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Design & Study of Reinforced Earth (RE) Panel - A Review

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Abstract: Reinforced Earth (RE) walls, also known as Mechanically Stabilized Earth (MSE) walls, have become one of the most widely used retaining structures in modern civil engineering due to their flexibility, cost effectiveness, rapid construction, and superior performance under static and seismic loading conditions. These systems consist of compacted backfill soil reinforced with geosynthetic materials, steel strips, geogrids, or geotextiles, combined with facing elements such as precast concrete panels, modular blocks, or metallic facings. In recent years, reinforced earth panels have gained significant importance in highway embankments, bridge abutments, flyovers, railway infrastructure, retaining structures, and slope stabilization projects. The increasing demand for economical and sustainable retaining systems has encouraged extensive research on the design, behavior, seismic performance, material optimization, and long-term durability of reinforced earth wall panels. This review paper presents a comprehensive study of previously published research articles related to reinforced earth wall systems and reinforced earth panels. The review includes studies on seismic behavior, deformation characteristics, reinforcement stiffness, backfill materials, drainage conditions, cost analysis, finite element modeling, experimental investigations, and comparative studies between conventional retaining walls and reinforced earth structures. Various researchers have demonstrated that reinforced earth walls provide significant economic advantages over conventional RCC retaining walls, with cost savings ranging from 35% to 50%. Several studies also highlighted the superior seismic resistance, flexibility, reduced settlement, and faster construction associated with reinforced earth wall systems. The literature review further reveals that recent investigations are focusing on sustainable materials such as marble waste, crumb rubber, fly ash, and cohesive soil stabilization techniques for improving wall performance and reducing environmental impact. Numerical modeling software such as PLAXIS 2D, PLAXIS 3D, and FLAC has been widely adopted for analyzing wall behavior under static and dynamic loading conditions. Despite considerable progress, several research gaps still exist in the areas of panel connection behavior, durability under aggressive environmental conditions, optimization of panel geometry, long-term field monitoring, and behavior under combined loading conditions. This review identifies important research gaps and provides future directions for improving the structural efficiency, sustainability, and durability of reinforced earth panel systems.

Keywords: Reinforced Earth Wall, Mechanically Stabilized Earth (MSE), Reinforced Earth Panel, Retaining Wall, Geogrid Reinforcement, Geosynthetics.

I. INTRODUCTION

Rapid urbanization, industrialization, and expansion of transportation infrastructure have significantly increased the demand for efficient retaining structures in modern civil engineering projects. Conventional retaining structures such as gravity retaining walls, cantilever retaining walls, and counterfort retaining walls have been widely used for many decades. However, these structures require large quantities of concrete and steel, occupy significant space, and are highly sensitive to differential settlement. In addition, the construction of conventional retaining walls is time consuming and expensive, especially for large height embankments and weak soil conditions. To overcome these limitations, Reinforced Earth (RE) technology or Mechanically Stabilized Earth (MSE) systems were developed.

Reinforced earth structures consist of compacted backfill soil reinforced with tensile reinforcement elements such as steel strips, geogrids, geotextiles, welded wire mesh, or polymeric reinforcements. These reinforcements interact with the soil through friction and confinement, thereby improving the shear strength and stability of the soil mass. Facing panels are provided at the exposed face of the wall to prevent erosion and maintain the geometry of the structure. Reinforced earth panels are important structural components of RE walls because they transfer loads, maintain alignment, provide aesthetic appearance, and resist local soil pressures. Precast reinforced concrete panels are commonly used due to their durability, strength, and ease of installation. Modern reinforced earth wall systems are widely adopted in highway embankments, railway structures, flyovers, bridge abutments, retaining walls, approach roads, coastal protection works, and slope stabilization projects. One of the major advantages of reinforced earth walls is their flexibility. Unlike rigid RCC retaining walls, reinforced earth walls can tolerate differential settlement without developing severe cracks. This makes them suitable for weak soil conditions and seismic regions. Moreover, reinforced earth walls require less construction time, reduced excavation, lower labor requirements, and comparatively lower maintenance costs. In recent years, researchers have focused on improving the design methodology, seismic performance, reinforcement configuration, drainage behavior, durability, and sustainability of reinforced earth wall systems. The use of waste materials such as fly ash, crumb rubber, marble waste, recycled aggregates, and industrial by-products has also gained attention for promoting sustainable construction practices. This review paper presents a detailed analysis of previous research related to reinforced earth wall panels and identifies the important research gaps in the field. The study aims to provide a clear understanding of the behavior, design, performance, and future development of reinforced earth panel systems in modern infrastructure engineering.

