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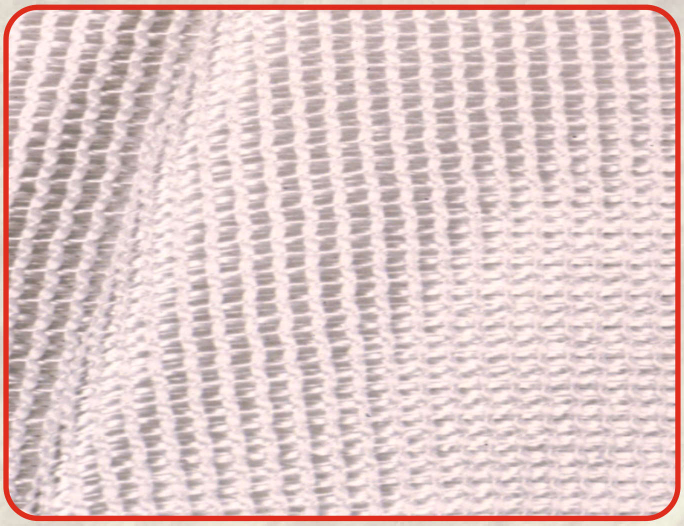
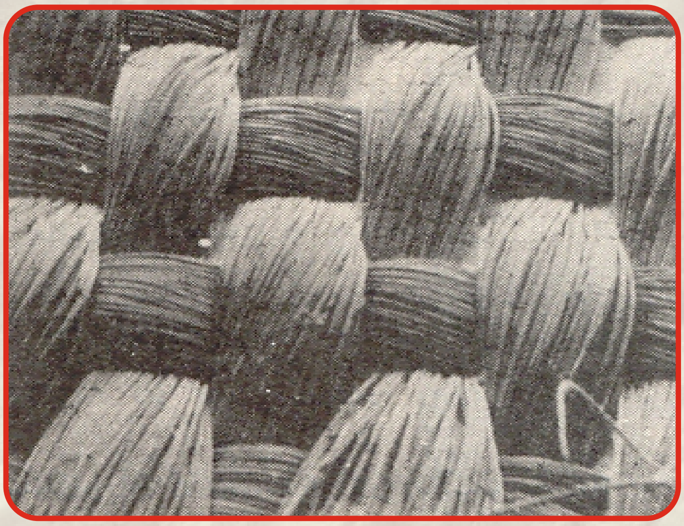
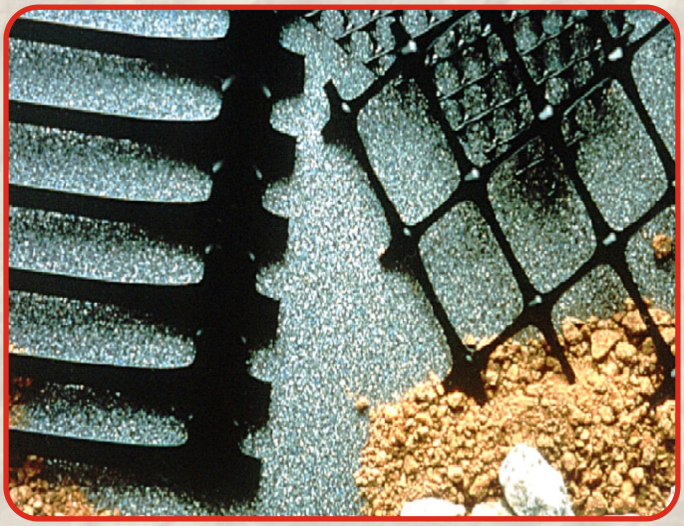
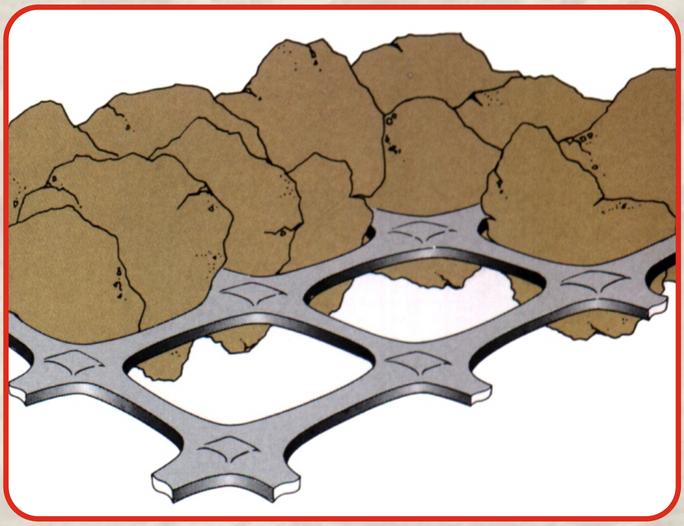

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Geosynthetics are now being increasingly used the world over for every conceivable application in civil engineering, namely, construction of dam embankments, canals, approach roads, runways, railway embankments, retaining walls, slope protection works, drainage works, river training works, seepage control, etc. due to their inherent qualities. Its use in India though is picking up, is not any where close to recognitions. This is due to limited awareness of the utilities of this material and developments having take place in its use.

The aim of the journal is to provide latest information in regard to developments taking place in the relevant field of geosynthetics so as to improve communication and understanding regarding such products, among the designers, manufacturers and users and especially between the textile and civil engineering communities.

The Journal has both print and online versions. Being peer-reviewed, the journal publishes original research reports, review papers and communications screened by national and international researchers who are experts in their respective fields.

The original manuscripts that enhance the level of research and contribute new developments to the geosynthetics sector are encouraged. The work belonging to the fields of Geosynthetics are invited. The manuscripts must be unpublished and should not have been submitted for publication elsewhere. There are no **Publication Charges**.

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INDIAN JOURNAL OF GEOSYNTHETICS AND GROUND IMPROVEMENT

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IGS – India is making all out efforts to spearhead various applications of geosynthetics in the real world problems. Indian Journal of Geosynthetics and Ground Improvement is one of its important means to underscore the accomplished applications and the potential to be harnessed. When India is manufacturer of some of the best products in the field of engineered textile of the world, people expect it to be a place of innovative applications in roads, railways, walls, foundations, hydraulic structures, etc. and actually India has presented several success stories and unique applications. This journal is instrumental in highlighting such case studies and at the same time some innovations in the methods and design philosophies to equally inspire the researchers and the practicing engineers. I expect this issue to be a matter of great interest to the civil engineers in general and place a land mark of its own. I would make an earnest request to all working in this field to kindly contribute their best to benefit the world.

Dr. G.L. Sivakumar Babu
President
Indian Chapter of
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FROM THE EDITOR'S DESK

Dear IGS India Members,

IGS – India is making all out efforts to spearhead various applications of geosynthetics in the real world problems. Indian Journal of Geosynthetics and Ground Improvement is one of its important means to underscore the accomplished applications and the potential to be harnessed. When India is manufacturer of some of the best products in the field of engineered textile of the world, people expect it to be a place of innovative applications in roads, railways, walls, foundations, hydraulic structures, etc. and actually India has presented several success stories and unique applications.

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Please feel free to reach out if you have any questions or if further information is required.

Best regards,

A.K. Dinkar
Member Secretary
Indian Chapter of
International Geosynthetics Society

GEOSYNTHETIC REINFORCED SOIL SLOPES AND WALLS FOR HILL ROADS : CASE STUDY

Pranavkumar Shivakumar[1], Satish Naik[2]

1. INTRODUCTION

Geosynthetic reinforced soil slopes and walls are innovative and sustainable solutions in geotechnical engineering that leverage the combination of soil and geosynthetic materials to create stable, durable, and economical structures for various applications. These structures are designed to address challenges related to slope stability, erosion control, and retaining wall construction. Geosynthetic reinforced soil structures often offer cost savings compared to traditional RCC retaining walls, both in terms of materials and construction time. These structures can be designed with environmentally friendly materials and construction techniques, promoting the use of local materials, and minimizing their impact on the surrounding ecosystem. Geosynthetic reinforced soils structures are also suitable for a wide range of soil types and site conditions, making them adaptable to diverse engineering challenges like steep terrains, high rainfall regions and regions of high seismic activity.

One key application area for geosynthetic reinforced soil slopes and walls are for provision of retention work of roads, highway projects and bridge approaches. The slope protection works for construction of highway infrastructure in hilly terrains typically involve the use of geosynthetic reinforced soil walls and slopes for retention work on the valley side. Best Geotechnics Pvt. Ltd. is a prominent and specialised Geotechnical, Geosynthetics and Foundation Engineering firm, with 13 years of Industry experience involving design and construction of reinforced soil walls and slopes. Best Geotechnics has significant experience in design and supervision for construction of geosynthetic reinforced soil slopes and walls in hilly terrains in the states of Himachal Pradesh, Shillong, Sikkim, and Maharashtra from which a couple of examples are presented in Figure 1. In the present paper we primarily focus on the case study for design and construction of Geogrid – Reinforced Soil Walls and Slopes for Kaithlighat – Shakral stretch as a part of Shimla Bypass Project (Package – 1) in the state of Himachal Pradesh.

2. SHIMLA BYPASS PROJECT (PACKAGE – 1) DETAILS

National Highways Authority of India (NHAI) is involved in the planning and development of new national highway projects, as well as the expansion and upgrading of existing highways. NHAI has decided to undertake the "Construction of Four Laning of NH-5 from Kaithlighat to Shakral Village (Shimla Bypass Package-I From KM. 128+835 to KM. 146+300 for Design Length – 17.465 KM) in the State of Himachal Pradesh on Hybrid Annuity Mode (HAM)". NHAI has awarded the work to the Concessionaire "Shimla Bypass Kaithlighat Shakral

Fig. 1 : Examples of Reinforced Soil Structures for Highway Projects designed by Best Geotechnics Pvt. Ltd.

1. Sr. Geotechnical Engineer, Best Geotechnics Pvt. Ltd.

2. Director, Best Geotechnics Pvt. Ltd.

Private Limited" (SBKSPL) and Concessionaire has appointed SP Singla Constructions Private Limited (SPSCPL) as EPC Contractor. The Contractor has arranged "M/s Best Geotechnics Pvt. Ltd, Mumbai" for design and supervision of Reinforced Soil Walls and Slopes as a part of the project.

The site of the 4 Lane with paved shoulder Project highway comprises development of National Highway NH-5 from Kaithlighat to Shakral Village, from Km. 128+835 to Km. 146+300 with Design length – 17.465 Km in the state of Himachal Pradesh on HAM. Figure 2 provided below portrays an index map of the project highway. The highway stretch includes 21 planned Viaducts/VOP/Major Bridge cum Viaducts. The project involves design and construction of approximately 2.5 kilometers of geogrid – reinforced soil walls and slopes for retention work of highway cross section elements within the Right of Way (ROW) primarily on the valley side. The reinforced soil walls and slopes being constructed for the project have metallic fascia in the form prefabricated L – Shaped welded wire mesh with a wraparound geogrid as system of reinforcement.

3. DESIGN PRINCIPLES OF REINFORCED SOIL WALLS AND SLOPES

Reinforced soil structures are a composite system created by the interaction between soil reinforcing elements and select granular backfill. Structures built with this system, are different from conventional earth-retaining structures since they make use of an entirely different method of support. Conventional retaining structures may be classified as externally stabilised systems since they use an external gravity RCC wall against which stabilising forces are mobilised. Reinforced Soil structures are termed as internally stabilised systems because the soil reinforcing elements are installed within the soil mass and extend beyond the potential failure plane. With an internally stabilised system, shear transfer to mobilise the tensile capacity of closely spaced reinforcing elements eliminates the need for a structural wall and, instead, substitutes a composite material, comprising reinforcing elements and granular soil, as the principal structural unit. A facing is needed on an internally stabilised system, but its primary functions are to prevent local ravelling and provide an architectural finish rather than primary structural support. Facing treatments ranging from vegetation to flexible metallic systems with wraparound synthetic reinforcements are applied to prevent unravelling and sloughing of the face.

The design of steep reinforced soil slopes up to 70 degrees slope angle is primarily based on rotational slope stability analysis of the structures based on the principles of limit equilibrium method. The design codes followed for design of reinforced soil slopes are FHWA–NHI–10–025 [1] which is in accordance with Ministry of Road Transport & Highways (MoRTH) Specifications of Road and Bridge Works, 5th Revision, 2013 [2]. The design includes the use of an allowable stress design approach for estimating the factor of safety for the critical slip surface for both short term and long term loading conditions and for all possible modes of failure. As illustrated below in Figure 3, there are three failure modes for reinforced slopes:

Fig. 2 : Index Map of Project Highway

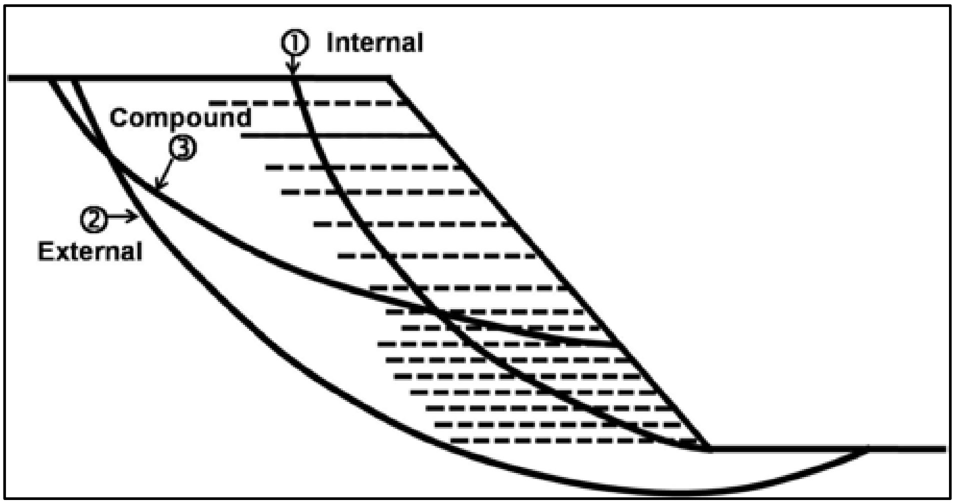

Fig. 3 : Failure modes for reinforced soil slopes

- Internal, where the failure plane passes through the reinforcing elements.
- External, where the failure surface passes behind and underneath the reinforced zone.
- Compound, where the failure surface passes behind and through the reinforced soil zone.

The design of reinforced soil slopes is based on the modified limit equilibrium slope stability analysis incorporating the extra resisting forces and moments provided by the geosynthetic reinforcements crossing the potential failure surface based on their tensile capacity and orientation as displayed in Figure 4. The assumed orientation of the reinforcement tensile force influences the calculated slope safety factor. In a conservative approach, the deformability of the reinforcements is not considered, and thus, the tensile forces per unit width of reinforcement Tr are assumed to always be in the horizontal direction of the reinforcements.

When close to failure, however, the reinforcements may elongate along the failure surface, and an inclination from the horizontal can be considered. Tensile force direction is, therefore, dependent on the extensibility and continuity of the reinforcements used, and the following inclination is suggested for different kinds of reinforcement:

- Discrete, strip reinforcements (like steel straps): T parallel to the reinforcements.
- Continuous, sheet reinforcements (like geogrids): T tangent to the sliding surface.

