance of interface particles, or a mixture of both, based on the form of reinforcement [9]. The tension transmission pathways for standard ribbed steel strips are seen in Figure 1. MSE designs have become a common alternative to conventional reinforced concrete retention walls for more than thirty years since their civil engineering implementation. Retaining walls, bridge abutments, sea walls, commercial storage walls, and other structures are among their many uses. They have two main benefits over conventional walls: they are much less expensive and, because of their intrinsic stability, they can tolerate comparatively large differential settlements without causing structural damage [10-12].

Henri Vidal's work on an advanced technology he named Strengthened Earth was written in 1963. Vidal explained how retaining frameworks of any height might be built utilizing tensile reinforcement mounted in compressed lifts of earth fill (1978). In 1967, the first highway systems were constructed in physically difficult terrain in France, proving the principle of infrastructure, constructability, and economy. Mechanically Supported Earth became the common term for these fortified soil systems as the technique became more commonly adopted and expanded to other countries (MSE). Thanks to their strong load-bearing ability, versatility, and economy accomplished by providing granular fill and strengthening elements, MSE walls have become the favored technique of earth retention infill circumstances [13]. Burke et al. [14] used a finite element method to run computational simulations on a total geosynthetic strengthen soil structure. It stood 2.8 meters tall and was built on a 20-centimeter-
thick soil base. It was exposed to Kobe earthquake movements scaled to a 0.4 g acceleration amplitude. The block facings and borders were modeled as elastic materials linearly throughout the study. An ambulatory surface model of power strengthening roles was used to model the geosynthetic reinforcement, while a generic plasticity model was used to model the backfill and base dirt. An updated version of the DianaSwandyne-II program was used to perform the study under 2D plane strain conditions. While the bottom blocks displacement at the shaking end tends to provide a greater magnitude has the experimental findings, the analysis findings have been very similar to the experimental findings, and it has been concluded that the greatest settlement in the research occurred behind the reinforced line.

Morrison et al., 2006, examined slender MSE constructs as part of ongoing research on Propped (MSE), where space for the strengthened zone is restricted due to the existence of a near-vertical rock face or an established framework. Tavakolian and Sankey [15] find that adding reinforcement directly with the outside face of the current (e.g., tied back) framework or to the nail heads in the case of a soil nail wall will reduce deformation of the exposed (new) MSE wall. Sankey and Rafalko [16] conducted additional research and found that SMSE walls as thin as 0.4H could be effectively built in highways retaining wall environments. Simply stated, where an MSE wall is not exposed to externally imposed earth pressure, the necessary mass for stabilization and deformation control is lower than since this earth pressure is applied. The impact of backfill soil on the unnecessary movement of the MSE wall were investigated by Hossain et al. [17]. Increased wall movement or even collapse may be caused by backfill with high fine content and low drainage behavior. The case analysis of an MSE wall on State Highway 342 in Lancaster, Texas, is presented in this article. Just 5 years since its completion, the top of the MSE wall has shifted as far as 300±450 mm. To evaluate the MSE wall movement's potential triggers, a comprehensive site and lab investigative research program was performed. Soil boring and resistivity imaging is part of the site inquiry (RI). According to the findings and analyses, the existence of high fine material may have triggered the excessive displacement of the MSE wall. In this article, the MSE wall displacement was also simulated utilizing PLAXIS. The real behavior of the MSE wall and the movement predicted by the model were quite similar.

2. Benefits and drawbacks of MSE
Mechanically reinforced earth walls come in various shapes and sizes and may be utilized in different circumstances, including highway programs; they are used as temporary frameworks. Use as dikes or surface drainage mechanisms. As containment structures around oil reservoirs, as containment structures around gas storage tanks, as additional height to dams and levees to maximize space, as storage areas. When working on a building site with low soil, Bridge abutments, and wing walls in seismically active environments [18]. A gravity-based system is a full MSE wall. It relies on its mass to withstand imposed forces such as lateral earth stresses, water pressures, seismic loads, and human-caused loads. MSE walls are less expensive than concrete walls and can tolerate more significant overall and differential settlements. Furthermore, since no support structures (e.g., scaffoldings) or curing time is needed, their design is easier and faster. They are often resistant to both constant and complex loads (e.g., earthquakes) [19].