II. LITERATURE REVIEW

The literature review provides a comprehensive understanding of the previous research studies related to reinforced earth (RE) walls, mechanically stabilized earth (MSE) wall systems, and reinforced earth panels used in modern infrastructure projects. Various researchers have investigated the structural behavior, seismic performance, deformation characteristics, reinforcement materials, facing panel systems, cost effectiveness, and long-term stability of reinforced earth structures under different loading and environmental conditions. The review of previous studies indicates that reinforced earth walls offer several advantages over conventional retaining structures, including improved flexibility, reduced construction cost, faster construction, better settlement tolerance, and superior seismic resistance. Recent research has also focused on the utilization of sustainable materials, waste products, advanced numerical modeling techniques, and innovative reinforcement systems for improving the efficiency and durability of reinforced earth wall systems.

[1] Comparative Design and Cost Analysis of Reinforced Soil (MSE) Walls and RCC Cantilever Retaining Walls (2025) by Dipak Pawar, Divya Waghmode, Dhruva Nagrale, Saurav Baviskar, Yogesh Bafna, and Dr. S. B. Randhavane presented a comparative study between Reinforced Cement Concrete (RCC) cantilever retaining walls and Reinforced Soil or Mechanically Stabilized Earth (MSE) walls. The study analyzed the design methodology, construction requirements, and cost effectiveness of both retaining systems for wall heights ranging from 3.2 m to 6.4 m. The design of RCC retaining walls was carried out using Limit State Design as per IS 456:2000, while the reinforced soil walls were designed according to BS 8006:2010 guidelines. In reinforced soil walls, geogrids were used as reinforcement with segmental panel facings, whereas RCC walls required significant quantities of cement, steel reinforcement, formwork, and curing processes. The cost analysis revealed that reinforced soil walls were approximately 40.80% more economical than RCC cantilever retaining walls. Additionally, reinforced soil walls demonstrated better performance in seismic regions, required shorter construction time, and had lower environmental impact due to reduced material consumption. The study concluded that reinforced soil (MSE) walls provide a cost-effective, durable, and environmentally sustainable alternative to conventional RCC retaining walls, particularly for highway and infrastructure projects requiring efficient soil retention systems.

[2] Engineering Assessment of Reinforced Earth Wall and Vehicular Underpass Sections in a Six-Lane Highway: Analysis, Causes, and Remedial Measures (2025) by Rahul Shende, Mayuresh Patil, V. Srinivasan, Anjan Patel, and Anirban Mandal investigated the structural performance and deficiencies of reinforced earth (RE) walls constructed in vehicular underpass sections of a six-lane highway project. The study involved detailed field observations, geotechnical investigations, concrete panel testing, and design assessment to identify the causes of structural issues observed in the RE walls. The research highlighted several problems such as unsuitable backfill material, inadequate drainage systems, and improper design considerations, including ineffective soil nailing design. The analysis revealed that these deficiencies significantly affected the stability of the reinforced earth wall, especially under saturated and submerged conditions.

The study also examined the performance of RE panels and reinforcement elements and proposed soil nailing as a retrofitting measure to improve the stability and durability of the structure. The findings emphasized the importance of proper material selection, adequate drainage provisions, and accurate design methodology for ensuring long-term performance of reinforced earth wall systems. The research concluded that detailed post-construction evaluation and appropriate remedial measures are essential for maintaining the structural safety and serviceability of reinforced earth retaining structures in highway infrastructure projects.

[3] Experimental Evaluation of Mechanically Stabilized Earth Walls Reinforced with Glass Fiber Reinforced Polymer Bars Embedded in Marble Waste–Sand Mixtures (2025) by **Shabir Hussain, Irshad Ahmad, Irfan Jamil, Fasih Ahmed Khan, Mansoor Ullah, Saif ul Islam, Mudassir Iqbal, and R. Nawaz** experimentally investigated the structural behavior of Mechanically Stabilized Earth (MSE) walls using sand and marble waste–sand mixtures as backfill material reinforced with 12 mm Thread Wrapped Glass Fiber Reinforced Polymer (TW-GFRP) bars. A large-scale wall model having dimensions of 1.23 m length, 0.92 m width, and 1.53 m height was constructed to evaluate face deflection and vertical settlement. Linear Vertical Displacement Transducers (LVDTs) were installed at different locations to measure deformation characteristics of the wall. Different proportions of marble waste such as 14% marble powder, 28% marble rubble, and 21% combined marble powder and rubble were mixed with sand to determine the optimum backfill composition. The experimental results indicated that the addition of marble waste significantly reduced wall deformation, where average face deflection decreased by 13%, 18%, and 27% and vertical settlement decreased by 21%, 26%, and 36% respectively for the three mixtures. The study concluded that marble waste–sand composite materials combined with GFRP reinforcement can effectively improve the stability, load-bearing capacity, and sustainability of reinforced earth structures while reducing construction costs.