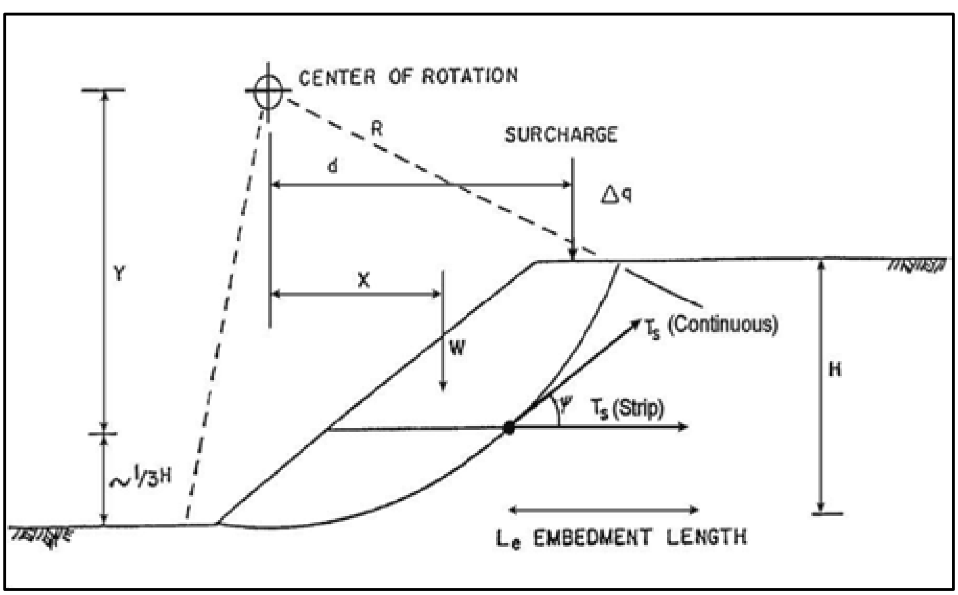

Fig. 4 : Modified Limit Equilibrium Analysis for Reinforced Soil Slope Design

The design of reinforced soil slope is typically done using a conventional slope stability analysis computer program that has been modified to account for the stabilizing effect of geosynthetic reinforcements. The design of reinforced soil slopes in Shimla Bypass Project was done on one such software termed Reinforced Earth Slope Stability Analysis (ReSSA/ReSSA+). Such programs account for reinforcement strength and pullout capacity, compute reinforced and unreinforced safety factors automatically, and have a grid-based searching routine to help locate critical failure surfaces post analysis. The design of reinforced soil walls is more rigorous and involves additional design checks apart from the global slope stability analysis. The guidelines utilized for design of reinforced soil walls are FHWA–NHI–10–024 [3] which is based on Load and Resistance Factor Design (LRFD).

This is an update on the earlier design manual of FHWA-NHI-00043 (Elias et al., 2001 [4]) which uses the Allowable Stress Design (ASD) approach for design of reinforced earth walls. The Indian guidelines for design of reinforced earth walls which is again based on LRFD methodology is IRC SP – 102 [5]. The reinforced earth walls are designed for external stability similar to conventional RCC gravity retaining walls. The typical modes of failure for reinforced earth walls with respect to external stability are Sliding, Limiting Eccentricity or Overturning and bearing capacity failures as shown in Figure 5 below.

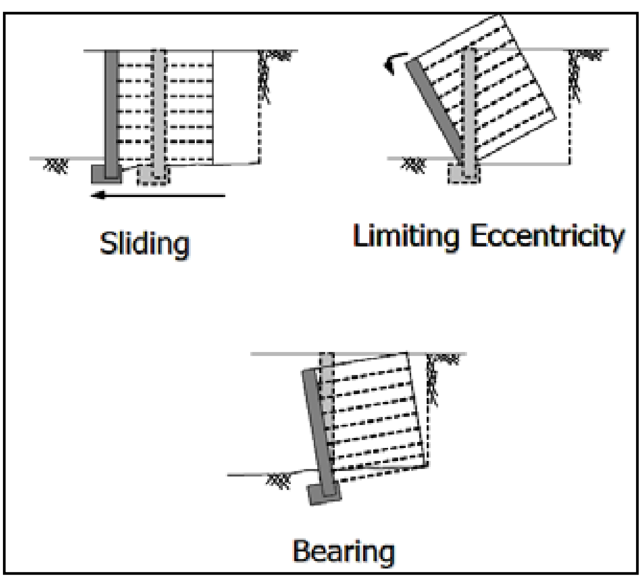

Fig. 5 : Failure modes for reinforced earth walls with respect to external stability

As discussed earlier, reinforced earth walls are considered as internally stabilized system, hence the design process involves the check for internal stability of the reinforced earth wall. The internal stability design checks for reinforced earth walls involve for check against rupture, pullout and sliding for each reinforcement layer.

When using geosynthetics (considered as extensible reinforcements) for soil reinforcement, the potential failure surface for assessing pullout capacity is determined by the tie - back wedge method as shown in Figure 6.

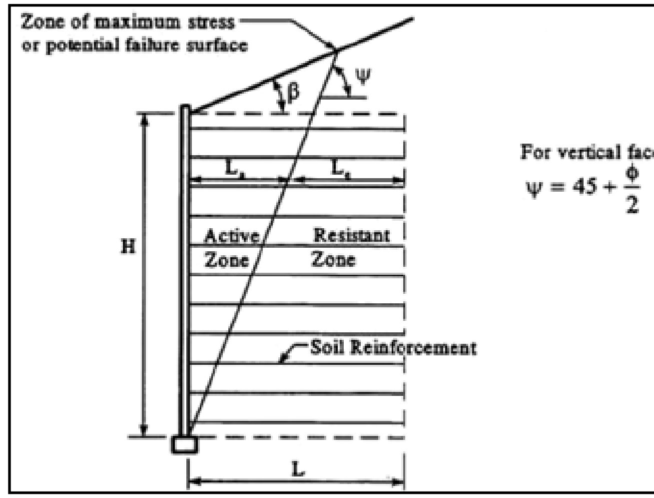

Fig. 6 : Potential failure for geogrid reinforced soil walls for internal stability calculations

The lateral earth pressure is estimated using the active earth pressure coefficient as estimated by Rankine's earth pressure theory for wall batter angle less than 10 degrees and using Coulomb's equation for wall batter greater than 10 degrees. The tensile capacity or grade, length and the vertical spacing of the reinforcements are adjusted to satisfy the design checks for both internal and external stability criterion according to the guidelines as discussed above. The design for geogrid reinforced walls at Shimla Bypass Project was done using MSEW/MSEW+ software following the guidelines of FHWA–NHI–10–024 which is recommended in the MoRTH Specifications of Road and Bridge Works, 5th Revision, 2013.

4. DESIGN AND CONSTRUCTION ASPECTS OF GEOGRID REINFORCED SOIL WALLS AND SLOPES AT SHIMLA BYPASS PROJECT (PACKAGE – 1)

The primary component of geogrid reinforced soil walls and slopes is the backfill present in the reinforced and retained zone. The backfill used in the reinforced zone is required to meet design guidelines as prescribed in Section 3104, MoRTH Specifications of Road and Bridge Works, 5th Revision, 2013. The fill used in the reinforced soil should be tested to ensure that the angle of shearing resistance is equal to or greater than the design value of angle of shearing resistance and the materials conform to the MoRTH specifications and other criteria specified in the designs and drawings. The tests to be conducted shall include wet sieve analysis, liquid limit and plastic limit, maximum dry density and optimum moisture content using heavy compaction and angle of shearing resistance using direct shear test. The grading limit as per MoRTH specifications is provided in Table 1.

Table 1 : Gradation Limit for Reinforced Fill as per MoRTH specifications

Sieve Size	Percentage Passing
75 mm	100
425 microns	0 – 60
75 microns PI ≤ 6	< 15

The soil used for reinforced and retained fill for the geogrid reinforced soil slopes and walls at Shimla Bypass project are sourced from the excavated material from the tunnel and hill side excavations. The soil sourced is then screened to meet the gradation requirements as mentioned in Table 1. The gradation results for the backfill used in the project is represented in the particle size distribution curve shown in Figure 7.

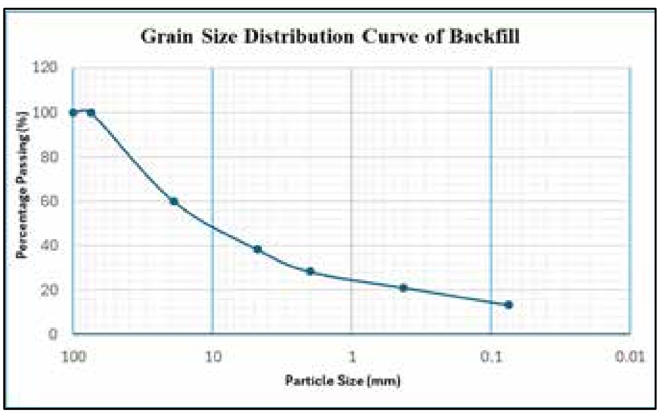

Fig. 7 : Gradation Analysis for Reinforced Fill used in Shimla Bypass Project

The angle of internal friction of the reinforced and retained backfill used for design of reinforced soil slopes and walls was considered as 34 degrees. The results for the direct shear tests (drained) performed on the backfill utilized for Shimla Bypass project as shown in Figure 8 below. The test results indicate a friction angle of approximately 38 degrees but as per MoRTH guidelines and IRC SP – 102 recommendations the design angle of friction of backfill used in reinforced zone is limited to 34 degrees on the conservative side unless the direct shear test is performed on a large shear box.

Another important component for reinforced earth structures with respect to design and construction considerations is the fascia. The geogrid reinforced soil walls and slopes designed at Shimla Bypass project are provided with a welded wire mesh fascia consisting of hot – dipped galvanized steel L – Bars, long bars and support struts. The height of each welded wire mesh unit is 400 mm. The reinforced soil slopes are designed at 70 degrees batter angle and the reinforced soil wall is designed at 84 degrees batter angle. The desired fascia angle is achieved by providing the specific offset between two consecutive welded wire mesh units. The spacing of geogrid reinforcements is kept as 800 mm for primary geogrids contributing to internal and external stability of the reinforced soil structures. A secondary geogrid is placed between two primary geogrids which contributes to the local stability of the fascia unit. The geogrid reinforcements are connected to the reinforced soil slope in a complete wraparound manner and extended into the reinforced backfill for 1.2 m length. We also provide a coir erosion blanket behind the geogrid wrap around reinforcement for erosion control and to promote vegetation growth. The combination of welded wire

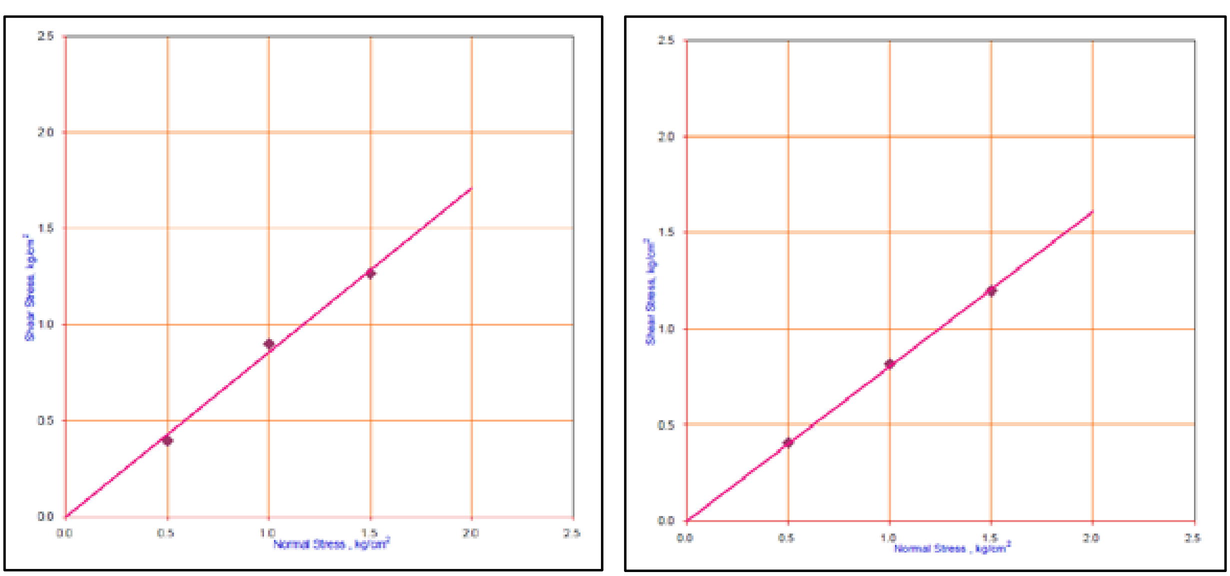

Fig. 8 : Direct Shear Test results for Reinforced Fill used in Shimla Bypass Project

mesh unit with erosion control blanket and local seeds constitutes a vegetated or green fascia for the reinforced soil slopes at Shimla Bypass Project. Figure 9 portrays the welded wire mesh unit along with wraparound geogrid and coir erosion blanket as implemented in reinforced soil slopes construction at Shimla Bypass project.

The design guidelines and MoRTH specifications indicate that reinforced soil walls require a 600 mm drainage layer in front of the fascia. Keeping this in mind a layer of rocks/boulders of width 600 mm is placed in front of the welded wire mesh unit and the geogrid reinforcement is wrapped around the second long bar placed at the bottom of the unit as shown in Figure 10. The size of the boulders is regulated between 1.5 times to 2.5 times the mesh opening size (225 mm to 375 mm) as indicated in the guidelines for gabion rockfill, IRC: SP: 116 – 2018[6].

Another important consideration for design and construction aspects for reinforced structures are the drainage elements provided. As per FHWA guidelines, the ideal backfill composition to be considered "free – draining" material is that the fines content (grain size less than 75 microns) should be less than 3 to 5 % by weight and that the fines should be non – plastic. When the amount of the fines is more than 3 to 5%, the permeability is significantly reduced, and drainage requirements must be carefully evaluated as groundwater and/or infiltration of surface water can result in build-up of seepage/hydrostatic forces within the reinforced soil mass. Special precaution is also advised for hillside construction due to the potential for seepage to occur through retained soil and rock seams, faults and joints during rain events that may not be apparent during subsurface exploration and construction. Keeping the above points in mind we have provided geocomposite drainage sheets on the excavated hill side and perforated


Fig. 9 : Welded wire mesh unit along with wraparound geogrid and coir erosion blanket for reinforced soil slopes at Shimla Bypass Project


Fig. 10 : Welded wire mesh unit connection with geogrid and 600 mm drainage layer for reinforced soil walls at Shimla Bypass Project

PVC pipe with one – half wrapped with geotextile as drainage elements for the reinforced soil structures at Shimla Bypass project as displayed in Figure 11.

The project location for Shimla Bypass Project (Package – 1) falls under seismic zone – IV as per IS 1893 (2002) [7]. The design horizontal seismic coefficient kh is dependent on the zone factor (Z). For reinforced soil walls the seismic analysis is done using a pseudo static method, namely the Mononobe-Okabe (M-O) method [8,9] for estimating the lateral earth pressures. The horizontal seismic coefficient kh is taken as Z/2 i.e. 0.12 for Zone – IV and the vertical seismic coefficient kv is taken as 0 as per IRC and FHWA guidelines. As per IRC – SP 102 recommendations, the allowable stress design approach (as per FHWA-NHI-00043 guidelines) is followed for seismic design of reinforced soil walls. The design of reinforced soil slopes includes the check for seismic slope stability which considers the additional forces and moments due to the horizontal seismic coefficient, kh taken as Z/2 i.e. 0.12 incorporated into the limit equilibrium method. The design procedure for reinforced soil slopes seismic slope stability is principally the same as design guidelines for high embankments in road projects as provided in IRC 75 – 2015 [10]. The static and seismic slope stability design for reinforced soil slopes for Shimla bypass project (package – 1) is done using ReSSA/ReSSA+ software. The reinforced soil structures have shown superior performance in the past for seismic activity as compared to conventional retaining walls due to its flexibility and capacity to tolerate deformations due to earthquake loading.

5. CONCLUSIONS

Geosynthetic reinforced soil walls and slopes have been successfully implemented for earth retention and slope protection works for various highway projects in India specifically for projects in hilly terrains. The advantages of geosynthetic reinforced soil structures are numerous in terms of promoting sustainable construction through the use of natural and often times locally available materials. The versatility of the structures in terms of reinforcement and fascia types make it possible for its application in multiple site conditions. For construction in hilly terrains, geogrid reinforced soil structures enhance the slope stability of retaining structures specifically in seismically active regions residing in the northern and north-east regions of the country. The national and international guidelines for design and construction of reinforced soil structures are well established which makes it easier for implementation in various projects. This paper talks about the detailed design and construction aspects of geogrid reinforced soil structures through the lens of a case study namely the Shimla bypass project (package – 1).

REFERENCES

[1] FHWA-NHI-10-025, "Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volume II", November 2009

[2] Ministry of Road Transport & Highways (MoRTH) "Specifications of Road and Bridge Works", 5th Revision, 2013

[3] FHWA-NHI-10-025, "Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volume II", November 2009

[4] Elias, V, Christopher, B.R. and Berg, R.R. (2001). Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, Design and Construction Guidelines, U.S. Department of Transportation, Federal Highway Administration, Washington DC, FHWA-NHI-00043, 418 p.