These systems are common with contractors and builders because of their cost-effectiveness and durability. Simple building, limited heavy machinery usage, more land accessible for construction, and quicker construction than standard concrete walls are only a few of them. It also eliminates the need for skilled labor and the need for wall finishing and site preparation. It may be installed in small spaces or places where a concrete wall would be almost difficult to install. On the other side, it cuts down on the need for land acquisition. Earth walls that have been mechanically stabilized are susceptible to elastomeric deformation and strong resistance to seismic loads. MSE walls may be seen as tall buildings with a wall height of more than 60 feet mixed with other materials. MSE could come in various shapes and sizes, reducing the need for drilling for footings and allowing it to be used in places of shallow soil [20]. Regarding the disadvantages of MSE architecture, the wall must have a minimum diameter to be stable. Furthermore, the strengthened soil mass must be made up of granular material, which may be pricey if not readily accessible. Eventually, the strengthened part must be engineered to resist deterioration and corrosion, which may seriously weaken the composite structure's mechanical actions.
3. Choosing the right wall

There are some considerations to remember when planning and constructing a retaining wall, regardless of whether it is for residential or industrial usage. Since they are all buildings, the same treatment level can be given to walls as it is to bridges. You can wonder what kind of wall would function better for the place, how deep the footing needs to be dug, whether it needs to be strengthened, or even what material is best for the area, depending on the application and the expertise. Before you start planning and selecting aesthetics for your wall, you must first consider the position and environmental conditions that could trigger your wall to collapse. To prevent being an obstacle or crumbling, a retention wall needs advanced preparation and proper layout. This article discusses several important considerations to remember early in the design process and advice on selecting the right kind of retaining wall for your project. The three significant components' characteristics and materials will differ, and an engineer must choose the most effective material combination depending on the design specifications for the wall. Modular precast concrete panels or wire mesh are used as facing components.

When it comes to aesthetics, reliability, building process, and planned settlement, each face has its own benefits collection. Steel or geosynthetic soil supports, in the shape of stripes or ladders, are often used. Pullout and tensile capability, corrosion resistance, and toughness are all special to each soil reinforcement choice. The gradation, plasticity, electrochemical characteristics, and overall consistency of the backfill should all be carefully considered to ensure the wall's construction and efficiency. It is available on-site or via a dealer.

Both retaining walls have the same goal: to keep soil behind them. Nevertheless, depending on the project, precise specifications can differ. Small landscape stone walls surrounding a garden to massive soil-retaining schemes along a highway are both examples of walls. Others may help control erosion caused by heavy rainfall or the development of a terraced yard to minimize upkeep. When you first start designing, there are a few things to keep in mind that will influence the material and form of the wall you create. When deciding on a position for your wall, make sure you have a clear view of property boundaries, as well as both above and below-ground infrastructures, such as stormwater drainage systems and irrigation, when picking a venue, other items to care for include: When the wall is on a slope, cutting into a hillside, natural drainage patterns A retention wall can obstruct natural drainage structures and also have environmental effects downstream and where the wall is near the land boundaries and Surcharge Loads, based on the wall height.