[4] Physical and Numerical Models of Mechanically Stabilized Earth Walls Using Self-Fabricated Steel Reinforcement Grids Applied to Cohesive Soil in Vietnam (2024) by **Truong-Linh Chau, Thu-Ha Nguyen, and Van-Ngoc Pham** investigated the structural behavior of Mechanically Stabilized Earth (MSE) walls reinforced with self-fabricated galvanized steel reinforcement grids using locally available cohesive soil in Vietnam. A full-scale experimental model of the MSE wall was constructed and instrumented to study the distribution of tensile forces along different reinforcement layers and the lateral displacement of the wall facing. The reinforcement grids were fabricated using CB300V steel with 3 cm ribs to provide adequate bonding with the backfill soil. The study applied different loading conditions to evaluate the stability and performance of the reinforced soil wall. Experimental results showed that the wall failed at a load of 302 kN/m², which is approximately 15 times higher than the design load of 20 kN/m², indicating high structural stability. The maximum lateral displacement observed at the top of the wall facing was 3.9 mm, which was significantly lower than the allowable displacement limits for retaining walls. The failure surface within the reinforced soil mass exhibited a parabolic sliding shape, consistent with theoretical predictions. Additionally, numerical modeling using FLAC 7.0 software was carried out, and the results showed good agreement with the physical experimental model. The study concluded that self-fabricated galvanized steel reinforcement grids combined with locally available cohesive soils can effectively be used for constructing MSE walls, providing a cost-effective and sustainable alternative for reinforced earth structures.

[5] Performance of Mechanically Stabilized Earth Wall System with Geogrid with and without Backfill Pressure (2024) by **Mustafa Maadh Badr and Qassun S. Mohammed Shafiqu** studied the structural performance of Mechanically Stabilized Earth (MSE) retaining walls reinforced with geogrid under different backfill pressure conditions. The research used PLAXIS 3D numerical modeling software to simulate the behavior of the geogrid reinforced retaining wall constructed using soil from Erbil, Iraq. The study mainly focused on the effect of lateral earth pressure and additional loads on the displacement behavior of the retaining wall. The results indicated that when additional loads were applied on the MSE retaining wall, the horizontal displacement of the wall increased only slightly, demonstrating the stability and effectiveness of geogrid reinforcement in improving soil resistance against tensile forces. The reinforcement enhanced internal friction within the soil mass and improved the overall performance of the retaining wall system. The study concluded that geogrid reinforced MSE walls provide an efficient and reliable solution for retaining structures even under additional loading conditions, making them suitable for infrastructure projects where stability and soil reinforcement are required.

[6] Seismic Response of MSE Walls with Various Reinforcement Configurations: Effect of Input Ground Motion Frequency (2024) by **Irem Zeynep Yildirim, Berk Turkel, and Erol Guler** investigated the seismic behavior of Mechanically Stabilized Earth (MSE) retaining walls under different ground motion frequencies using numerical analysis.

The study employed two-dimensional finite element modeling to evaluate the response of an 8 m high MSE wall subjected to earthquake loading conditions. Various reinforcement configurations such as reinforcement length, vertical spacing, and axial stiffness were analyzed to understand their effect on wall performance. Seven different input ground motion accelerograms with equal Arias Intensity but varying frequencies between 1 Hz and 8 Hz were applied to the numerical models. The results indicated that the MSE wall experienced rotation near the top under seismic conditions, and the acceleration amplification was influenced by the frequency of ground motion. The highest normalized acceleration amplification factor within the wall was recorded as 1.86 when the excitation frequency approached the fundamental frequency of the wall system (around 4 Hz). The study also found that reinforcement parameters with a length-to-height ratio between 0.5 and 1, axial stiffness between 600–1200 kPa, and vertical spacing of 0.4–0.6 m provided satisfactory performance under moderate seismic loads. The research concluded that reinforcement configuration and input ground motion frequency significantly influence the seismic response and stability of MSE walls, and proper design of reinforcement parameters is essential for improving the earthquake resistance of reinforced earth structures.