[5] IRC: SP:102 – 2014, "Guidelines for Design and Construction of Reinforced Soil Walls", 2014

[6] IRC: SP: 116 – 2018, "Guidelines for Design and Installation of Gabion Structures", 2018

[7] IS 1893-1 (2002): Criteria for Earthquake Resistant Design of Structures, Part 1: General Provisions and Buildings [CED 39: Earthquake Engineering]

[8] N. Mononobe and H. Matsuo, "On the determination of earth pressures during earthquakes," in Proceedings of the World Engineering Congress, p.9, Tokyo, Japan, 1929

[9] S. Okabe, "General theory of earth pressures," Journal of the Japan Society of Civil Engineering, vol.12, no.1, 1926.

[10] IRC: 75 – 2015, "Guidelines for the Design of High Embankments", 2015.

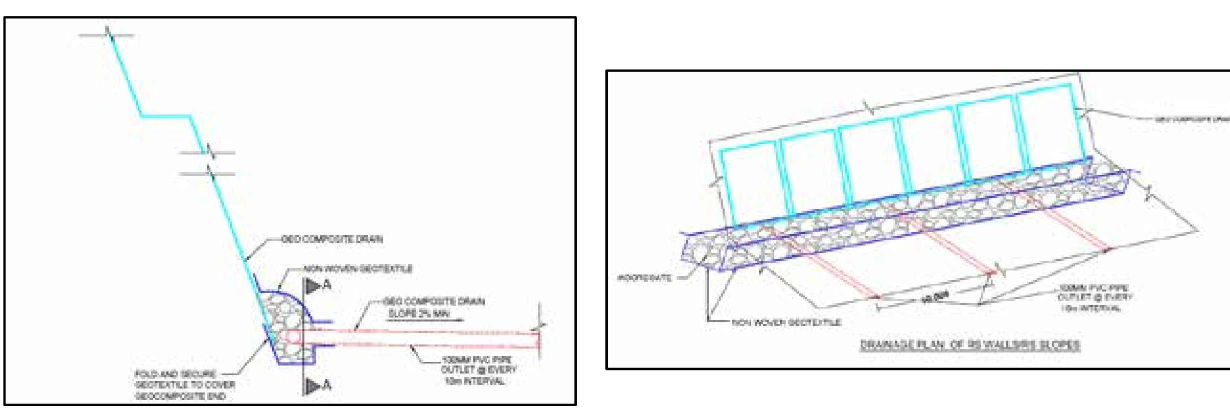

Fig. 11 : Drainage plan for reinforced soil structures at Shimla Bypass Project (Package – 1)

DISTRESS IN REINFORCED SOIL STRUCTURES – CAUSES AND REMEDIATION METHODS

Dr. Apoorva Agarwal[1], Ushma Garg[2], Dr. Deepak Manjunath[3], Atanu Adhikari[4]

ABSTRACT

To create sturdy and long-lasting structures, engineers have created reinforced soil structures, which combine soil with discrete materials (usually geosynthetics like steel strips, geogrids, or geotextiles). In civil engineering, these constructions are frequently utilised for retaining walls, slopes, embankments, and bridge abutments, among other purposes. The idea behind reinforced soil structures is to use reinforcing materials to enhance the overall strength and stability of the structure. Despite being sturdy and frequently utilized in civil engineering due to their affordability and simplicity of construction, they may experience problems in specific situations. Reinforced soil structures may encounter distress, most of which are caused by design flaws, inadequate construction techniques, inadequate drainage design etc. The distress is reinforced soil structures can be avoided by adopting good construction practices like vigilant during the construction activity. However, after adopting good construction practices at site, distress happens in such structures, and they require remediation strategies to rehabilitate distressed reinforced soil structures. This paper is an attempt to understand the probable causes of distress in reinforced soil structures and the remediation measures which can be adopted to reduce the distress in reinforced soil structures. This paper will act as a guide to the engineer working in the rehabilitation of distressed Reinforced Soil structures.

Keywords *: distressed, rehabilitation, reinforced soil structures, slopes, remediation strategies*

1. INTRODUCTION

The Reinforced Earth® technology was invented by French architect-engineer Henry Vidal in 1963. The first Reinforced Earth structure was built in Pragnieres, France in 1965 (Fang, 1991). It is used to retain soils behind structures like retaining walls, bridge abutments, vehicular underpasses etc. using the reinforcing elements. Reinforcing elements are required to cater tensile stresses developed in soil. A strong interaction between the inclusion and the soil is the foundation of the idea of soil reinforcement. Although friction is the most frequent interaction, passive pressure can also be mobilized (Jarrett & McGown, 1987). These walls are built using the combination of soil and reinforcements, which provide the stability against the lateral earth pressure. The main components of the system are:

1. Foundation: To guarantee stability, the wall is anchored into the earth using a proper foundation. Depending on the site's characteristics and the wall's height, this foundation may be deep or shallow.
2. Reinforcement: Steel strips, geogrids, and other geosynthetic materials are examples of materials that can be used for reinforcement. These reinforcements are mechanically connected to the wall's face components and inserted into the soil mass at regular intervals.
3. Backfill: Compacted earth is used to fill the space behind the layers of reinforcement. The primary resistance against lateral stresses occurring on the wall is provided by this soil.
4. Facing: Installing the wall's facing components, which can be comprised of modular blocks, precast concrete panels, or other materials, creates a sturdy and visually appealing surface. Additionally, the loads from the backfill are distributed to the reinforcing layers via the facing elements.
5. Drainage: To prevent hydrostatic pressure building behind the wall, which could cause instability, proper drainage is crucial. To aid in water drainage, drainage materials like gravel or perforated pipes are frequently used within the backfill.
6. Surcharge: Extra surcharge loads could occasionally be applied to the wall's top. For the structure to be stable, these loads must be taken into consideration in the design.

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4. M.Tech, Chief Development Officer, Terre-Armee

The codal guidelines presented in IRC-SP:102 (2014), FHWA-NHI-10-024 (2009), FHWA-NHI-10-025 (2009), FHWA-NHI-00-043(2001), NF P 94-270 (2009) and BS 8006-1 (2010) gives the detail explanation about the design of these structures. Reinforced soil walls, although robust and commonly used in civil engineering for their cost-effectiveness and ease of construction, can face distress under certain conditions. Distress in reinforced soil walls can manifest in various forms, often related to factors such as design flaws, inadequate construction techniques, environmental factors, or improper maintenance.

This paper is an attempt to understand in detail the causes of distress in Reinforced Soil structures and the remediation measures adopted to rehabilitate distressed Reinforced Soil structures. This paper will act as a guide to the engineer working in the rehabilitation of distressed Reinforced Soil structures.

2. CAUSES FOR DISTRESS IN REINFORCED SOIL STRUCTURES

The distress in reinforced soil structures could be due to various many factors ranging from design to operations. Some common types of distress in reinforced soil structures are:

(a) **Constructing a utility below already constructed reinforced soil structures**: Many a times, due to change in plan and profile at the later stage of the project, some utilities are constructed after the completion of reinforced soil structures or when major portion of the structure is constructed. In such cases, the precast utilities are tried to be pushed below these structures. The pushing of precast utility below these structures creates cavity and thus affecting the dense state of reinforced fill.

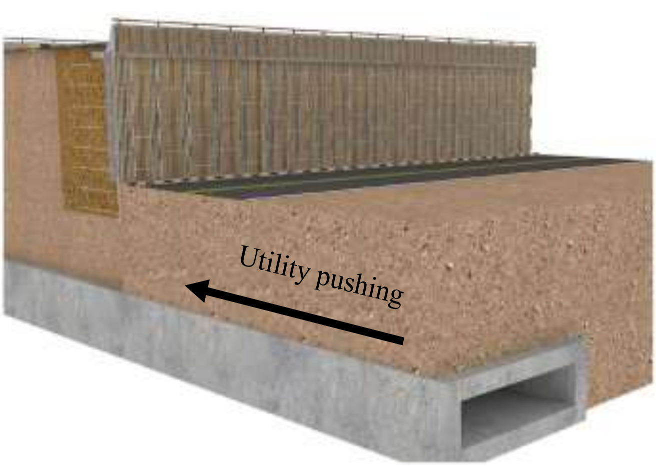

Fig. 1 : 3D image of utility pushing below reinforced soil structures

(b) **Inadequate connection strength**: Sometimes the non- engineered connections of insufficient strength are installed in reinforced soil structures which lead to connection failure and thus causing distress in the structure.

(c) **Non-Compliant structural fill**: The quality of reinforced fill plays a crucial role in the long-term behaviour of RE wall. Considering the guidelines in codes like IRC: SP 102 (2014), BS 8006-1 (2010), FHWA-NHI-024 (2009), FHWA-NHI-00-043 (2001), the reinforced fill should comply with the specifications given in Table 1.

Table 1 : Standard specifications for use as a structural fill for Reinforced Earth Wall applications (Prasad & Ramana (2016); Agarwal et al. (2023))

S. No.	Property	Unit	Permissible limit
1.	Max. particle size mm	19	102
2.	% fines (below 0.075 mm)	%	0-15
3.	Plasticity Index (PI)	%	6 (max.)
4.	Angle of shearing resistance (φ)	°	> 30
5.	Organic content	%	< 1
6.	Coefficient of uniformity (Cu)	-	≥ 4
7.	pH	-	5-10 (steel reinforcement)
			3-9 (PET reinforcement)
			>3 (PP and HDPE reinforcement)
8.	Resistivity	ohm-cm	> 3000 (only for steel reinforcement)
9.	Chloride content	ppm	< 100
10.	Sulphate content	ppm	< 200

The design of reinforced soil structure is dependent on the proper estimation of the values defined in Table 1. The codal practice defines the testing method to obtain those values. However, due to the wide variation in reinforced fill properties, the testing methods need to be updated as per the site condition. However, same testing method is employed for all types of reinforced fills and thus, sometimes, improper estimation of the properties is obtained. In those cases, reinforced soil structures face distress due to improper testing protocol.

(d) **Using small lengths or no reinforcement in the top panels**: Top panels tend to rotate if they are not properly anchored in the backfill. The phenomenon of pullout plays a crucial role in the top portion of the wall. Also, the unsupported panels and large spacing of the reinforcements in the top part of the structure are matter of concern and can lead to distress in structure (Figure 2).

Fig. 2 : Structure showing no reinforcement at top panel

(e) **Improper Compaction of structural fill**: As per BS 8006 (2010), 100 mm of post construction settlement is allowed in the concrete panel structures. However, due to poor compaction, the strain level at which the force is mobilized is high as compared to well compacted fill.

(f) **Unrealistic design parameters due to inaccurate and insufficient geotechnical investigation**: Often, the testing protocols adopted for geotechnical investigation of the site does not depict the accurate condition. For instance, the undrained unconsolidated soil parameters of foundation/existing slope are generally considered for long term stability. However, for long term stability, drained parameters to be used. Due to the use of unrealistic parameters in the design, the structure faces destressing in long term.

(g) **Ignoring minimum embedment depth recommended in design code**: The embedment depth of structure plays an important role in the overall stability. It provides passive resistance to the base of the structure. It plays an important role in case of slopes with steep angles. BS 8006-1 (2010) provides a guidance on the minimum embedment depth for structures. To save the cost of excavation, the criteria is ignored which leads to exposure of the base of structure and can lead to distress.

(h) **Improper drainage condition:** Proper drainage plays an important role in the stability of the structure. If the structure drainage system is not designed properly, the chances of distress in the structure increases many folds. Few instances where the distress of structures occurred due to improper drainage are:

a. The area experiencing severe rains which were of unprecedented magnitude after the construction of reinforced soil structures.

b. Continuous rainfall during the construction might lead to increased water content in the fill and washing of soil.

c. Rainfall effects the pore water pressure in the soil, thus increasing the seepage forces which are not considered in the design.

(i) **Structural fill settlement**: Poor compaction during construction, insufficient drainage and use of noncompliant structural fill results in distressing in structure. Due to settlement, the stresses on the connection increases and thus, lead to connection failure.

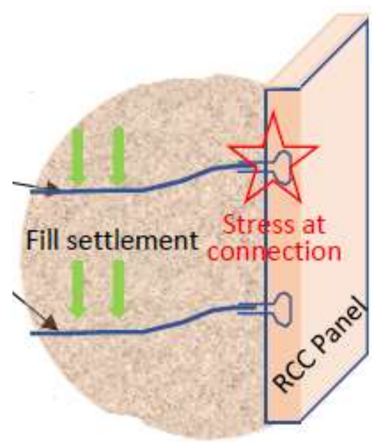

Fig. 3 : Effect of fill settlement on connection

3. GOOD PRACTICES TO BE FOLLOWED AT SITE

Reinforced soil structures are robust structures and require negligible maintenance. However, due to poor operation practices, these structures experiences distress and can lead to failure. To eliminate the distress in these structures, good operation practices should be followed and few of these practices are:

(a) **Replacement of damaged facing**: It might be imperative to replace or repair the face material (such as segmental blocks, geosynthetic reinforcement, or concrete panels) if it is damaged during construction. To maintain structural integrity of the facia, this may entail replacing the face elements entirely or only repairing them by filling the surficial crack with cement slurry.

(b) **Replacement of damaged reinforcement**: During the construction activity and handling at site, it is common phenomenon that the soil reinforcement might experience damage which might effect the performance of reinforced soil structure at later stage. It is thus recommended to replace the damaged soil reinforcement during construction phase only.

(c) **Improvement of foundation soil**: If the foundation soil has insufficient shear strength, soil improvement techniques may be employed. This could be achieved by employing ground improvement techniques like installing prefabricated vertical drains, stone columns for deep ground improvement and installing biaxial geogrids or geocells for shallow ground improvement.

(d) **Monitoring and Maintenance**: Implementing a routine maintenance and monitoring program is crucial to identifying any early warning indicators of discomfort and acting before they become more serious problems. This could involve regular maintenance tasks like controlling vegetation and cleaning drainage systems, as well as recurring inspections and instruments for monitoring structure motions.

4. REMEDIATION MEASURES TO BE ADOPTED

The goal of remediation techniques is to deal with the causes of distress by restoring the structure's integrity and stability. Some of the common distress remediation techniques employed for reinforced soil structures are:

(a) **Diagnosis and Assessment**: A detailed assessment of the severity and underlying causes of the distress is necessary before implementing any repair plans into action. To precisely identify the underlying issues, this may entail monitoring, material testing, visual inspections, and structural analysis.

(b) **Dismantling of structure**: Sometimes, the distress in the structure could be corrected by dismantling it and rebuilding the structure. It can be done by excavating the compacted fill, installing fresh reinforcement layers, compacting back the soil.

(c) **Drainage Improvement**: Insufficient drainage might cause the backfill material to get saturated, weakening it and creating instability. The hydrostatic pressure behind the structure can be reduced and water buildup can be avoided by upgrading the existing drainage systems. For the existing structure, perforated drainage pipes can be installed to collect and divert water. These pipes should be wrapped with non-woven geotextiles to prevent soil particles entering from blocking them.

(d) **Structural remediation**: Structural remediation methods such installing grouted tiebacks, or anchors or soil nails may be required in extreme cases of distress structural failure. It is required to strengthen and to prevent future damage to the existing structure.

5. STRUCTURAL REMEDIATION OF DISTRESSED STRUCTURES

Depending on the extent of distress in structure, different techniques may be utilized. Some of the common methods of the structural remediation of distressed reinforced soil structures are:

a. Installing Soil Nails or Anchors: Soil nails or ground anchors are inserted into the reinforced soil of the structure and thus provide additional lateral support. This method is effective for stabilizing walls experiencing excessive lateral pressure (Figure 4).

Fig. 4 : The drilling operation for installation of soil nail

(b) **Additional drainage systems**: Poor drainage can contribute to distress in reinforced soil structures by increasing hydrostatic pressure. In case where there is an issue with the drainage, semi-perforated pipes can be installed in the structure to dissipate hydrostatic pressure. Also, subsurface drains can be constructed at site, to dissipate excess runoff water which otherwise can pond near structure and can lead to distress in the structure.

6. CONCLUSIONS

The present paper is an attempt to highlight the common issues faced with reinforced soil structures. This paper highlights the major causes which can result in distress in reinforced soil structures and are often related to factors such as design flaws, inadequate construction techniques, inadequate drainage design etc. Few of the common causes for the distress in reinforced soil structures are Constructing a utility below already constructed reinforced soil structures, inadequate connection strength, non-compliant structural fill, using small lengths or no reinforcement in the top panels, improper compaction of structural fill, unrealistic design parameters due to inaccurate and insufficient geotechnical investigation, ignoring minimum embedment depth recommended in design code, improper drainage condition, structural fill settlement etc.