Soil: The soil that forms the floor or base must be inspected to ensure that it is strong enough to hold the wall. The form, bearing capacity (soil's ability to withstand a load), stress variables, and friction angle (resistance to movement) of the soil utilized for the base and strengthened region, as well as the retained soil zone, must all be determined. The base soil must be firm, dry, and heavy in general, and it must not be wet. Infilling wet soils, including clay earth, is often not advised. They are still wet, but any extra rainfall will not pass through to the drainage systems. Wet soil will also expand and compress in freezing temperatures, causing harm to the wall. Sandier soils, on the other side, make for better drainage. Examine the geotechnical study for information on on-site vegetation, vast soils, low chemical characteristics, groundwater levels, and more. To begin the design, you must measure the corresponding wall heights, footprint measurements, slopes, and setback angle, all based on the location's elevation and grade. It would help if you still remembered that the retained substance would inevitably shift downslope due to gravity. This must be discussed in the design to reduce the sum of lateral earth pressure behind the wall, which, if it exceeds its highest value, will cause the wall to collapse. The height of your wall is determined by the soil and slope, setback, and block dimension. Reinforcement of the Wall: If gravity alone is not enough to hold the wall, various reinforcing options depend on the wall shape, height, design, friction, slope, soil content, and other factors. MSE is soil that has been reinforced artificially with steel or geosynthetics (such as geogrids). Geogrid is usually woven in a grid pattern from a high-tensile cloth. It is rolled down into the ground between the layers of retaining wall blocks. Soil nailing, ground anchors, and rock bolts are examples of other forms of reinforcing megastructure.

Since water is the most popular cause of retaining wall failure, it is essential to ensure that the wall has adequate drainage and that there will not be any water accumulation behind it. Determine future surface water supplies to ensure that runoff next to the wall site is taken into consideration. To reduce the amount of hydrostatic pressure generated by groundwater, grade the site for drainage patterns and
install a drainage system behind the wall. Backfilling with dirt, utilizing drain pipes, and utilizing "weep" holes to enable water to flow through the wall are examples of drainage systems. A hydrology review can be conducted on broader wall programs, including for transportation.

4. Types of retaining walls
Gravity concrete block, Inclined concrete block, Gabion Basket, Reinforced concrete block, L form, concrete triblock, Timber triblock, and Reinforced Earth are the eight types of retaining walls mentioned. Some of the categories are easy to build, whereas others are more complex. Some people live for a long time, and others live for a limited time, which is inexpensive, whereas some are more costly. Retaining walls are classified Retaining Walls into Sheet Pile, Cantilever, Gravity, Reinforced Soil as shown in Figure 2 [21].

4.1 Gravity retaining wall
Gravity retention walls are the most common of retaining walls, relying on brute weight and density to keep the dirt at bay. Since it is primarily about weight, these retention walls may be made out of a broad range of materials. Bricks, pavers, and unmortared stone are only a few choices, with dry-stacked stone being one of the more common. Shorter walls do not require additional support, but others may require at least a small trench to fit into, and others will require a concrete footer to rest on [22].

4.2 Cantilevered Retaining Wall
Cantilevered retention walls use a retaining wall affixed to a slab base that goes beneath the soil the wall is protecting in an "L" form, which is often called strengthened retaining walls steel bars that go across the masonry or concrete retaining wall. The weight of the above-ground soil keeps the slab in place, preventing the wall from tipping over. Because of its strength, this design is common in commercial retaining walls. Additional vertical wings to the base offer additional strength and rigidity in a "counter-fort" or "buttressed" retaining wall [23].

4.3 Sheet Piling Retaining Wall
A sheet pile retention wall is a thin wall of concrete, Timber, or vinyl that is pressed directly into the dirt. It is commonly utilized where space is limited. A vertically corrugated frame is sometimes used to provide extra support. Only weaker soils are suitable for these pilings, and a simple rule of thumb is to push one-third of the sheet piling into the field for every two-thirds that would be above it. Larger walls, like anchored retaining walls, will require further anchoring [24].