[7] Numerical Analysis of Shored Mechanically Stabilized Earth Walls (2024) by Sundaravel, Deviprasad B. S., and Dodagoudar G. R. investigated the deformation behavior and stability of shored mechanically stabilized earth (SMSE) walls using numerical modeling techniques. In this study, a finite element (FE) model was developed using PLAXIS software to analyze the performance of MSE walls supported with soil nail systems. A parametric sensitivity analysis was carried out to determine the most influential parameters affecting the maximum lateral displacement of wall facing and the global factor of safety of the reinforced earth system. The study also developed predictive equations using multiple linear regression analysis to estimate wall displacement and stability parameters. The results showed that the governing failure mechanism of the SMSE wall follows a bilinear failure plane, whose inclination angle is approximately 10° lower than the conventional Rankine failure surface. The analysis further indicated that the external stability of SMSE walls is more critical compared to conventional MSE walls, particularly under certain loading conditions. The study concluded that special attention must be given to reinforcement–facing connections and interface behavior, as these components are vulnerable to failure and significantly influence the overall stability and performance of reinforced earth retaining structures.

[8] Seismic Response Compression of Various MSE Walls Based on 3D Modeling (2023) by Muhammad Akbar, Huali Pan, Guoqiang Ou, Georgios Nikitas, and Bilal Ahmed investigated the seismic behavior of mechanically stabilized earth (MSE) retaining walls using advanced three-dimensional nonlinear finite element modeling (FEM). The study analyzed the performance of reinforced concrete and hollow precast concrete panel MSE walls under earthquake loading conditions. Various parameters such as vertical pressure, horizontal pressure, lateral earth pressure, settlement of the wall, settlement of reinforced backfill, and foundation settlement were examined to evaluate the seismic performance of the wall system. The results indicated that seismic motion significantly influences the displacement and stability of MSE walls, particularly with increasing wall height. The study also compared the numerical simulation results with AASHTO design guidelines to validate the analytical model. The findings revealed that hollow precast concrete MSE walls exhibited lower displacement and settlement compared to conventional reinforced concrete walls, making them a more practical and efficient alternative for earthquake-prone regions. The research concluded that finite element modeling is an effective tool for evaluating the seismic response of reinforced earth walls and can assist engineers in optimizing the design of MSE wall systems for improved structural resilience.

[9] Design of R.C.C. Retaining Wall and Reinforced Earth Wall for 6 Meter Height (2023) by Roshan Patel and Hariram Sahu presented a comparative study on the design and performance of reinforced cement concrete (RCC) retaining walls and reinforced earth walls for a height of 6 meters. The study aimed to evaluate the structural efficiency and economic feasibility of both types of retaining systems used in modern infrastructure projects. The research highlighted that conventional RCC retaining walls are rigid structures that require strong foundations and cannot tolerate significant differential settlement, which increases construction cost especially for higher wall heights and weak soil conditions. In contrast, mechanically stabilized earth (MSE) or reinforced earth walls utilize tensile reinforcing elements within the soil mass, which significantly increases soil strength and allows the construction of steep or vertical retaining structures. The inclusion of reinforcement elements and facing systems prevents soil raveling and improves overall stability. The study concluded that reinforced earth walls are more economical and flexible compared to RCC retaining walls, particularly for medium to large height retaining structures, making them a suitable alternative for infrastructure projects such as bridges, flyovers, and highway embankments.

[10] Seismic Performance of Mechanically Stabilized Earth Walls with Sand–Crumb Rubber Backfills of Varying Proportion (2023) by Tirtha Sathi Bandyopadhyay, Pradipta Chakraborty, and Amarnath Hegde investigated the seismic behavior of geogrid reinforced mechanically stabilized earth (MSE) walls using sand–crumb rubber mixtures as backfill material. The study employed shaking table experiments to evaluate the dynamic response of reinforced earth wall models subjected to different earthquake base motions. Eight different combinations of sand and crumb rubber were used as backfill to examine their influence on wall deformation, backfill settlement, earth pressure, acceleration amplification, and strain in geogrid reinforcement layers. The experimental results showed that the addition of crumb rubber significantly improved the seismic performance of MSE walls. It was observed that wall displacement and backfill settlement decreased as the rubber content increased, and the maximum displacement at the top of the wall was reduced by approximately 45% when 30% crumb rubber was added under high peak ground acceleration conditions. The study also identified a two-wedge failure mechanism with the failure envelope inclined at about 49° from the vertical. Furthermore, the strain in the geogrid reinforcement decreased with increasing rubber content. The research concluded that 30% crumb rubber mixed with sand can be considered an optimum proportion for improving the seismic performance of reinforced earth walls while also reducing construction costs and promoting the use of recycled materials in highway infrastructure projects.