This paper also highlights few of the good practices to be followed at site during construction. If the structure experiences distress even after adopting good practice, remediation measures need to be implemented at site. Some of the methods are diagnosis and assessment of the distress structure, dismantling of structure, drainage improvement and lastly structural remediation by installing soil Nails or anchors and by providing additional drainage systems.

This paper is purely based on the site experience and will act as a guide to the engineer working in the rehabilitation of distressed reinforced soil structures.

6. REFERENCES

1. Fang Hsai-Yang (1991), Foundation Engineering Handbook, 2nd Ed., Springer Science and Business Media, New York, pp. 778-792.
2. Jarrett Peter M. and McGown Alan (1987), NATO Advanced Research Workshop on the “Application of Polymeric Reinforcement in Soil Retaining Structures”, Kluwer Academic Publishers, The Netherlands, pp. 3-68.
3. IRC-SP:102 (2014), Guidelines for Design and Construction of Reinforced Soil Walls, Indian Road Congress, New Delhi, pp.1-80
4. FHWA-NHI-10-024 (2009), Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volume 1, U.S. Department of Transportation Federal Highway Administration, New York, pp. 1-306
5. FHWA-NHI-10-025 (2009), Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volume 2, U.S. Department of Transportation Federal Highway Administration, New York, pp. 1-378
6. FHWA-NHI-00-043(2001), Mechanically Stabilized Earth Walls and Reinforced Soil Slopes: Design and Construction Guidelines, U.S. Department of Transportation Federal Highway Administration, New York, pp. 1-394.
7. NF P 94-270 (2009), Geotechnical design, Retaining Structures, Reinforced fill and Soil Nailing Structures, France, pp. 1-181
8. BS 8006-1 (2010), Code of Practice for Strengthened/Reinforced Soils and Other Fills, British Standard, London, pp. 1-280.
9. Prasad, P. S., & Ramana, G. V. (2016). Imperial smelting furnace (zinc) slag as a structural fill in reinforced soil structures. Geotextiles and Geomembranes, 44(3), 406-428.
10. Agarwal, A., Ramana, G. V., Datta, M., Soni, N. K., & Satyakam, R. (2023). Pullout behaviour of polymeric strips embedded in mixed recycled aggregate (MRA) from construction & demolition (C&D) waste–Effect of type of fill and compaction. Geotextiles and Geomembranes, 51(3), 405-417.

BUILDING A FOUNDATION FOR RESILIENT INFRASTRUCTURE: THE CRITICAL ROLE OF MATERIAL AND SYSTEM QUALITY IN MECHANICALLY STABILIZED EARTH WALLS

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ABSTRACT

Mechanically Stabilized Earth Walls (MSEWs) also known as reinforced soil walls (RSW), are engineered systems that utilize soil reinforcement materials, such as geogrids, geostrips or geotextiles, to stabilize and reinforce earth structures against external forces. The fundamental principle behind MSEWs lies in harnessing the inherent strength of soil, augmented by properly designed reinforcement elements, to create structurally reliable solutions. By integrating the natural properties of soil with modern engineering techniques, MSEWs offer a flexible and adaptable solution for a wide range of geotechnical challenges becoming integral components of modern civil engineering projects, including retaining walls, bridge abutments, and slope stabilization.

The selection of materials and systems for MSEW construction plays a pivotal role in determining the structure's integrity, resilience, and service life as MSEWs are designed to endure extremely variable environmental conditions and diverse external loads. Hence, the selection of high-quality materials and the application of robust construction methods is paramount to ensuring these structures reliability and durability. Utilizing substandard materials or inadequately designed systems can lead to a myriad of challenges, including structural failure, excessive deformation, and costly repairs.

This paper examines the importance of selecting high-quality materials and systems for MSEW construction to prevent the need for repairs and remedial actions. Through case studies and best practices, this paper provides insights into effective strategies for mitigating risks and optimizing the performance of MSEWs.

Keywords *: MSEW, Geostrip, Geosynthetics, Quality, Sustainability*

1. INTRODUCTION

RSW are engineered systems that utilize soil reinforcement materials, such as geogrids, geostrips or geotextiles, to stabilize and reinforce earth structures against external forces. The fundamental principle behind reinforced soil (RS) utilizing the strength of soil and enhancing further by inclusion of tensile elements to create structurally reliable solutions. By integrating the natural properties of soil with modern engineering techniques, RSWs offer a flexible and adaptable solution for a wide range of geotechnical challenges becoming integral components of modern civil engineering projects, including retaining walls, bridge abutments, and slope stabilization.

These structures have gained widespread acceptance in Indian road sector due to their versatility, cost-effectiveness, and durability. However, the long-term performance and stability of MSEWs are intrinsically linked to the quality of materials and systems selected during construction. The selection of materials and systems for MSEW construction plays a pivotal role in determining the structure's integrity, resilience, and service life as MSEWs are designed to endure extremely variable environmental conditions and diverse external loads.

Hence, the selection of high-quality materials and the application of robust construction methods is paramount to ensuring these structures reliability and durability. Utilizing substandard materials or inadequately designed systems can lead to a myriad of challenges, including structural failure, excessive deformation, and costly repairs. In recent times, number of failures of such structures have increased in India. Therefore, it is imperative to prioritize quality in material and system selection to ensure the reliability and longevity of MSEWs.

This paper examines the importance of selecting high-quality materials and systems for MSEW construction to prevent the need for repairs and remedial actions. By exploring the impact of material and system quality on MSEW performance, as well as identifying key

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factors influencing selection decisions, this paper aims to underscore the significance of quality assurance in MSEW projects. Through case studies and best practices, this paper provides insights into effective strategies for mitigating risks and optimizing the performance of MSEWs.

2. TYPICAL COMPONENTS OF MSE WALLS

2.1 Reinforced Soil

RS rely on the inherent strength and stability of soil as the primary building material. The choice of soil type is critical and depends on factors such as shear strength, particle size distribution, and permeability. Commonly used soils include granular materials like sand and gravel, as well as cohesive materials such as clay. The properties of the selected soil play a significant role in determining the overall performance and stability of the MSEW structure.

Granular soils, such as sand and gravel, are often preferred for MSEW construction due to their excellent drainage properties, high permeability, and good load-bearing capacity. Granular soils provide good compaction characteristics and are relatively easy to work with during construction. These soils, such as AASTHO #57 stones in the USA or other typical structural fills, are commonly used in Countries where manpower is not available, its cost is extremely relevant, or the material is available on site (such as in case of quarries). However, these backfill materials, are not the only solution available for the achievement of stable and durable MSEW structures.

Locally available soils, which may include a variety of materials such as sand, gravel, and clay are also frequently used for MSEW construction in many areas. This possibility offers several benefits in terms of sustainability and cost reduction:

- Reduced Environmental Impact: Utilizing locally available soils minimizes the need for extensive transportation of construction materials, thereby reducing carbon emissions and traffic congestion associated with material transport. This practice helps lower the project's overall environmental footprint and contributes to sustainability efforts by conserving energy and natural resources.
- Cost Savings: Locally available soils are often more cost-effective compared to imported or specially sourced materials. By using indigenous soils found within or near the construction site, project developers can significantly reduce material acquisition costs, transportation expenses, and associated fees. This cost-saving measure can lead to overall project cost reduction and improved financial viability.
- Promotion of Regional Economy: Supporting local soil resources promotes economic growth and development within the region. By sourcing materials locally, construction projects contribute to the local economy by generating employment opportunities, stimulating business activities, and fostering community prosperity. This localized approach to material procurement strengthens regional resilience and reduces dependence on external suppliers.

Locally available soils might lack adequate strength or stability. Lime and concrete are commonly used materials for soil stabilization, offering effective solutions for enhancing soil parameters and improving overall MSEW performance. These techniques are often used in Europe (e.g. Italy, Belgium, UK) as they proved to increase the strength of the stabilized soil, allowing for higher load-bearing capacity and reduced deformation under applied loads. The stabilization treatments also enhance the durability of the soil mass, making it resistant to environmental factors such as moisture, freeze-thaw cycles, and chemical degradation, minimizing swelling and shrinkage behavior and improving the overall stability. The use of fly ash is also established to improve soil compaction and increase shear strength.

Other engineered fill materials used for the construction of MSEWs could be recycled concrete aggregate or crushed stone as these fill materials provide consistent engineering properties and can be tailored to meet specific project requirements.

Many different options in terms of reinforced soil choice are available, however it must be understood that as the natural soil's structural capacity decreases, there is a corresponding increase in the necessity for engineered reinforcement to ensure the stability and performance of the construction project.

2.2 Reinforcement Materials

Mechanically Stabilized Earth Walls might utilize a diverse range of reinforcement materials tailored to specific project requirements and site conditions. Among the most common reinforcement materials selected are geogrids, geostrips, and geotextiles, which offer versatile solutions for stabilizing soil structures. Nowadays, the advantages of geosynthetic reinforcements, including corrosion resistance, easy to handle nature, wide range of tensile strength and polymer compositions, resistance to biological degradation, compatibility with soil, and environmental sustainability, make them preferred options for MSEW construction over traditional steel reinforcements. These benefits contribute to cost-effective, durable, and environmentally friendly MSEW solutions.

When selecting geosynthetic reinforcement for reinforced fill structures, several aspects should be verified to ensure optimal performance and durability. These aspects include:

- Tensile Strength: the tensile strength of the geosynthetic reinforcement indicates its ability to withstand applied loads and provide effective reinforcement to the soil mass. The long-term resistance is key to ensure suitability for MSEW applications.
- Chemical Resistance: the chemical resistance of the geosynthetic reinforcement must ensure compatibility with soil conditions and potential exposure to aggressive substances, such as chemicals or contaminants at the design temperature. Materials with thick and high chemical resistance coatings can mitigate degradation and ensure long-term performance also in challenging environments such as lime stabilized soils.
- Durability: the durability of geosynthetic reinforcements under specific environmental conditions, including exposure to ultraviolet (UV) radiation, temperature fluctuations, moisture, and biological activity shall be verified, and proper reduction factor considered in the design.
- Creep Behaviour: the creep behaviour of the geosynthetic reinforcement refers to its tendency to deform under sustained loads over time. A deep assessment of creep resistance properties to ensure minimal deformation and long-term stability of the MSEW structure, particularly in applications subject to continuous or cyclic loading.
- Installation Requirements: the installation requirements and compatibility of the geosynthetic reinforcement with construction techniques and equipment shall be considered.
- Manufacturing Standards and Quality Control: the geosynthetic reinforcement must complies with relevant manufacturing standards, such as ASTM (American Society for Testing and Materials) or ISO (International Organization for Standardization) or IS (Indian Standards) and undergoes rigorous quality control measures. The reinforcement shall meet specified performance criteria and testing certificate from third party reliable laboratories shall be available to define mechanical properties, durability, creep and chemical resistance.
- Supplier Reputation and Support: reputable suppliers with proven track record of providing high-quality geosynthetic reinforcements and comprehensive technical support is key for the long -term performance of an RS structure. It is always recommended to deal with suppliers who offer expertise in RS design, installation guidance, and post-construction support and monitoring to ensure successful project outcomes.

By carefully considering these aspects and verifying the suitability of geosynthetic reinforcements for MSEW applications, engineers and project stakeholders can select the best reinforcement materials to optimize structural performance, longevity, and cost-effectiveness of MSEW projects.

2.3 Facing Elements

Facing materials are integral components of reinforced fill structures, serving multiple purposes including structural support, aesthetic enhancement, and environmental protection. When selecting facing materials for MSEWs, engineers consider various factors to ensure optimal performance and durability. These materials must possess sufficient structural integrity to withstand the imposed loads and maintain stability over the design lifespan of the structure. Additionally, aesthetic considerations play a crucial role, with designers opting for materials that enhance the visual appearance of the structure while complementing the surrounding landscape or architectural features. Weather resistance is another essential aspect, as facing materials must endure exposure to environmental elements such as moisture, temperature fluctuations, UV radiation, and freeze-thaw cycles. Erosion control properties are also important to prevent soil erosion and surface runoff behind the MSEW, especially in sloped or exposed locations prone to erosion.

Facing elements can be connected to the reinforcement layers using either mechanical connection or friction connection methods. In both cases compatibility with the selected reinforcement system, whether geostrips, geogrids, geotextiles, or other types, is crucial to ensure proper and well-established integration and load transfer between the facing and reinforcement layers. The connection shall be properly testing and approved by third party like British Board of Agrément (BBA) and NTPEP (National Transportation Product Evaluation Program).

2.4 Drainage System

Drainage-related problems are recognized as one of the leading causes of failures in MSEW structures. The drainage system is a critical component of MSEWs, responsible for managing water infiltration and controlling hydrostatic pressure within the soil mass. Integrating a robust drainage system into MSE walls is essential for ensuring effective water management and preserving the structural integrity of the entire system. Properly designed and installed drainage components mitigate the risk of water-related issues, such as erosion, settlement, and slope failure, enhancing the overall performance and longevity of the reinforced soil structures.

If the reinforced soil used is not free-draining, additional measures can be implemented to improve drainage. This system typically includes perforated drainage pipes, granular drainage layers, and drainage geocomposite installed behind the facing elements. These components facilitate the timely removal of excess water from the MSEW structure, preventing saturation-induced instability, soil erosion, and hydrostatic pressure buildup.

3. THE RELEVANCE OF MATERIAL AND SYSTEM QUALITY

Central to the success of any RS project is the quality of materials and systems used in the construction, which directly influences the long-term performance, structural integrity, and resilience to external forces. As MSEWs continue to gain prominence in modern infrastructure projects such as retaining walls, wing walls, bridge abutments (also true abutments), the importance of ensuring material and system quality cannot be overstated.

The adherence to high standards of quality assurance throughout the project lifecycle is paramount to avoid costly remedial actions and infrastructures inefficiencies. From the selection of certified materials to the integration of approved systems, meticulous attention to quality ensures that these structures meet performance expectations, withstand environmental challenges, and deliver lasting value to communities. By exploring simple processes of material and system quality assurance, as well as the benefits and challenges associated with their implementation, the importance of prioritizing quality in MSEW construction practices is underscored.

To provide deeper insights and tangible examples, a concrete facing panel system reinforced with polymeric strips, commercially known as Maccaferri MacRes system, has been selected and will be described. The Paraweb reinforcing geostrips have been identified as one of the most tested reinforcements, in use since 1977 when the first trial wall was built in the UK at the Transport Research Laboratory's facility at Crowthorne in Berkshire.

3.1 Material performance

Through a comprehensive understanding of material and system quality considerations, engineers and stakeholders can navigate the complexities of RS projects with confidence, ultimately achieving sustainable and resilient infrastructure solutions for the future. National or local approvals play a crucial role in setting standards for quality, providing assurance to engineers, contractors, and regulatory authorities.

In the qualification process of geosynthetic reinforcements like geostrips, thorough testing is imperative to ensure their long-term performance and durability. European (EN), International Organization for Standardization (ISO) and ASTM standards provide comprehensive guidelines for conducting these tests, establishing rigorous criteria to evaluate the suitability and effectiveness of geosynthetic materials in various applications. Key tests include but are not limited to tensile strength, elongation, creep behaviour, puncture resistance, and durability assessments. These standards, such as ISO 10319 for tensile strength and elongation, and ISO 12957 for determining creep behaviour, outline precise testing methodologies and acceptance criteria crucial for assessing the material's performance over extended periods. It is also important to deeply analyse the results coming from the tests as not all reports are the same. When talking about creep, for example, the reference to SIM (Stepped Isothermal Method) Accelerated Creep Test as per ASTM D 6992 only is not enough, according to the requirements of ISO/TS 20432: 2022, to predict the long term rupture behaviour of a material. The material shall be further tested at minimum 2000h or 10000h and SIM data can be combined. It is obvious that the more a material is subject to tests the greater its reliability can be. There are products in the market that can provide much more than the minimum requirements. Maccaferri Paraweb long-term creep rupture test data has been validated with over

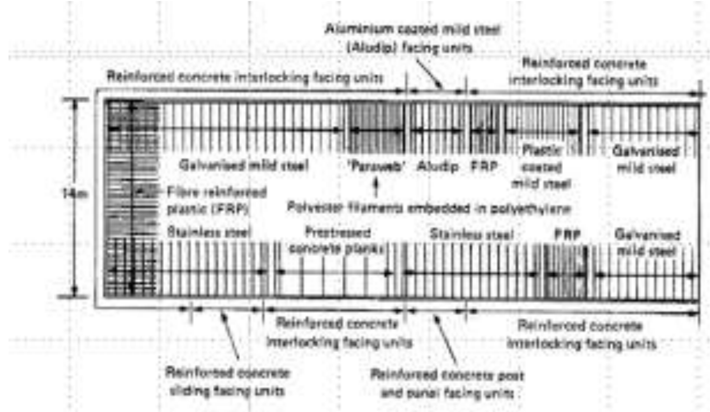

Figure 1 : First trial wall at Transport Research Laboratory's facility at Crowthorne in Berkshire.