![Figure 2](image_url)

**Figure 2.** Different types of return walls.
5. Comparison between PLAXIS MSE model and experimental

5.1 Experimental Model 1
Model MSE Walls and Field Investigation Fibertex G–100, nonwoven geotextile reinforcement was used to build 250 cm wide and 240 cm high model MSE walls with 0.30 m vertical spacing a folded back at the facing. Four specially fabricated steel-type shutters of 0.40 m high by 1.00 m long were used to form these model MSE walls' vertical facing, resulting in a smooth and uniform face finish. Two type shutters were mounted on either side at 2.5 m apart, and the required size of Fibertex G–100, a nonwoven geotextile sheet (first layer), was applied without creases on the levelled compacted ground surface (Figure 3) [25]. A 50 mm thick layer of fill material was manually put over the geotextile base, flattened by the grader, and compacted utilizing a 2-ton stone roller at its optimal moisture content. The same backfill soil was blended with 10% cement material and compacted near the facing concurrently with the placing of respective backfill to form a 30 cm thickness built on soil-facing by cement (Figure 3a) [25]. Load research was performed on the walls built with cement adapted backfills after a 7-day curing cycle by inundating the walls to mimic an utterly wet condition. With a hydraulic jack's support, a 30 cm diameter and 38 mm thick steel plate has been placed centrally over the model MSE walls' top surface. The load was determined using a 20-ton proving ring responding against the Knetledge loading frame (Figure 3b), and the settlements were measured using two dial gauges with a least count of 0.001 cm placed on the steel plate throughout load testing [25].

Figure 3. Applied model, a) preparing the model and b) Applying cyclic loading during testing [25].

Figure 4 shows a standard plot for a wall with a museum backfill at an elevation of 1.80 m above ground level. For various test conditions, the facing deformations at different wall elevations proportional to the ultimate loads were determined from these graphs. Variation in these facing deformations as a function of wall height. The maximum lateral deformations in the face for completely wet conditions of walls with cement adjusted marginal backfills are decreased to about one-third of those of walls with plain backfills, suggesting that their efficiency is enhanced. The reality that marginal soils have been untouched by wetting after cement alteration supports these patterns. The built-on soil-facing by cement may also be offered the perfect aesthetics by plastering the wall [25].

Figure 4. The variation of lateral facing deformation with loading under different conditions [25].
5.2 Experimental model 2
The experimental behavior of the model MSE wall was studied by Shivananda and Bincy is shown in Figure 5 [26]. A static load may be used to determine load-carrying capability. The laboratory model MSE walls are constructed using facing components as paver blocks and Geosynthetic strips to reinforce sizes 900 mm, 600 mm, and 450 mm, in three separate cases open strip reinforcement, End block anchored strips, Continuous strips so one face to another face. Continuous strip reinforcement worked well in strong load-carrying capability and minimal deformation from one face to the next. This technique is ideal for building embankment roads since it reduces the road's slope thickness. The MSE wall was tested using a 90 cm x 60 cm x 45 cm model box with MSE backfill sand and Geosynthetic strips as stabilization and containment using a loading unit. Loads are seen in three situations: 1. Reinforcement with open strips Strips grounded at the end of the block and strips continuous from one face to the other. The maximum stress that the wall could withstand by utilizing the open strip approach is 25.42 kN/m², the maximum stress that the wall can withstand by using end block anchored strips is 63.55 kN/m², and the maximum stress that the wall can withstand by using continuous strips from one face to another face is 177.45 kN/m². At maximum tension, settlement and s/B percent are determined.

![Figure 5](image-url)

**Figure 5.** Stress-strain behavior graph and Bearing capacity s/B % behavior graph [26].

6. PLAXIS MSE
Won and Langcuyan [27] studied the compaction impact on panel-type MSE walls' behavior using a 3D numerical analysis as shown in Figure 6. The compaction effect on the MSE walls' actions was explored using a sequence of computational studies in this research. The findings revealed that the MSE wall's horizontal displacement (HD) increased dramatically throughout development and then decreased due to introducing a surcharge load after completion as shown in Figure 7. Furthermore, because of the introduction of a surcharge load during the installation, the reinforcement stresses increased considerably during the construction and decreased marginally. Consequently, when modeling MSE walls, it is crucial to account for compaction loads such that lateral displacement (LD) at wall facing is not underestimated during construction and is not overestimated due to surcharge load implementation afterward. The compaction loads use affected the HD at the wall facing. Throughout the building, the heavier compaction load causes further HD at the wall facing. According to the reinforcement content, the LD at the wall facing increased to 3.5 times as the compaction load increased from 0 to 35 kPa. After the introduction of a surcharge load, the significant consequences of compaction become apparent. The HD of MSE walls that were not exposed to compaction loads was more significant than those of MSE walls exposed to compaction loads. According to the reinforcement content, HD at the wall facing reduced by up to 80 percent (on average) as the compaction load rose from 0 to 35 kPa.
8