[11] Effect of Reinforcement Stiffness on Response of Back-to-Back MSE Wall upon Infiltration (2022) by G. Rajagopal and S. Thiyyakkandi investigated the influence of reinforcement stiffness on the behavior of back-to-back Mechanically Stabilized Earth (MSE) walls subjected to rainwater infiltration. The study used a finite element (FE) numerical modeling approach to analyze the performance of reinforced earth walls constructed with different types of backfill materials, including select fill, marginal fill, and hybrid fill soils. The research aimed to understand how rainfall infiltration affects wall displacement, reinforcement tension, and the overall factor of safety. The results showed that reinforcement stiffness plays a significant role in controlling wall deformation, particularly in walls constructed with marginal fill soils. As the stiffness of reinforcement increased, the facing displacement of the wall decreased, while the tension in the reinforcement layers increased. However, for walls constructed with select fill and hybrid fill materials, the influence of reinforcement stiffness was less significant, and satisfactory performance was observed even with lower stiffness reinforcement. The study also revealed that the reduction in safety factors during infiltration conditions was largely independent of reinforcement stiffness. The research concluded that reinforcement stiffness is an important design parameter for reinforced earth walls, especially when marginal backfill soils are used and when structures are subjected to rainfall infiltration conditions.

[12] Effect of Earth Reinforcement, Soil Properties and Wall Properties on Bridge MSE Walls (2021) by Zaid Momani, Eyosias Beneberu, and Nur Yazdani investigated the performance of Mechanically Stabilized Earth (MSE) retaining walls used in highway bridge structures through three-dimensional numerical modeling. The study focused on understanding how different parameters such as soil properties, reinforcement characteristics, and wall material properties influence the stability and movement of MSE walls with precast concrete panels. Several factors including soil pore water pressure, soil cohesion, type and length of earth reinforcement, reinforcement slippage or breakage, and concrete strength of the panels were analyzed. The results indicated that wall movement is significantly influenced by pore water pressure and the integrity and length of reinforcement layers. Soil cohesion was found to have only a minor effect on wall displacement. The study also revealed that flexible geogrid-reinforced walls experienced greater lateral movement, increasing by approximately 13–20 mm compared with steel grid reinforced walls. However, the stresses in steel grids remained below the yielding limit, while geogrids experienced relatively higher stresses without rupture. The study concluded that geogrid reinforcement can be effectively used in MSE walls if proper attention is given to slippage resistance and wall deformation control, while the use of steel grids requires non-cohesive soil conditions to minimize corrosion. Additionally, proper drainage systems are essential to reduce pore pressure and maintain the stability of reinforced earth retaining structures.

[13] Seismic Response of Mechanically Stabilized Earth Wall for Widened Embankment (2021) by Vikas Mante, Faizanjunaid Mohammed, and Krishna Karthika Gorla analyzed the seismic behavior of mechanically stabilized earth (MSE) retaining walls used for widening highway embankments. The study used numerical modeling techniques based on PLAXIS-2D software to evaluate the performance of an existing embankment strengthened with geogrid reinforcement and soil nailing. The objective of the research was to improve the structural stability of the embankment while accommodating increased traffic loads and ensuring resistance against seismic forces. The modeling and analysis were carried out following the Federal Highway Administration (FHWA) guidelines, and the seismic response of the MSE wall was compared with that of a conventional retaining wall. The study also compared pseudo-static and pseudo-dynamic analysis methods to evaluate the displacement behavior and stability of the reinforced earth wall.

The results indicated that MSE walls exhibit better seismic performance, lower displacement, and improved stability compared to conventional retaining walls. The research concluded that geogrid reinforcement combined with soil nailing significantly enhances the seismic resistance and structural performance of MSE walls, making them suitable for highway embankment widening projects in earthquake-prone regions.

[14] Study of Cost Effectiveness of Reinforced Earth Wall over Conventional Retaining Wall Considering Different Heights (2021) by Sami Raj Sahu, Deeksha Shrotriya, and Barun Kumar examined the economic feasibility of reinforced earth walls compared with conventional retaining walls for different wall heights. The study explained that reinforced earth walls are composite structures formed by the interaction of soil and reinforcement, where friction between the soil and reinforcement layers transfers forces and allows the soil mass to behave as a cohesive structure. With the increasing demand for efficient soil retention systems in urban infrastructure such as bridges, flyovers, and underpasses, reinforced earth walls have emerged as a practical alternative to conventional retaining structures. The research focused on comparing construction costs for retaining walls and reinforced earth walls at various heights and evaluated their economic benefits. The results showed that reinforced earth walls are significantly more economical than conventional retaining walls, and the cost advantage increases with the increase in wall height. The study also highlighted that the cost effectiveness of reinforced earth walls can be further improved by selecting suitable combinations of geogrid reinforcement and backfill materials depending on soil conditions and loading requirements. The study concluded that reinforced earth walls provide an economical, durable, and efficient solution for modern infrastructure projects requiring soil retention systems.