69000h of continuous testing to prove the performance in the “real” long term. Compliance with ISO standards not only facilitates uniformity and comparability of test results but also enhances the overall safety and sustainability of infrastructure projects, mitigating risks associated with material degradation and structural failure over time. Adherence to these standards is fundamental to ensure that geosynthetic reinforcements meet stringent quality requirements, providing engineers and stakeholders with confidence in the long-term stability and reliability of MSE walls and other geotechnical structures.

It is extremely important to make sure that the testing for evaluation of the material performance is carried out by international laboratories accredited to run the specific evaluation according to the required standard. This will ensure that all the set-up parameters and procedures will be properly followed as per the selected testing procedure. Test results may display significant discrepancies if all test conditions are not met.

Certification bodies like the British Board of Agrément (BBA) and NTPEP (National Transportation Product Evaluation Program) play a vital role in ensuring the quality and reliability of products used in civil engineering and infrastructure projects. These bodies conduct comprehensive evaluations and testing procedures to certify products, including geosynthetic reinforcements like geostrips, for their suitability and performance in various applications. The scope of certifications offered by these bodies encompasses rigorous assessment criteria, including material properties, durability, and compliance with relevant industry standards and specifications. Achieving certification from reputable organizations such as BBA and NTPEP not only validates the quality and integrity of the product but also provides engineers, designers, and project stakeholders with assurance regarding its reliability and performance under real-world conditions. Certified products undergo thorough scrutiny and testing, leading to more accurate and trustworthy analyses and design calculations. Moreover, certification facilitates regulatory compliance and promotes confidence among end-users, ultimately contributing to the safety, longevity, and sustainability of infrastructure projects.

It is not only a matter of technical performance: in today's environmentally conscious world, the importance of Environmental Product Declarations (EPDs) for products like reinforcements cannot be overstated. EPDs provide comprehensive and transparent information about the environmental impacts associated with the production, use, and disposal of a product throughout its lifecycle. For reinforcements used in Mechanically Stabilized Earth walls and other geotechnical applications, EPDs play a crucial role in assessing their sustainability and environmental footprint. By analyzing factors such as raw material sourcing, manufacturing processes, energy consumption, and emissions, EPDs enable engineers, designers, and decision-makers to make informed choices that prioritize sustainability. Furthermore, EPDs facilitate comparisons between different products, empowering stakeholders to select options that minimize environmental harm and promote resource efficiency. Incorporating sustainable reinforcements not only helps reduce the overall carbon footprint of MSE wall systems but also contributes to the long-term resilience and environmental stewardship of infrastructure projects. Therefore, embracing EPDs and prioritizing sustainability in reinforcement selection are essential steps towards building a more environmentally responsible and resilient built environment.

3.2 System performance

The preceding paragraph summarises the significance of quality and reliability of individual components through proper testing at accredited laboratories. However, it is also crucial to evaluate the behaviour of the MSE wall as a cohesive system to ensure its integrity and performance.

In the USA, each Department of Transportation (DOT) holds the responsibility of approving MSEW for usage in their respective projects. Each State QPL/APL (Quality Product List or Approval Product List) includes all system that proved suitability and reliability for the use in infrastructure projects. These approval processes typically involve testing, evaluation, and documentation of performance characteristics, ensuring that only high-quality and proven systems are included in approved product lists. Consequently, specifying MSE wall systems certified by recognized bodies and endorsed by local and national authorities not only ensures compliance with standards and regulations but also instils confidence in the reliability and performance of these crucial infrastructure components.

International bodies such as BBA in the UK, HITEC (Highway Innovative Technology Evaluation Center) or the IDEA program provide review and evaluation of MSE walls. These technical evaluation reports rigorously evaluate MSE wall systems for compliance with industry standards, performance criteria, and regulatory requirements, therefore they serve as concise summaries of the major characteristics of the system analysed. The analysis of a system through these programs aids state and local agencies in efficiently assessing RSS technology, facilitating its adoption within the construction sector. By obtaining certifications from reputable organizations such as those mentioned above, MSE wall system manufacturers demonstrate their commitment to meeting stringent quality and safety standards.

Procuring the entire MSEW system from a single supplier is important for accountability and risk mitigation, rather than sourcing individual components from different sources. By obtaining the entire system from a unified entity, responsibility for the compatibility and performance of the MSEW system rests squarely with the supplier. This consolidated approach not only streamlines communication and coordination but also minimizes the potential for misalignment or conflicts between various components. Moreover, in the event of unforeseen issues or failures, having a single point of contact simplifies the resolution process, as there is no ambiguity regarding accountability. Conversely, piecing together an MSEW system from disparate sources introduces complexities and uncertainties, as different suppliers may have varying quality standards, material specifications, and compatibility requirements. This fragmented approach increases the likelihood of coordination challenges, potential gaps in accountability, and difficulty in troubleshooting or addressing issues effectively. Therefore, investing in a cohesive MSEW system from a trusted and reputable supplier is crucial for ensuring the overall success of the project.

3.4 Companies Certifications

In the realm of construction and engineering, company certifications serve as crucial indicators of quality, reliability, and adherence to industry standards. Certifications such as the CE certificate and compliance with ISO 9001 standards signify a company's commitment to meeting rigorous criteria for product quality, safety, and environmental management. The CE certificate for example, mandated for products sold within the European Economic Area (EEA), attests to compliance with EU regulations and ensures that products meet essential health, safety, and environmental protection requirements. On the other hand, ISO 9001 certification demonstrates a company's dedication to implementing robust quality management systems, encompassing processes for continuous improvement, customer satisfaction, and adherence to statutory and regulatory requirements. These certifications not only support confidence in customers, contractors, and regulatory bodies but also enhance market access, facilitate international trade, and drive competitiveness. By obtaining and maintaining certifications such as CE and ISO 9001, companies demonstrate their commitment to excellence, fostering trust, accountability, and sustainability across the construction industry.

4. Conclusions

Reinforced fill structures represent a versatile and sustainable solution to various geotechnical challenges in civil engineering projects. This paper aim was to explore the fundamental principles, typical components, and the relevance of material and system quality in MSEW construction. The importance of the selection of high quality materials and systems, as well as the importance of product, system and company certification in ensuring product reliability and performance, has been emphasised in the hope of shifting the focus from remedial action to a more proactive and conservative approach that will result in long-term cost effective solutions. Additionally, it is imperative to prioritize environmental sustainability in the design and common practice of MSEW construction to minimize ecological impact and promote long-term environmental stewardship. Environmental Product Declarations (EPDs) shall serve as invaluable tools for designers and authorities, providing comprehensive information on the environmental impacts of products throughout their lifecycle, thereby facilitating informed decision-making and enabling the selection of more sustainable options for MSEW construction.

By prioritizing quality assurance, sustainability, and accountability in MSEW projects, engineers and stakeholders can ensure the successful delivery of resilient and reliable infrastructure. Moving forward, continued research, innovation, and collaboration among industry stakeholders are essential to further enhance the effectiveness and sustainability of MSEW solutions, addressing evolving challenges and advancing the field of geotechnical engineering.

5. REFERENCES

AASHTO M 57 Standard Specification for Materials for Embankments and Subgrades

ISO 10319:2015 Geosynthetics Wide-width tensile test

ISO 12957-1:2018 Geosynthetics Determination of friction characteristics Part 1: Direct shear test

ISO 12957-2:2005 Geosynthetics Determination of friction characteristics Part 2: Inclined plane test

ASTM D6992, 2009. Standard test method for accelerated tensile creep and creep-rupture of geosynthetic materials based on time-temperature superposition using the stepped isothermal method.

ISO/TS 20432:2022 Guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement

ISO 9001:2015 Quality management systems Requirements

SUSTAINABLE INFRASTRUCTURE DEVELOPMENT & RISK REDUCTION: CASE STUDY OF STABILITY ANALYSIS OF GEOGRID SUPPORTED SLOPE

Alok Bhargava1

ABSTRACT

This article presents details of how the issue of slope stability was resolved using the first principles of soil mechanics. The plot required for installation of electrical substation has a boundary with private land. Just at the verge of the boundary there exists an 8m high cliff, substation being at lower level & private land at higher level. No activity from higher elevation can take place as the jurisdiction is separate & the boundary wall exists at higher elevation at cliff edge. The layout of electrical substation is such that it does not leave sufficient space to have a sufficient factor of safety for slope stability in line with slip circle method and soil parameters. To ensure the safety of work force, materials & machinery safe slope of soil was adopted to retain the cliff. Stability of slope was evaluated using method of slices without reinforcement which is generally accurate for practical pur-poses. As factor of safety was not adequate, the stability check with reinforcement was carried out. The design tensile force required for reinforcement was obtained. From design tensile force the ulti-mate tensile strength requirement of geosynthetic reinforcing material was carried out. The lateral stability was checked using basal reinforcement resisting outward horizontal thrust of slope. The ge-ogrid parameters were taken from British Board of Agreement HAPAS certificate.

Keywords: Slip Circle Method, Geogrid, lateral stability, Rotational stability.

1. INTRODUCTION

The sustainable growth is not only a part of global challenge but is a question of survival for most of the Asian countries. The size of Asian markets is growing rapidly. The Asian region is having 60% of world's population. The middle class & higher class of population are bulging out of proportion which reflects a shuffling in the economical classification of population. In times to come world's growth in energy consumption, urbanization, automobile usage, airline travel and carbon emissions will come from emerging economies of Asian countries.

The Asian economy share of global economy is rising because it is adding continuously to the overall economy of the world & thereby increasing its own share whereas the developed countries are having stable share.

The term SUSTAINABLE DEVELOPMENT was coined by Brundtland Commission around three decades back only. If the Asian countries also follow the path of advanced countries in terms of energy & other natural resources there will be dearth of energy security, quality water & air, favorable climatic conditions, ecosystem on land & in oceans, food security and much more which we cannot envisage right now.

Economic conflicts & wars to get access to natural resource areas may occur due to deteriorating situ-ation. To achieve the sustainable growth at current level of economy is a big task. Countries like China have lowered the growth forecast to gain time & space to save the natural resources which would have depleted at faster growth rate.

2. SUSTAINABLE GROWTH

Sustainable growth means developing a low carbon economy which is efficient & uses the natural resources judiciously. It should protect the environment, reduce the emissions & prevents biodiversity loss.

Emerging economies must capitalize on new green technologies & production method.

To achieve faster growth rate to come at par with advanced countries following measures must be adopted by developing Asian countries.

- Efficient & judicious use of natural resources.
- Low Carbon economy & reducing Carbon dioxide.
- Reduce the intensity of resource we use & consume.
- Promote greater energy security.
- Use of new technology like solar energy, wind energy, carbon capture & sequestration.
- Improve productivity.

1 COE (I) GE Vernova, NOIDA (UP)

3. CONSTRUCTION SECTORS A PARADIGM OF SUSTAINABLE GROWTH.

Construction sector & construction activities are major sources of economic growth, development & economic activities. Construction & engineering service industry play an important role in the economic uplift & development of the country. It can be regarded as a mechanism of generating the employment and offering job opportunities to millions of unskilled & skilled work force. It also plays key role in generating income in both formal & informal sector. It supplements the foreign exchange earnings derived from trade in construction materials & engineering services.

4. CASE STUDY OF INSTALLATION OF 330/132/33KV SUBSTATION IN AFRICAN COUNTRY

2x150MVA, 3X60MVA, 330/132/33kV substation was proposed to be installed in one of the coun-tries in Africa. The project structures will consist mainly of staff quarters, control room, transformers, and Equipment foundations etc.

Engineering had its best chance for success in the integrated Design-Build organization like GE Ver-nova. In much the same way that engineering is successful in the consolidated world of manufacturing, so too does it work best when design, construction, and other professional disciplines are aligned. As the integrated project team began its work multiple facets of value delivery were hypothesized, tested & enacted continuously. Team members across different functional lines considered the project in a holistic sense. Every idea affected the work of other team member. Thus, interfacing, instant feedback and a solution mentality were the norms. Because of its single source responsibility, the integrated Design build team focused not on getting money out of project, but on adding value to the project for the duration of facility's useful life.

The proposed project site is in one of the countries in Africa. It is a green field site which has recently been use as a borrow pit to source good soil material for road construction by a Chinese construction company. It slopes eastwardly due to the depression which forms a natural earth drainage path. Water was not present in the drainage during the test.

Fig. 1 : Site in the Initial stages

5. MAJOR CHALLENGES

- Accommodation of 330/132 kV substation in restricted space in "as is & where is" condition.
- Devise method to prevent sliding of vertical cliff. Prevent erosion of vertical cliff.

6. BRAINSTORMING SESSIONS

- As there was space constraint partially slope stabilization & partial grouting of cliff was pro-posed. (Figure 2)
- Gabion wall was proposed.
- Precast RCC panel retaining wall. (Figure 3)

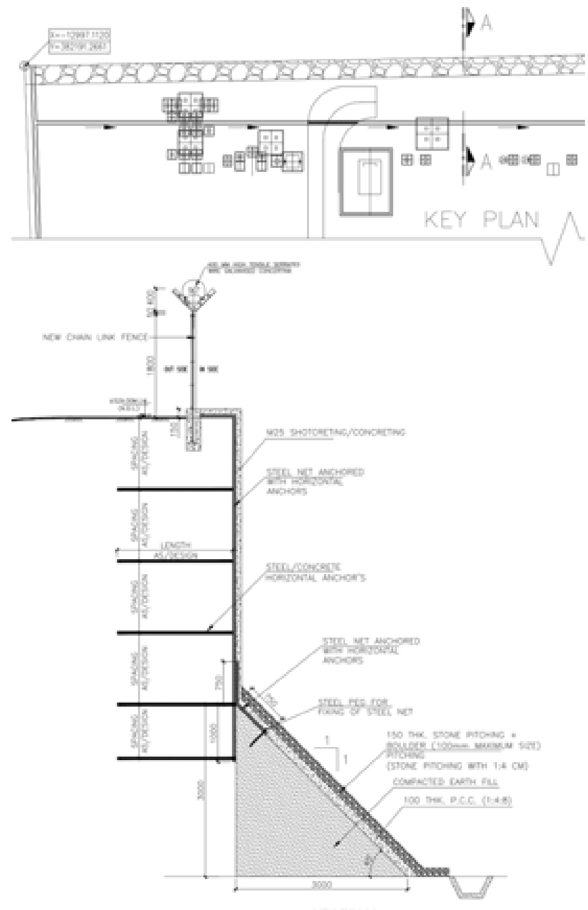

Fig. 2 : Solution - Partial slope stabilization & partial grouting

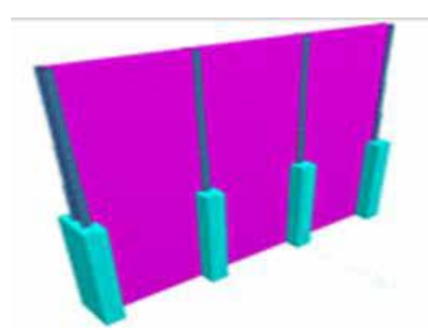

Fig. 3 : Solution - Precast panel retaining wall

- Stable Slope in front of cliff for Protection against sliding.
- The substation was located very near to wall & subsequently to cliff. The sequence was Soil cliff/ boundary – 33kV Bay—Transformer. It was proposed to relocate 33kV bay & provide sta-ble slope till we get sufficient space & then where the space is not sufficient the slope was sta-bilized using para link geogrid. (Figure 4)
- Method of shotcrete for protection of sloped surface of the mound.

7. OUTCOME OF SIX THINKING HATS

(a) Partial Stability & partial grouting had the disadvantage in collapsing of grouted portion. (Figure 2)

(b) Sufficient space was not available for construction of gabion wall.