Figure 6. Partially constructed MSE model and geometry model and components of MSE wall by 3D PLAXIS [26].

Figure 7. HD at the wall facing and HDR (horizontal displacement ratio) for Case 1 and 2-A–D at the end of construction: (a) HD at the wall facing, and (b) HDR [26].

7. Conclusions
Whatever wall structure you chose, ensure you have thoroughly assessed your project's site, soil, and drainage specifications. Many suppliers have in-house engineers that specialize in wall construction and can provide assistance. Online applications like Belgard SRW Design Software 1.0 will also help you improve design productivity and transform an idea into a complete design. Using the sensor for the existing bridge returning walls could help estimate the future issue to eliminate and find the best design with fewer issues. PLAXIS software program is considered one of the best choices to simulate the soil
and the interaction between the soil and the concrete body by demonstrating the stress and strain of the structure and the lateral deformation. The MSE approach is used to solve the infrastructure problems that are faced in transportation programs. The technological challenges must first be solved. When assessing the overall feasibility of a solution to improve weak base soils, cost-effectiveness and building timeline impacts should be taken into account. MSE is costly, but it is often quite powerful.

References
[1] Zainab, S.A.K., Zainab, A.M., Jafer, H., Dulaimi, A.F. and Atherton, W., 2018. The effect of using fluid catalytic cracking catalyst residue (FC3R)” as a cement replacement in soft soil stabilisation”. International Journal of Civil Engineering and Technology, 9(4), pp.522-533.
[2] Hussain, A.J. and Al-Khafaji, Z.S., 2020. The fields of applying the recycled and used oils by the internal combustion engines for purposes of protecting the environment against pollutions. J. Adv. Res. Dyn. Control Syst, 12, pp.666-670.
[3] Al Masoodi, Z. O., Atherton, W., Dulaimi, A., Jafer, H. M., and Al Khafaji, Z., 2017. The effect of a high alumina silica waste material on the engineering properties of a cement-stabilised soft soil. The 3rd BUiD Doctoral Research Conference, British University in Dubai, Dubai, AUE.
[4] Al-Khafaji, Z.S., Jafer, H., Dulaimi, A. And Atherton, W., Al Masoodi, Z., 2017. The Soft Soil Stabilisation Using Binary Blending of Ordinary Portland Cement And High Alumina Silica Waste Material. in The 3rd BUiD Doctoral Research Conference, the British University in Dubai, 13th May 2017, UAE. Dubai, 13th May 2017, UAE.
[5] Hussain, A. J. and Al-Khafaji, Z. S., 2020. Reduction of environmental pollution and improving the (Mechanical, physical and chemical characteristics) of contaminated clay soil by using of recycled oil. Journal of Advanced Research in Dynamical and Control Systems, 12(4 Special Issue), pp. 1276–1286.
[6] Al-Khafaji, Z.S., AL-Naely, H.K. and Al-Najar, A.E., 2018. A review applying industrial waste materials in stabilisation of soft soil. Electronic Journal of Structural Engineering, 18, pp.16-23.
[7] Han, J. and Leshchinsky, D., 2010. Analysis of back-to-back mechanically stabilized earth walls. Geotextiles and Geomembranes, 28(3), pp. 262–267.
[8] Ingold, T.S., 1982. Reinforced earth (No. Monograph).
[9] Ahmad, H., Bezujen, A. and Zornberg, J. G., 2020. Interaction mechanisms in small-scale model MSE walls under the strip footing load. Geosynthetics International, pp. 1–36.
[10] Mitchell, J. K., 1990. North American practice in reinforced soil systems. in Proc. ASCE Conf. on the Design and Performance of Earth Retaining Structures, pp. 3233–3346.
[11] Schlosser, F., 2000. Mechanically stabilized earth retaining structures in Europe, Design and Performance of Earth Retaining Structures. Geotechnical Special Publication, (25), pp. 347–378.
[12] Jones, C., 1996. Earth reinforcement and soil structures. London; New York: T. Telford'. ASCE Press.
[13] Anderson, P.L., Gladstone, R.A., Brabant, K. and Sankey, J., Back-to-Back MSE Walls–A Comprehensive Understanding. In Innovations in Geotechnical Engineering (pp. 431-447).
[14] Burke, C., Ling, H. I. and Liu, H., 2004. Seismic response analysis of a full-scale reinforced soil retaining wall, in Proc. 17th ASCE Engineering Mechanics Conf., Newark, DE.
[15] Tavakolian, R. and Sankey, J., 2009. Sandwich Connection design for Shored Reinforced Earth Walls. Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering: The Academia and Practice of Geotechnical Engineering, 2, pp. 1441–1444
[16] Sankey, J. E. and Anderson, P. L., 1999. Effects of stray currents on performance of metallic reinforcements in reinforced earth structures. Transportation Research Record, 1675(1), pp. 61–66.
[17] Hossain, M. S., Kibria, G., Khan, M. S., Hossain, J., and T. Taufiq, 2012. Effects of backfill soil on excessive movement of MSE wall., Journal of Performance of Constructed Facilities, 26(6), pp. 793–802.
[18] Robinson, W. F., 1987. Feasibility of implementing a flexible employee benefit system at MSE Inc.
[19] Stuedlein, A. W., Allen, T. M., Holtz, R. D., and Christopher, B. R., 2012. Assessment of
reinforcement strains in very tall mechanically stabilized earth walls. Journal of geotechnical and 
geoenvironmental engineering, 138(3), pp. 345–356.