[15] Comparative Study of Conventional Retaining Wall and Mechanically Stabilized Earth Wall Using PLAXIS 2D (2019) by Naved Qureshi, Arpita Patel, and Bhoomi Kamdar presented a numerical comparison between conventional retaining walls and mechanically stabilized earth (MSE) walls using PLAXIS 2D finite element modeling software. The study aimed to evaluate the structural behavior and performance of both retaining systems under different loading conditions. Simulation models of conventional reinforced concrete retaining walls and MSE walls reinforced with geogrids were developed and analyzed for at-rest and active earth pressure conditions with both zero and variable surcharge loads. The analysis focused on parameters such as total stress, effective stress, deformation patterns, shear force, and bending moment in the wall structure. The results indicated that MSE walls can accommodate greater differential settlement and exhibit better deformation characteristics compared to conventional retaining walls, especially in locations with weak subgrade conditions. The numerical findings were also verified through manual calculations for validation. The study concluded that mechanically stabilized earth walls are more economical and flexible structures, making them a suitable alternative to conventional retaining walls for highway embankments and soil retention structures.

[16] Full-Scale Mechanically Stabilized Earth (MSE) Walls under Strip Footing Load (2018) by Hamzeh Ahmadi and Adam Bezuijen investigated the behavior of reinforced earth retaining walls through two full-scale experimental model tests. The study compared the performance of rigid facing and flexible facing MSE walls while keeping other parameters constant, including the number and type of geogrid reinforcement layers, spacing between layers, and soil properties. The research analyzed the loads and tensile strains developed in the reinforcement layers under horizontal and vertical earth pressures as well as under strip footing loading conditions. The results were compared with analytical approaches such as the AASHTO design method and the empirical K-stiffness method. The study also examined the effect of compaction loads during construction on geogrid behavior. The results indicated that tensile forces in reinforcement layers were lower in rigid facing walls compared to flexible facing walls, while the maximum strain occurred in the upper reinforcement layers directly beneath the strip footing load. It was also observed that wall deflection was higher in flexible facing systems, whereas rigid facing walls showed smaller deformation with maximum deflection occurring near the top of the wall. The study concluded that the rigidity of the facing panel significantly influences the structural behavior and load distribution of reinforced earth walls, and proper consideration of facing stiffness is essential in the design of MSE wall systems.

[17] Design and Construction of Bridge Embankment Using R.E. Wall Panels (2018) by S. Sandana Socrates, Dr. S. Lavanya Prabha, and S. Raja studied the design, analysis, and construction techniques of bridge embankments using reinforced earth (RE) wall panels. The study focused on the use of Mechanically Stabilized Earth (MSE) technology for constructing bridge embankments where precast reinforced earth panels act as the facing elements of the structure. The analysis of the embankment stability was carried out using Excel and PLAXIS 2D software to evaluate the response of the structure under different loading conditions. The research considered important parameters such as surcharge load, soil fill properties, and soil reinforcement characteristics, which significantly influence the stability of the embankment.

The study also introduced Para-web technology as a modern alternative to conventional geogrid reinforcement for soil stabilization. Various filling materials were examined, and it was observed that fly ash exhibited higher strength compared to other alternative fill materials, making it a suitable material for embankment construction. The results indicated that reinforced earth wall panels enable faster construction, reduce the requirement of skilled labor, minimize differential settlement, and improve the load-bearing capacity of the embankment. The study concluded that the use of reinforced earth technology provides an efficient, economical, and sustainable solution for bridge embankment construction in highway infrastructure projects.

[18] Analysis, Design & Cost Comparison between Counterfort Retaining Wall and Mechanically Stabilized Earth Wall (2018) by Naveena N presented a comparative analysis of counterfort retaining walls and Mechanically Stabilized Earth (MSE) walls for highway infrastructure applications. The study focused on evaluating the structural design, analysis, and economic feasibility of both retaining wall systems for a roadway section located in the Badanguppe–Kellamballi Industrial Area, Chamarajanagara District, Karnataka. The retaining structures were designed based on geotechnical investigation data and the critical height of the embankment along the selected road alignment between chainage 300 m and 540 m. Detailed cost estimation for both retaining wall systems was carried out using the Schedule of Rates (SOR) 2015–2016 of PWP & IWTD, Mysore Circle. The analysis showed that the cost of constructing a counterfort retaining wall was significantly higher compared to the MSE wall for the same site conditions. The results indicated that the use of a mechanically stabilized earth wall resulted in approximately 47% cost savings compared to the counterfort retaining wall. The study concluded that MSE walls are a more economical and efficient alternative for retaining earth in highway and railway projects, particularly in areas with embankments and varying site conditions.