(c) Construction of stable slope in front of Cliff. Sufficient space was not available to construct the same.

(d) Precast panel retaining wall construction was unsafe as heavy machinery had to be used (Figure 3)

(e) Relocation of existing 33kV bays between the cliff & transformer to some other available area. This allowed construction of stable slope in front of cliff in partial stretch. In remaining stretch where space was insufficient slope was stabilized using geogrid. (Figure 4)

The following Best Practicable Environmental Options (BPEO) was accepted.

The 33kV bay was relocated. The slope stability was checked using first principles of slice method.

Where the space was not sufficient Para link was used @interval of 1m along the height of slope.

To reduce the carbon footprint & introduce green element it was decided to use geocell along the length of slope & grass turf.

The plot required for installation of electrical substation has a boundary with private land. Just at the verge of the boundary there exists an 8m high cliff, substation being at lower level & private land at higher level. No activity from higher elevation can take place as the jurisdiction is separate & the boundary wall exists at higher elevation at cliff edge. The layout of electrical substation is such that it does not leave sufficient space to have a sufficient factor of safety for slope stability in line with slip circle method and soil parameters. To ensure the safety of work force, materials & machinery safe slope of soil was adopted to retain the cliff. Stability of slope was evaluated using method of slices without reinforcement which is generally accurate for practical purposes. As factor of safety was not adequate being 1.24<1.5, the stabil-ity check with reinforcement was carried out. The design tensile force required for reinforcement was obtained. From design tensile force the ultimate tensile strength requirement of geosynthetic reinforcing material was carried out. The lateral stability was checked using basal reinforcement resisting outward horizontal thrust of slope. The Factor of Safety with reinforcement is 2.38>1.5. The geogrid parameters were taken from British Board of Agreement HAPAS certificate. (Figure 5)

Slope stability against sliding. The analysis of stable slope to prevent collapse of vertical cliff was con-ducted.

Following factors affecting slope stability were analyzed to determine factor of safety of proposed slope.

(a) Density

(b) Shear strength

(c) Cohesion value

(d) Internal friction angle

Fig. 4 : Proximity of substation to vertical cliff

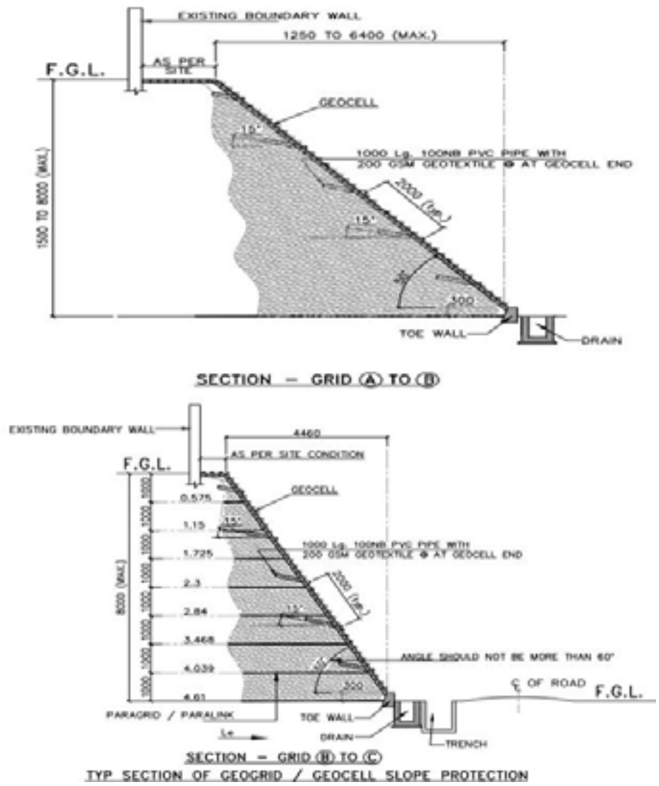

Fig. 5 : Slope stability with & without geogrid

(e) Particle size distribution.

(f) Para link parameters as per BBA HAPAS certificate

7.1 Slope protection

Every day, a 15 m² lawn provides all the oxygen needed by one person to breath for the day. As well as being a great converter of Carbon dioxide to oxygen, turf is much better than trees &shrubs at taking carbon from the air and locking it up in the soil. Turf has much better; more fibrous root system meaning more carbon will be locked up. If we consider all the living organisms that live in the root zones, we have more carbon trapped in the roots.

Research have shown that a hectare of turf can lock up to 3 tons of carbon per year for 30 years.

Turf is a natural form of pollution control and acts as a filter, leaving only pure water to recharge our fresh ground water supplies. It reduces nutrients sediments & chemicals effectively from the water per-colating through it.

A recent study conducted on a 40ºC day showed a green sport field had an average temperature of 45.6ºC, whilst a nearby concrete tennis court had a surface temperature of 78ºC, and clay brick pavers had an average temperature of 73.7ºC. Concrete was 32.4ºC hotter than turf.

Turf protects against bushfires, absorbs noise pollution in some areas by 20%. It reduces the glare compared to hard surface.

It is a natural breeding ground for certain animals and insects that are critical for maintaining a balanced ecosystem. Turf is a great dust suppresser and preventative for erosion.

The slope protection of an embankment/sloped profile/ mound consists of

Slope erosion control. A sustainable environment friendly methodology for eco restoration of the slope mound by application of geocell material and growing media in the mound slope with vegetation planta-tion of deep-rooted trees, shrubs, herbs & grass over entire sloped area along with effective drainage system & rainwater harvesting system to prevent any rain cuts, soil erosion & water contamination in the nearby surface or ground water was envisaged.

8. EVALUATION OF INTANGIBLE VALUE ADDED DUE TO GREEN INITIATIVE.

The vegetative plantation on sloping area of mound is around (x) m² areas. The intangible values added to the project on account of Corporate Sustainability Initiative were as follows.

- Avoidance of evolution of Carbon Di oxide gas by replacing shotcrete (100mm thick) with grass turf (assuming embodied energy of producing concrete is about 380 kg of CO2 per m³ concrete in struc-tural components such as floors)

  264kg of CO2 per Rm of slope

- Avoidance of heat of hydration by replacing shotcrete (100mm thick) with grass turf (Assuming heat of hydration as 446kJ/kg of cement & consumption of 300kgs /cum of concrete)

  92723 kJ of heat per Rm of slope

- Avoidance of heat of hydration by replacing stone pitching (150mm thick) with grass turf (Assum-ing heat of hydration as 446kJ/kg of cement & consumption of 150kgs /cum of stone pitching)

  46361 kJ per Rm of slope

- Avoidance of Suspended Particulate Matter in the air by not leveling the land to Natural Ground Level.

- Oxygen generated from the green cover (Assuming 0.84 kg of oxygen is generated from 15m² of turf per day)

  0.4kg/day per Rm of slope

- Absorption of carbon (Assuming one hectare of turf can lock up to 3 tons of carbon per year for 30 years)

2.1 kg of carbon /Rm of slope/year for 30 years.

- As compared to shotcrete surface the glaring & radiation of heat on a hot day will be comparatively less. For example, on day having ambient temperature of 40º C the green surface will have 32ºC temper-ature lesser than shotcrete surface. & 28ºC less than stone paved surface.

9. CONCLUSIONS

Scientists have been warning since the second half of the twentieth century that the present type, and levels, of development are not sustainable.

Consequences of environmental degradation do not respect national or state boundaries; the issue is no longer region or nation specific. Our future is linked together. Sustainable growth is comparatively new area of knowledge in which scientists, economists, philosophers, and other social scientists are working together.

The question of development or growth is perennial. At all times value analysis & engineering should be adopted to answer questions like where we want to go, what our goals are and what we want to pass as our legacy to generations to come.

Please remember "We have not inherited the world from our forefathers – we have borrowed it from our children."

REFERENCES

1. Mahendra Siregar, David Nellor.: Driving sustainable global growth. Asia's Emerging Economies. East Asia Forum - Economies Politics & Public Policy in East Asia & the Pacific.
2. Michael Spence.: Sustainable Growth a National Issue in Asia. Fung Global Institute-Article.
3. David Weight.: Whole Life Costs Concrete Vs. Steel. Building Magazine – Economics-23.06.2006 issue.
4. Development-Understanding Economic Development – National Council of Educational Research & Training: Social Science textbook for Class X., India.
5. British Board of Agreement HAPAS Certificate, https://www.naue.com/.
6. Sustainable Growth-for a resource efficient, greener and more competitive economy, European Commission –Priority –Europe 2020, https://www.commission.europa.eu/.
7. Science proves that environmentally speaking Buffalo turf is good-By Todd Layt, The Buffalo Grass Review Site provided by Oz breed Environmental Turf & Plant Breeding, https://www.softleafbuffalograss.com.au/.

CALENDER OF UPCOMING EVENTS

Sl. No.	Event Name	Place	Date
1.	GeoAmericas2024 – 5th PanAmerican Regional Conference on Geosynthetics	Toronto, Canada	April 28 - May 1, 2024
2.	International Geotechnical Innovation Conference (IGIC 2024)	Jeddah, Saudi Arabia	May 05-06, 2024
3.	Technical Workshop: Reinforcement and Drainage in Soil Structures	Barcelona, Spain	June 25-27, 2024
4.	GEOANZ #2 – Advances in Geosynthetics	Melbourne, Australia	July 09-11, 2024
5.	GeoAsia8 – 8th Asian Regional Conference on Geosynthetics	Brisbane, Australia	June 10 -13, 2025
6.	EuroGeo 8 – 8th European Regional Conference on Geosynthetics	Lille, France	September 15 -18, 2025
7.	13 ICG – 13th International Conference on Geosynthetics	Montreal, Canada	September 13 - 17, 2026

TWO-TIERED REINFORCED SOIL WALL AT BIMALGARH RBB, ODISHA

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INTRODUCTION

The development of country's infrastructure is vital to the growth of its sectors and the overall economy. The infrastructure sector primarily comprises of electricity, roads, telecommunications, railways, irrigation, water supply and sanitation, ports and airports, storing facilities, and oil and gas pipe lines. Road & Highways account for the highest share in infrastructure sectors followed by railways and urban public transport. The project of rehabilitation and up-gradation of existing 2-lane to 4-lane standards to Koida to Rajamunda approximately 53 km section of NH-215 (new NH-520) under National Highways Development Project (NHDP) scheme, have been awarded to M/s. KMC – RKD (JV). M/s Techfab Industries Ltd. was the Reinforced Soil Wall (RSW) technology provider for the project.

Along this 53 km section from Koida to Rajamunda, the structure at Bimalgarh, Road Over Bridge (ROB) at chainage 245+936 was of significance importance, due to higher level differences between Koida side (A1 side) and Rajamunda side (A2 side). The maximum height of RSW required was more than 20 m at Rajamunda side (A2 side) of ROB, according to the project plan and profile. Fig. 1 represents the key plan of ROB at chainage 245+936 of Koida to Rajamunda section.

The IRC SP: 102-2014 states that if heights of RSW exceed 15 m, then walls should be designed with a berm at an intermediate height if polymeric reinforcements are used. As the height of RSW at Rajamujda side (right side) exceeded 15 m, the requirement of providing an intermediate berm arises.

The incarnation of the reinforced soil retaining systems provide extra tensile strength to soil and serves our purpose (Schlosser 1988).[1] Reinforced soil wall with discrete panel of 'T' shape panel (i.e. T-Panel) as a facia was specified for the project. RSW's superiority both technically and economically is advantages in comparison with conventional retaining wall construction. Also, as documented by Durukan in 1992, the compact design of RSW can be constructed in congested areas where there is a limitation of space. [2]

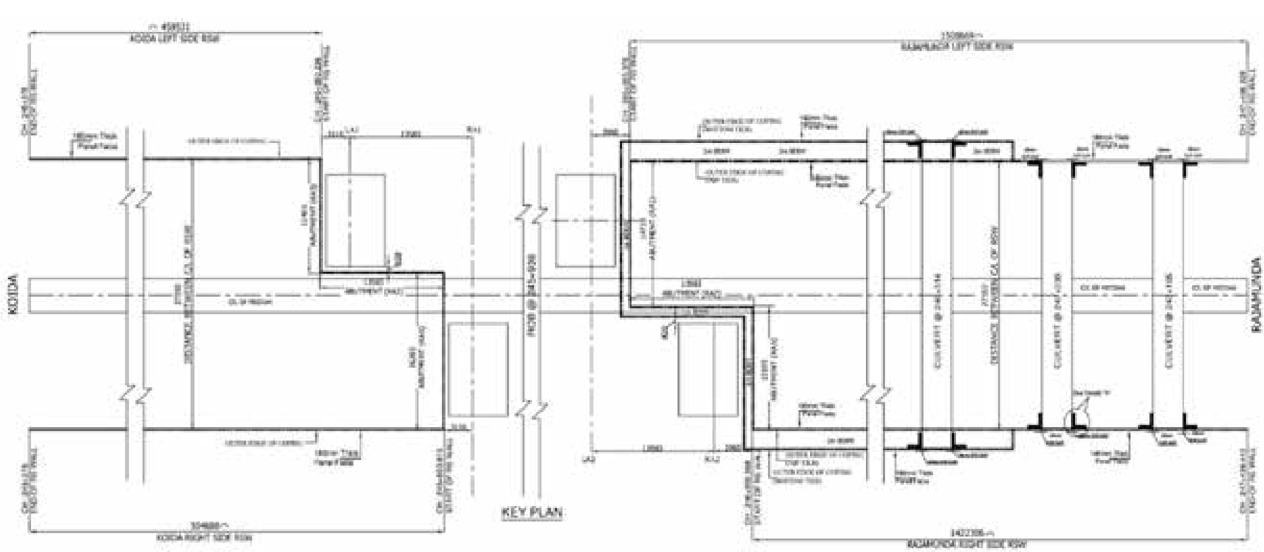

Fig. 1 : Key plan of ROB at chainage 245+936 of Koida to Rajamunda section

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The RSW with two types of height class were proposed at Bimalgarph ROB chainage 245+936:

(a) 15.6 m of maximum height of single tier RSW at Koida side as shown in Fig. 2 and

(b) 22.8 m of Maximum height of two tiered RSW at Rajamunda side with 2 m wide berm as shown in Fig. 3.

The connection between panel and geogrid was adopted with a loop and toggle connection system as shown in Fig. 4.