[20] Elias, V., Christopher, B.R., Berg, R.R. and Berg, R.R., 2001. Mechanically stabilized earth walls 
and reinforced soil slopes: design and construction guidelines (updated version) (No. FHWA-
NHI-00-043). United States. Federal Highway Administration.

[21] Khan, A.J. and Sikder, M., 2004. Design basis and economic aspects of different types of retaining 
walls. Journal of Civil Engineering (IEB), 32(1), pp.17-34.

[22] Pain, A., Choudhury, D. and Bhattacharyya, S.K., 2017. Seismic rotational stability of gravity 
retaining walls by modified pseudo-dynamic method. Soil Dynamics and Earthquake 
Engineering, 94, pp.244-253.

[23] Callisto, L. and Soccodato, F.M., 2010. Seismic design of flexible cantilevered retaining 
walls. Journal of geotechnical and geoenvironmental engineering, 136(2), pp.344-354.

[24] Stuart, D. M., 2004. Project-specific steel sheet piling applications’, Practice periodical on 
structural design and construction. 9(4), pp. 194–201.

[25] S. G. Reddy and G. V Praveen, ‘Field Investigation on Wall Facing Deformation of Mechanically 
Stabilized Earth (MSE) Walls Constructed Using Cement Modified Marginal Soil with Built-In 
Facing’, pp. 19104–19109, 2017, doi: 10.15680/IJIRSET.2017.0609197.

[26] P. Shivananda and V. K. Bincy, ‘Experimental Behavior of Model Mse Wall’, vol. 8, no. 2, pp. 
4101–4106, 2019.

[27] Won, M.-S. and Langcuyan, C. P., 2020. A 3D numerical analysis of the compaction effects on the 
behavior of panel-type MSE walls. Open Geosciences, 12(1), pp. 1704–1724.