[19] Full-Scale Mechanically Stabilized Earth (MSE) Walls under Strip Footing Load (2018) by Hamzeh Ahmadi and Adam Bezuijen investigated the structural behavior of mechanically stabilized earth walls through two full-scale experimental model tests. The study compared the performance of MSE walls with rigid facing panels and flexible facing panels, while keeping other parameters constant such as the number of geogrid reinforcement layers, spacing between reinforcement layers, and the type of soil used as backfill. The research analyzed the distribution of loads and tensile strains in reinforcement layers under horizontal and vertical earth pressures as well as under strip footing loads. The experimental results were compared with analytical approaches such as the AASHTO design method and the empirical K-stiffness method. The findings revealed that tensile forces in reinforcement layers were lower in rigid facing walls compared to flexible facing walls. The maximum strain in reinforcement layers was observed in the upper reinforcement layers directly beneath the strip footing load. Additionally, the maximum wall deflection in flexible facing walls was greater than in rigid facing walls. For rigid facing systems, the maximum displacement occurred near the top of the wall, whereas for flexible facing systems the maximum deflection occurred at approximately $z/H = 0.81$ from the top of the wall. The study concluded that the rigidity of facing panels significantly affects the load distribution and deformation behavior of reinforced earth walls, and proper consideration of panel stiffness is important in the design of MSE wall systems.

[20] A Review on Economic Analysis of Reinforced Earth Wall with Different Types of Reinforcing Materials (2015) by Harangad Singh and Dr. Saleem Akhtar reviewed the economic feasibility and performance of reinforced earth walls using different types of reinforcing materials. The study analyzed the cost effectiveness of reinforced earth retaining walls for different heights by comparing various reinforcement materials such as copper strips, aluminum strips, galvanized carbon steel strips, and synthetic geogrids. The research highlighted that reinforced earth walls are widely used in infrastructure projects such as bridge abutments and highway construction due to their safety, flexibility, and economic advantages. The authors discussed the evolution of reinforced earth technology from the early use of steel straps and welded wire mesh to modern geosynthetic reinforcements like geogrids and geotextiles. The study found that geosynthetic reinforcements provide a cost-effective and corrosion-resistant alternative to metallic reinforcements, especially in aggressive environmental conditions. It was also observed that reinforced earth walls are more economical and flexible than conventional reinforced concrete retaining walls, making them suitable for sites with weak foundations and seismic regions. The paper concluded that selecting appropriate reinforcement materials significantly influences the overall cost, durability, and performance of reinforced earth wall systems, and geosynthetics offer a promising solution for sustainable and economical construction.

[21] Design and Behaviour of Mechanically Stabilized Earth Wall (2015) by Haresh D. Golakiya and Mittal D. Lad studied the design principles and structural behavior of mechanically stabilized earth (MSE) walls used as earth retaining structures in highway and infrastructure projects.

The research explained that traditional retaining walls such as gravity and cantilever reinforced concrete walls are rigid structures that cannot accommodate large differential settlements, especially in weak soil conditions. To overcome these limitations, the mechanically stabilized earth technique is adopted, which involves alternate layers of compacted soil and reinforcing elements such as steel strips, welded wire mesh, polymer grids, or geotextiles. These reinforcing materials interact with the soil through friction and confinement, providing tensile strength and improving the overall stability of the soil mass. The study also analyzed the influence of different soil conditions, backfill materials, reinforcement types, and vertical spacing of reinforcement layers on the stability of MSE walls. The design of the wall was carried out according to BS 8006:1995 guidelines, considering various combinations of retained soil and backfill soil conditions. The results indicated that MSE walls are highly flexible structures capable of accommodating large settlements and providing cost savings of approximately 35% to 50% compared to conventional RCC retaining walls. The study concluded that proper selection of reinforcement materials, soil properties, and reinforcement spacing plays a significant role in ensuring the stability and performance of mechanically stabilized earth wall systems.