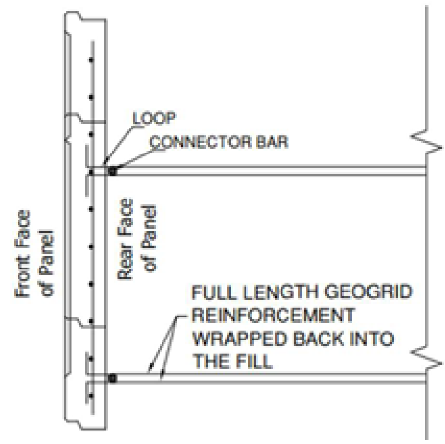

Fig. 4 : Cross-section of Panel showing connection details

DESIGN METHODOLOGY

Stability of a RSW depends on following factors: The geotechnical properties of foundation soil and infill soil

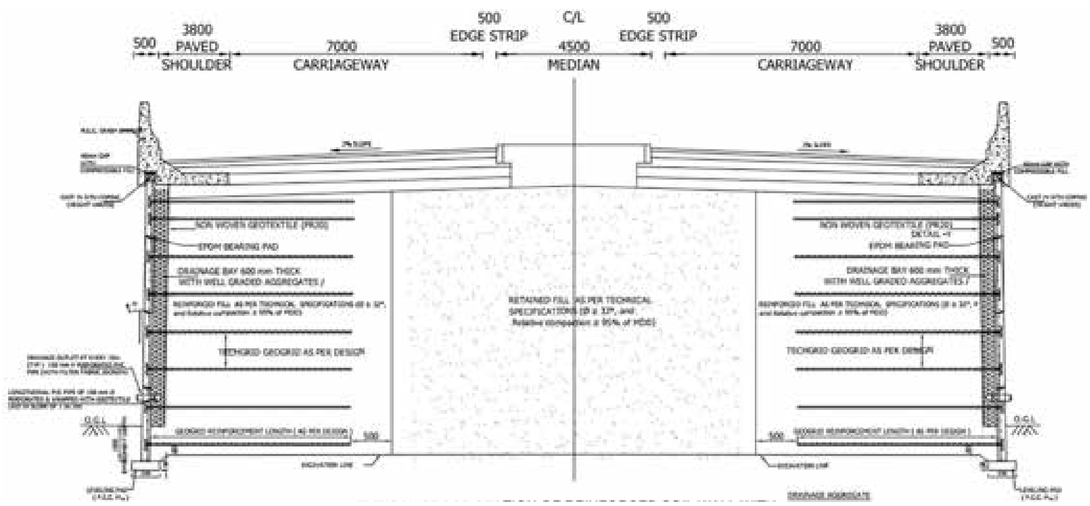

Fig. 2 : The typical cross-section of single tier RSW at Koida side up to height 15.6 m

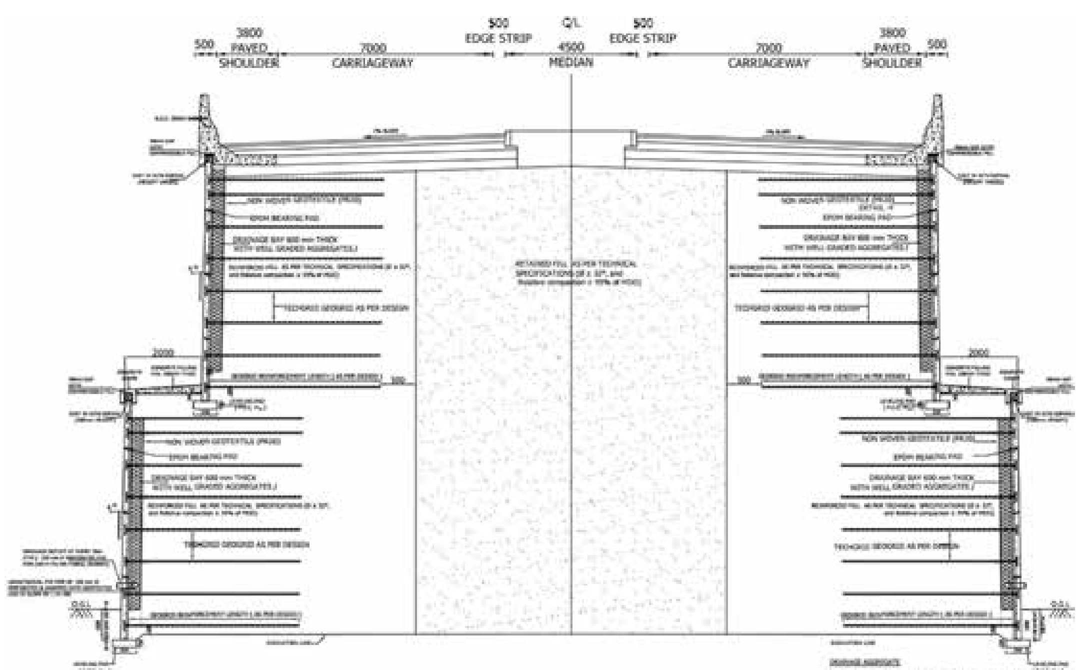

Fig. 3 : The typical cross-section of two tiered RSW at Rajamunda side upto height of 22.8 m

materials, quality of compaction and drainage, surcharge loads, embedment for RSW, type of reinforcement, presence of water table in subsoil and seismic zone. RSW with T-panel was designed based on prevailing codal guidelines taking care of all above factors. [3-9] The geogrids were designed as a reinforcement of backfilling in this RSW. The drainage bay 600 mm thick with well graded aggregates was suggested behind the T – Pannel facia for the easy escape of water from RSW. To avoid the escaping of backfill material from the facing, Nonwoven geotextile was placed behind the facia unit.

Reinforced soil wall was designed for various checks such as sliding, overturning and bearing capacity for external stability checks. The design was also checked for rupture and pullout for internal stability checks for all the layers. The above external and internal checks were carried out for static as well as seismic condition. The global stability checks were carried out in commercially available software for various cases like sudden draw down and seismic cases.

A. Panel Casting and Curing: At the time of casting care was taken for the placement of Panel reinforcement and connectors as per the approved drawings.

B. Excavation and Foundation Preparation:

Excavation was carried out as per dimensions mentioned in approved drawings. The trench for the levelling pad was excavated to the correct depth and width. In the reinforced soil zone, the ground was excavated to a depth of 400 mm (minimum) below the first layer of Geogrid. Roller was passed over the excavated ground for even finish and requirements compaction.

C. Foundation and Levelling Pads:

From the marked centerline of the levelling pad on the bottom of the trench the centerline was fixed with required offset to ensure final batter (1°) for the facing panels. Curing of poured concrete in levelling pad was done for minimum period of 24 prior to the commencement of panel placement.

D. Erection of first course of Panels:

The first or bottom course of RS wall consist of alternative full panels and half panels in the direction of construction was as per the representative arrangement shown in Fig. 5.

E. Placement of Drainage System:

Drainage system was placed as per the approved drawing.

F. Placement and compaction of fill:

Fill material was used as per the approved specifications. Fill material was placed and compacted in lifts with the compacting equipment to the desired degree of compaction. Atmost care was taken care during the deposition, spreading, leveling and compaction of the fill to avoid any damage, disturbance or misalignment of facing panels and geogrid.

G. Installation of Geogrid:

The geogrid of specified grade and length was placed in position as per the approved specifications layer by layer.

H. Caping Beam:

At the top of the upper most panels, provide a cast in-situ coping beam to achieve the required longitudinal profile.

Fig. 6 & 7 shows the site photograph of RSW on LHS and RHS side of Bimalgarh ROB under construction respectively.

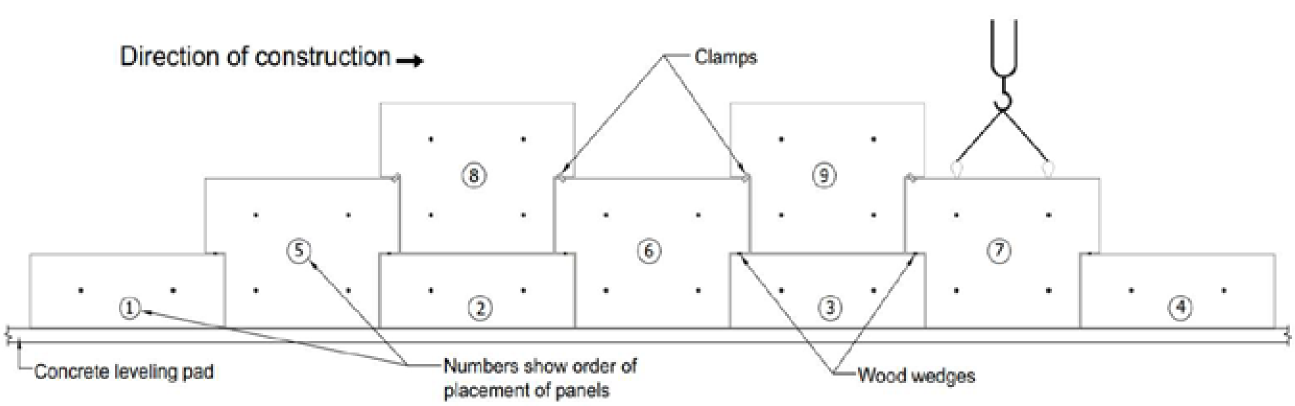

Fig. 5 : Panel Placement for Initial course

Fig. 6 : Site photograph of RSW on LHS side of Bimalgarh ROB

Fig. 7 : Site photograph of RSW on RHS side of Bimalgarh ROB

I. Intermediate Berm:

The 2 m wide berm was provided at sloping outward as shown in Fig. 8. the levelling pad was kept in such a way that it does not disturb the bottom tier's reinforcement and top tier wall was proper embedment. The concrete filling of 300 mm thickness near top tier and gradually decreasing near bottom tier was carried out in order to easy escape of water.

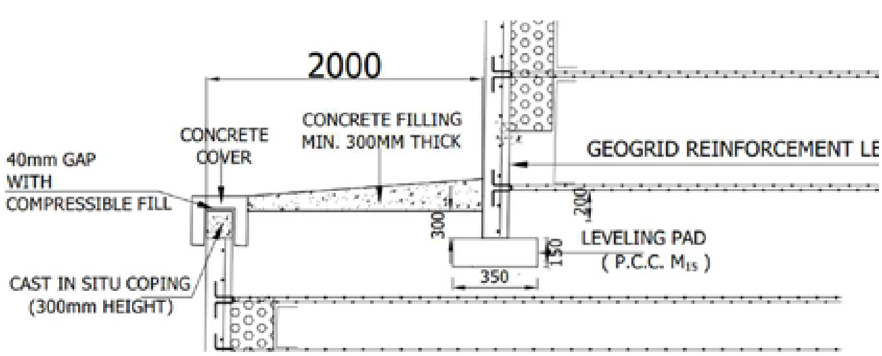

Fig. 8 : Details of 2 m wide intermediate berm

Product Supplied : Total Facing Area of RSW : 45,000 sqm

Geogrids : 2,26,000 sqm

Non-Woven Geotextiles : 14,400 sqm

The completed site photograph is shown in Fig. 9

REFERENCES

1. Schlosser (1988), the application of polymeric reinforcement in soil retaining structures, 3-65, by Kluwer Academic Publishers
2. Durukan, Z. (1992), Geotextiles and Geomembranes in R. Kerry Rowe, Cost analysis of reinforced soil walls, Volume 11(1)
3. BS 8006-1:2010, BIS Standards Publication, Code of practice for strengthened / reinforced soils a - and other fills, (2010)
4. FHWA-NHI-00-043 – Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Design & Construction Guidelines
5. AFNOR NF P94 270 – Geotechnical Design-Retaining Structures-Reinforced Soil Nailing Structures
6. NCMA – Design Manual for Segmental Retaining Walls
7. IRC: SP:102-2014 – Guidelines for Design and Construction of Reinforced Soil Walls
8. MORTH SECTION 3100 – Reinforced Soil
9. IRC: 56: 2011 – Recommended Practices for Treatment of Embankment and Roadside Slopes for Erosion Control.

Fig. 9 : Site photograph of completed structure

LESSONS LEARNED FROM FORENSIC INVESTIGATION OF DISTRESSED REINFORCED SOIL WALL

Laxmikant Yadu[1], Sunny Deol[2]

ABSTRACT

Reinforced soil walls (RSW) are retaining structures consisting of face panels, compacted backfill and geosynthetics reinforcements. Compacted soils have good strength in terms of compression solicitation but have very low tensile strength. The use of reinforcement is intended to provide sufficient tensile resistance to the compacted material. Reinforcement shall be fastened suitably for providing the required tensile resistance. Suitable fastening arrangements and holding facing panels are to fasten the reinforcement. Improper fastening arrangement of geogrids and interlocking of face panels, poor compaction of backfill material, Engineering properties of backfill material are most common causes for the premature failure of the in-service reinforced earth wall. A distressed reinforced earth wall is to be investigated forensically to identify the potential causes of failure. This paper presents the learning outcomes from the forensic investigations of distressed multiple RS walls. Further, it also presents the technical know-how of causes of failure, suitable rehabilitation measures to and avoid these failures by keeping suggested remedies during the design, construction and maintenance stage, by implementing good industry practices, during design, construction and maintenance stage.

Keywords *: Reinforced soil wall, settlement, geosynthetics, drainage, bulging.*

1. INTRODUCTION

The performance of the reinforced soil wall (RSW) depends not only on design but also the quality of cohesionless material that being used as backfill, strength of reinforcement and to a larger extent on the precision of construction methodology. Design and construction of RSW is an involved process requiring due diligence and quality control. Moreover, repairs and remedial measures are often laborious, difficult, time consuming, expensive, often ineffective in the long run and in most of the cases merely impossible to implement (IRC SP 102-2014). The designer, contractor and the concessionaire should therefore be cautioned that while there are several advantages of using RSW, these are not realized unless careful consideration is given to design as well as construction procedures. Failures of RSW lead to unserviceability and collapse condition. The construction of RSW should be therefore given due importance especially since it involves layer wise construction.

The construction of RSW by using various types of reinforcements is well accepted around the world because of theirdistinctiveness of aesthetic appearance, cost-effectiveness and rapid construction. The practice has been considerably sophisticatedby the introduction of geosynthetic reinforcements (Vidal. 1969a, Zornberg and Mitchell, 1994, Shinoda and Bathurst, 2004, Hatami and Bathurst 2006, Ling and Liu, 2009, Liu et al., 2009, Koerner 2010, Yoo et al., 2011, Liu, 2012, Yu et al., 2016, Allen and Bathurst, 2019, Liu et al., 2021b). In India, since 1990s a large number of RSW have been constructed for various types of purposes. Specified design procedures as mentioned in allied guidelines and specifications across the world were required to ensure the long-term internal, external, and facing stability of RSW (Yoo and Jung, 2006, Costa et al., 2013, Berg et al., 2020). Most of the design manuals are nearly conservative in determining the design parameters of reinforcement (Elias et al., 2001, Collin, 2001, Collin et al., 2002; Leshchinsky and Han, 2004, Yoo and Jung, 2006, Bathurst and Naftchalib, 2021). Although these widely used design methods are undoubtedly conservative for the design of RSW structures, there still exist various serviceability or stability problems in poorly designed structures, which resulted in excessive deformations, facial cracks, partial collapse, or complete failure of RS walls (Lee et al., 1994, Collin, 2001, Koerner and Koerner, 2013, Koerner and Koerner, 2018, Barani et al., 2017, Berg et al., 2020, Collin et al., 2021, Vandenberge et al., 2021, Xiao et al. 2021). The data indicated that more than 200,000 RS walls have been constructed across the world and nearly 3% of RS walls failed because of different reasons, such as inferior-quality backfills, inappropriate construction, and internal or external water (Koerner and Koerner, 2018). Some of the cases have been also reported on the failure of RS walls due to reinforcement ageing issues.

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In this paper, the learning outcome from the forensic investigations of various RS walls is presented. The causes of unserviciability and the structural problems of the RS walls belonged to various overpass bridges were investigated forensically and possible reasons are mentioned with critical observations. Further, design, materials, drainage provisions for the probable cause of unserviciability of RS wall were critically examined and presented.

1.1 Case history background and field observations

The construction of the RS wall required diligence and proper care of the design, material and workman ship. Learning out come of 7 flyovers are presented in this papers, construction of which were started almost at the same time but observations of unserviciabiliy was different in all the cases. Almost in all the flyovers the corridor was about 12.50 m in width, and serves as a convenient heavy traffic passages. The approach roads in both ends of the flyovers were supported by RS walls. The approach road in both sides is accompanied with a 6 m wide ramp at each side.The site visit has been carried out that includes Approaches (Carriageway), Reinforced Soil (RS) Walls, Flyover Abutments, Approach Slabs and Deck slab. During the visits the key observations were recorded along with Photographs. The key observations along with probable potential causes of defects observed on each structural element of flyovers have been reported. Vertical Profile of RS walls Elevated Carriageway and Date wise Construction schedule of approaches of flyovers were obtained from the construction agency.

1.1.1 *Site visit observations and review of data*

Observations recorded during the site visit for various structural elements and photographs taken are presented in Table 1.1 and Figs 1.1 (a to j) respectively.

Table.1.1 : Key observations during site visits

S. No.	Distress	Location	Observations
Reinforced Soil Wall & Abutment			
1.	Bulging/ leaning of fascia	RS Wall	• Severe bulging of RS wall near the abutment • Severe dislocation of RS wall panels
		Abutment	• Severe bulging of abutment fascia in horizontal and vertical plane towards pier. • Relative displacement of abutment panels, touching to the piers. • Abutment face panel is touching the dirt wall and Pier cap. • Severe dislocation of edge panels, prone to fall.
2.	Drainage hole & its drainability condition		• Drainage holes are not installed as per standard practice at various chainage of RS wall. • Geomembrane has been observed in some drainage holes. • Some drainage holes have been either clogged by soil or drain out pipes are damaged. • Longitudinal drainage pipes have been observed at lower level than the drain out pipes and are broken in most of the drain holes. • Location of drain holes have been provided at different elevations.
3.	Panel Edge Cracking	RS Wall & Abutment	• Edge cracking of few RS wall & Abutment panels Cracking of Edge panels of Abutment • Cracking of RS wall kerb beam Tilting of Traffic (Crash) barriers.
Pavement Surface condition of Approaches			
4.	Longitudinal Cracks	Lane-1, Lane-3	Series of high severity longitudinal cracks identified on inner lane (Speed lane) and outer lanes (Slow Lane) predominantly within 100m distance from approach slab.
5.	Patching	Lane-2, Lane 3	High severity cement concrete patching with settlement of approximate length of 4.5 m and width of 3.5m have been observed spread over approximately entire width of the carriageway.
6.	Depressions/ corrugations/ Settlements	Lane-1, Lane-3, and Lane-4	• High severity settlement/depressions have been observed within 170m from approach slab spread over entire carriageway. These settlements with high intensity lead to tilting of Traffic barriers and thereby alarming the critical condition for serviceability of approach road. • High severity settlement/depressions (sudden sinking of entire carriageway) varying from 150mm to 800mm have been observed and predominant within 15m from approach slab spread over entire carriageway. These settlements with high intensity lead to tilting of Traffic barriers and thereby alarming the critical condition for serviceability of approach road.