[22] Seismic Analysis of Reinforced Earth Wall: A Review (2015) by Siddharth Mehta and Siddharth Shah reviewed the concept and development of seismic analysis for reinforced earth retaining walls considering soil–structure interaction. The study presented a systematic overview of the historical development and current status of seismic design methods used for reinforced earth walls. Various analytical and numerical approaches, including finite element modeling, were discussed to understand the influence of seismic forces on reinforced retaining structures. The paper highlighted the effects of seismic acceleration, soil conditions, and reinforcement properties on the stability and design of reinforced earth walls. The study also discussed the importance of facing elements such as precast concrete panels, modular blocks, metal sheets, gabions, welded wire mesh, and geosynthetic wraps, which contribute to the overall stability of the wall system. It was observed that reinforced earth walls are highly flexible compared to conventional retaining structures, making them suitable for construction on soft foundations and in seismic regions. The reinforcement layers improve the bearing capacity of soil, reduce settlement, and help in controlling soil liquefaction under seismic loading conditions. The review concluded that proper seismic analysis and soil–structure interaction considerations are essential for the safe and efficient design of reinforced earth wall systems.

III. RESEARCH GAP

From the detailed review of previous research studies, it is observed that significant advancements have been made in the design, analysis, and application of reinforced earth (RE) walls and mechanically stabilized earth (MSE) wall systems. Most researchers have focused on the overall stability, seismic performance, cost effectiveness, reinforcement configuration, and numerical analysis of reinforced earth structures. Several studies also investigated the use of geogrids, steel strips, GFRP bars, crumb rubber, marble waste, and other sustainable materials to improve wall performance and environmental sustainability. However, despite extensive research on reinforced earth retaining systems, limited attention has been given to the detailed structural behavior and performance of reinforced earth panels, particularly under combined loading and long-term environmental conditions. Most of the available studies mainly concentrate on the behavior of the reinforced soil mass rather than the performance of the facing panels themselves. Very limited research has been conducted on panel thickness optimization, crack propagation, joint behavior, connection strength between reinforcement and panels, and long-term durability of precast reinforced earth panels. In addition, insufficient experimental investigations are available regarding the effects of moisture variation, temperature fluctuation, chemical attack, corrosion, freeze–thaw cycles, and repeated traffic loading on reinforced earth panel performance. Although several numerical studies using PLAXIS and FLAC software are available, large-scale field investigations and real-time monitoring studies are still lacking. Furthermore, the use of sustainable and innovative construction materials such as geopolymers, fiber reinforced concrete, recycled aggregate concrete, nano-material modified concrete, and industrial waste-based concrete for reinforced earth panels has not been extensively explored. There is also a lack of research on smart monitoring systems, sensor-based performance evaluation, and IoT-enabled maintenance techniques for reinforced earth wall structures. Existing design guidelines mainly focus on overall wall stability and provide limited recommendations regarding panel design optimization and durability assessment. Therefore, there is a need for comprehensive research focusing on the structural behavior, durability, sustainability, monitoring, and optimization of reinforced earth panels under static, dynamic, and environmental loading conditions to improve the long-term safety and efficiency of reinforced earth wall systems.

CONCLUSION

Reinforced Earth (RE) wall systems and Mechanically Stabilized Earth (MSE) structures have emerged as highly effective and economical alternatives to conventional retaining walls in modern civil engineering and transportation infrastructure projects. From the detailed review of previous research studies, it is observed that reinforced earth walls provide several advantages such as improved flexibility, higher seismic resistance, reduced differential settlement, lower construction cost, faster construction speed, and better adaptability to weak foundation conditions. Various researchers have demonstrated that the use of geogrids, steel strips, geotextiles, GFRP bars, and other reinforcement materials significantly improves the stability and load-bearing capacity of reinforced soil structures. Experimental investigations and numerical analyses using software such as PLAXIS 2D, PLAXIS 3D, and FLAC have confirmed the effectiveness of reinforced earth systems under static as well as dynamic loading conditions. The literature review also indicates that reinforced earth walls are more sustainable and environmentally friendly compared to conventional RCC retaining walls due to reduced consumption of concrete and steel materials. Recent studies focusing on the utilization of waste materials such as marble waste, crumb rubber, fly ash, and recycled materials have further enhanced the sustainability and cost effectiveness of reinforced earth construction. In addition, reinforced earth wall panels have shown excellent performance in highway embankments, bridge abutments, flyovers, railway structures, and slope stabilization projects. However, despite considerable research progress, several important aspects still require further investigation. Limited studies are available on the detailed structural behavior of reinforced earth panels, long-term durability under environmental exposure, panel connection mechanisms, crack behavior, and smart monitoring systems. Most previous research mainly focused on the stability of the reinforced soil mass rather than the performance optimization of facing panels. Therefore, future research should concentrate on sustainable panel materials, advanced reinforcement systems, full-scale experimental investigations, and real-time monitoring techniques to improve the durability, safety, and service life of reinforced earth structures.

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