(a) Bulging/leaning of RS wall fascia

(b) Dislocation of Edge and RS wall panels

(c) Cracking of Abutment fascia panels

(d) High Severity longitudinal cracks

(e) Severe dislocation of edge panels and Bulging of abutment

(f) Dirt wall, Abutment edge and RS wall panel condition

(g) Dislocation of RS wall panels

(h) Severe bulging/leaning of abutment fascia and severe dislocation of Abutment face panels

(i) Tilting of Traffic (Crash) barriers

(j) Drainage hole condition

Fig. 1.1 : Photographs of various defects of RS Wall

1.1.2 *Observations based on Vertical Profile data of RS walls*

Outward displacements were recorded at distinct chainages. These points were reviewed and validated with the field observations for each RS wall as shown in Table 1.2.

Table 1.2 : Panel displacements at different observed points

Flyover	Approach	Total no. of Points recorded	Total No. of Points ≥ 25mm displacement	% percentage	Total No. of Points ≥ 50mm displacement	% percentage	Total No. of Points ≥ 150mm displacement	% percentage
I	A-1 (LHS)	234	153	65%	95	41%	41	18%
	A-1(RHS)	230	151	66%	115	50%	54	23%
	A-2 (LHS)	104	30	29%	10	10%	1	1%
	A-2 (RHS)	83	49	59%	25	30%	2	2%
II	A-1 (LHS)	77	43	56%	28	36%	4	5%
	A-1(RHS)	95	62	65%	45	47%	12	13%
	A-2 (LHS)	129	85	66%	70	54%	35	27%
	A-2 (RHS)	134	79	59%	52	39%	3	2%
III	A-1 (LHS)	203	139	68%	104	51%	12	6%
	A-1 (RHS)	166	104	63%	65	39%	15	9%
	A-2 (LHS)	207	99	48%	67	32%	17	8%
	A-2 (RHS)	243	153	63%	102	42%	26	11%
IV	A-1 (LHS)	243	189	78%	152	63%	80	33%
	A-1 (RHS)	200	133	67%	89	45%	36	18%
	A-2 (LHS)	247	184	74%	147	60%	69	28%
	A-2 (RHS)	246	187	76%	161	65%	85	35%
V	A-1 (LHS)	196	70	36%	46	23%	20	10%
	A-1 (RHS)	183	38	21%	37	20%	12	7%
	A-2 (LHS)	227	92	41%	36	16%	20	9%
	A-2 (RHS)	232	51	22%	72	31%	39	17%

2. REVIEW OF THE ORIGINAL DESIGN, TESTING MATERIALS

2.1 Reinforced soil wall design

Original design of RS wall was provided by the executive agency and the same has been checked and found safe as per the codal provision.

2.2 Key observation on backfill materials

2.3 Field parameters of backfill materials

Field dry density was evaluated in the field by sand replacement method and checked from the design parameters.Field density obtained from the field was not matching with the maximum dry density. It reflects that proper compaction was not done.

2.3.1 *Laboratory parameters of backfill materials*

Backfill materials were collected from the field and various tests were done in the laboratory as per the codal provision to check the parameters considered in the design and detail project report for construction. It was found that gradation and shear parameters were not matching with the design parameters. Shear strengths parameters which wereconsidered for design of the RE wall was well below than the obtained from large direct shear test performed in the laboratory. The tension which is expected to develop in the reinforcement due to friction between back fill materials could not be developed because of less value of shear strength parameters.

3. PROPOSED REMEDIAL MEASURES OF FAILED RS WALL

3.1 Design mix of the backfill materials

Gradation and shear strength parameters are crucial parameters of backfill materials of RS walls. Since, shear strength parameters obtained by large direct shear test in the laboratory were not matching with design parameters hence it was suggested to mix some other suitable material with backfill to obtained the required parameters. Available alternative material to mix with backfill was chosen was sand as suggested by executive agency. Sand was mixed with the backfill materials in various proportions i.e. 10%, 20 % and 30 % to get required angle of internal friction by large direct shear test. 30% of sand mixed with backfill materials was suggested as suitable proportion after performing the large direct shear testand other required tests as per the codal provision.

4. CONCLUSIONS

Design and construction of RS walls is an involved process requiring due diligence and quality control. Moreover, repairs and remedial are often laborious, difficult, time consuming, expensive, often ineffective in the long run and in most of the cases impossible to implement. Careful consideration shall be given to design as well as construction procedures by the designer and construction agency. Failures can be in serviceability as well as collapse. (IRC SP 102-2014, Clause 7, Page No. 29).

Learning outcome in the form of conclusions are presented as follows:

1. Backfill materials must be of good quality and should meet the design parameters. Reinforcements must also fulfill the design parameters. Backfill materials and reinforcement must be tested before use.
2. Proper care must be taken sothat panels of RS walls should not dislocate or bulge. Because these bulging, displacements/dislocations may further magnified during the service life due to vehicular transient loadings and drainage loadings. These responses may affect the serviceability of the flyovers and quire immediate remedial/rehabilitation measures.
3. Drainability condition is inadequate for all the approaches and abutments of the flyovers. Drainage system at all the approaches must be as per standard practice of IRC SP 102-2014. Immediate corrective measures must be implemented as per the standard practices for improving the drainability condition if found unsuitable at any instant of construction.
4. No any distortions on dirt walls should be found during construction. These distortions may further magnify during the service life of the approach due to vehicular transient loadings and drainage loadings. These conditions may affect the serviceability of the flyovers.
5. Carriageway of approaches should be compacted and constructed properly. If found any distress, must be required immediate remedial/rehabilitation measures.

REFERENCES

ASTM D6433-11, "Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys", Published by ASTM International United States.

ASTM, 1992. Standard Test Method for Classification of Soils for Engineering Purposes. West Conshohocken, PA, USA.

Allen, T.M., Bathurst, R.J., 2015. An improved simplified method for prediction of loads in reinforced soil walls. J. Geotech. Geoenviron. Eng. 141 (11), 04015049.

Allen, T.M., Bathurst, R.J., 2019. Geosynthetic reinforcement stiffness characterization for MSE wall design. Geosynth. Int. 26 (6), 592–610.

Barani, A new finite element for back analysis of a geogrid reinforced soil retaining wall failure, Int. J. Civ. Eng., № 16, c. 435.

Bathurst, Reinforcement loads in geosynthetics walls and the case for a new working stress design method, c. 3

Bathurst, Geosynthetic reinforcement stiffness for analytical and numerical modelling of reinforced soil structures, Geotext. Geomembranes, № 49, c. 921.

Barani, O.R., Bahrami, M., Sadrnejad, S.A., 2017. A new finite element for back analysisof a geogrid reinforced soil retaining wall failure. Int. J. Civ. Eng. 16 (4), 435–441.

Bathurst, R.J., Allen, T.M., Walters, D., 2004. Reinforcement loads in geosynthetics walls and the case for a new working stress design method. Seoul, Korea. In: Shim, S.,

BS 8006 1:2010, "Code of Practice for Strengthened/ Reinforced Soils and other fills".

IRC 82-2015, "Code of Practice for Maintenance of Bituminous Road Surfaces (First Revision)", Published by Indian Road Congress, New Delhi.

IRC SP 102-2014, "Guidelines for design and construction of Reinforced Soil walls", Published by Indian Road Congress, New Delhi.

MORTH Specifications for Roads and Bridges (5th Revision)", Published by Indian Road Congress, New Delhi.

Bathurst et al. Geosynthetic reinforcement stiffness for analytical and numerical modelling of reinforced soil structures Geotext. Geomembranes 2021R.B. Berg et al. Case history on failure of a 67 m tall reinforced soil slope, Geotext. Geomembranes 2020

Bathurst, R.J., Naftchalib, M.F., 2021. Geosynthetic reinforcement stiffness for analytical and numerical modelling of reinforced soil structures. Geotext. Geomembranes 49 (4), 921–940.

Berg, R.B., Barry, R.C., Naresh, C.S., 2009. Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes-Volume I, Report No. FHWA-NHI-10-024. National

Highway Institute Federal Highway Administration, Washington, D. C. USA.

Berg, R.B., Collin, J.G., Taylor, T.P., Watts, C.F., 2020. Case history on failure of a 67 m tall reinforced soil slope. Geotext. Geomembranes 48, 802–811.

Bouazza, A., Vangpaisal, T., Jefferis, S., 2006a. Effect of wet dry cycles and cation exchange on gas permeability of geosynthetic clay liners. J. Geotech. Geoenviron. Eng. 132 (8), 1011–1018.

Collin, J.G., 2001. Lessons learned from a segmental retaining wall failure. Geotext.Geomembranes 19 (7), 445–454.

Collin, J.G., Stark, T.D., Lucarelli, A., Taylor, T.P., Berg, R.R., 2021. Stability and stress-deformation analyses of reinforced slope failure at Yeager airport. J. Geotech. Geoenviron. Eng. 147 (3), 04020179.

Costa, C.M.L., Zornberg, J.G., Costa, Y.D.J., 2013. Failure of geotextile-reinforced walls in centrifuge model tests. Adv. Mater. Res. 831, 321–325.

Elias, V., Christopher, B.R., Berg, R.R., 2001. Mechanically Stabilized Earth Walls and Reinforced Soil Slopes.

Collin, Lessons learned from a segmental retaining wall failure, Geotext. Geomembranes, 2001

Hornsey et al. The impact of mining solutions/liquors on geosynthetics, Geotext. Geomembranes 2010R.M.

Koerner et al. A database, statistics and recommendations regarding 171 failed geosynthetic reinforced mechanically stabilized earth (MSE) walls Geotext. Geomembranes 2013

Hatami, K., Bathurst, R.J., 2006. Numerical model for reinforced soil segmental walls under surcharge loading. J. Geotech. Geoenviron. Eng. 132 (6), 673–684.

Hornsey, W.P., Scheirs, J., Gates, W.P., Bouazza, A., 2010. The impact of mining solutions/liquors on geosynthetics. Geotext. Geomembranes 28 (2), 191–198.

Koerner, R.M., 2010. Design with Geosynthetics, fifth ed. Prentice-Hall Inc, Englewood Cliffs, New Jersey.

Koerner, R.M., Koerner, G.R., 2013. A database, statistics and recommendations regarding 171 failed geosynthetic reinforced mechanically stabilized earth (MSE) walls. Geotext. Geomembranes 40, 20–27.

Koerner, R.M., Koerner, G.R., 2018. An extended data base and recommendations regarding 320 failed geosynthetic reinforced mechanically stabilized earth (MSE) walls. Geotext. Geomembranes 46 (6), 904–912.

Lange, K., Rowe, R.K., Jamieson, H., 2007. Metal retention in geosynthetic clay liners following permeation by different mining solutions. Geosynth. Int. 14 (3), 178–187.

Lee, K., Jones, C., Sullivan, W.R., Trollinger, W., 1994. Failure and deformation of four reinforced soil walls in eastern Tennessee. Geotechnique 44 (3), 397–426.

Leshchinsky, D., Han, J., 2004. Geosynthetic reinforced multi-tiered walls. J. Geotech. Geoenviron. Eng. 130 (12), 1225–1235.

Ling, H.I., Liu, H.B., 2009. Deformation analysis of reinforced soil retaining walls-simplistic versus sophisticated finite element analyses. Acta Geotechnica 4 (3), 203–213.

Liu, F.Y., Ying, M.J., Yuan, G.H., Wang, J., Ni, J.F., 2021a. Particle shape effects on the cyclic shear behaviour of the soil-geogrid interface. Geotext. Geomembranes.

Liu, H., Wang, X., Song, E., 2009. Long-term behavior of GRS retaining wall with marginal backfill soils. Geotext. Geomembranes 27 (4), 295–307.

Liu, H., 2012. Long-term lateral displacement of geosynthetic-reinforced soil segmental retaining walls. Geotext. Geomembranes 32, 18–27.

Liu, H., Han, J., Parsons, L.R., 2021b. Mitigation of seasonal temperature change-induced problems with integral bridge abutments using EPS foam and geogrid. Geotext.

Lupo, J.F., Morrison, K.F., 2007. Geosynthetic design and construction approaches in the mining industry. Geotext. Geomembranes 25, 96–108.

Ma, L.J., Wang, H.Y., Chai, P.X., Sun, X.R., Mai, W.H., Wang, F., 2020. Degradation damage regularity of geosynthetic material under saline soil erosion. J. Arid Land Resour. Environ. 34 (10), 111–118 (in Chinese).

Mazzieri, F., Di Emidio, G., Pasqualini, E., 2017. Effect of wet-and-dry ageing in seawater on the swelling properties and hydraulic conductivity of two amended bentonites. Appl. Clay Sci. 142, 40–51.

Segrestin, P., Jailloux, J.M., 1988. Temperature in soils and its effect on the ageing of synthetic materials. Geotext. Geomembranes 7, 51–69.

Shinoda, M., Bathurst, R.J., 2004. Lateral and axial deformation of PP, HDPE and PET geogrids under tensile load. Geotext. Geomembranes 22 (4), 205–222.

Vandenberge, D.R., Valentine, R.J., Brandon, T.L., Wright, S.G., 2021. Case history: failure of the reinforced soil slope at Yeager airport, Charleston, West Virginia. J. Geotech. Geoenviron. Eng. 147 (1), 05020013.

Xiao C., Gaom S., Liu H., Du Y., Case history on failure of geosynthetics-reinforced soil bridge approach retaining walls, Geotextiles and Geomembranes, December 2021, Vol. 49, Issue 6, pp 1585-1599.

Yang, G.Q., Liu, H.B., Zhou, Y.T., Xiong, B.L., 2014. Post-construction performance of a two-tiered geogrid reinforced soil wall backfilled with soil-rock mixture. Geotext. Geomembranes 42 (2), 91–97.

Yoo, C., Jung, H.-Y., 2006. Case history of geosynthetic reinforced segmental retaining wall failure. J. Geotech. Geoenviron. Eng. 132 (12), 1538–1548.

Yoo, C., Jang, Y.S., Park, I.J., 2011. Internal stability of geosynthetic-reinforced soil walls in tiered configuration. Geosynth. Int. 18 (2), 74–83.

Yu, Y., Bathurst, R.J., Allen, T.M., 2016. Numerical modeling of the SR-18 geogrid reinforced modular block retaining walls. J. Geotech. Geoenviron. Eng. 142 (5), 04016003.

Zornberg, J.G., Mitchell, J.K., 1994. Reinforced soil structures with poorly draining backfills. Part I: reinforcement interactions and functions. Geosynth. Int. 1 (2), 103–148.

INTERNATIONAL GEOSYNTHETICS SOCIETY

The International Geosynthetics Society (IGS) was founded in Paris, on 10 November 1983, by a group of geotechnical engineers and textile specialists. The Society brings together individual and corporate members from all parts of the world, who are involved in the design, manufacture, sale, use or testing of geotextiles, geomembranes, related products and associated technologies, or who teach or conduct research about such products.

The IGS is dedicated to the scientific and engineering development of geotextiles, geomembranes, related products and associated technologies. IGS has 47 chapters, over 3,000 individual members and 161 corporate members.

The aims of the IGS are:

- to collect and disseminate knowledge on all matters relevant to geotextiles, geomembranes and related products, e.g. by promoting seminars, conferences, etc.
- to promote advancement of the state of the art of geotextiles, geomembranes and related products and of their applications, e.g. by encouraging, through its members, the harmonization of test methods, equipment and criteria.
- to improve communication and understanding regarding such products, e.g. between designers, manufacturers and users and especially between the textile and civil engineering communities

The IGS is registered in the USA as a non-profit organization. It is managed by five Officers and a Council made up of 10 to 16 elected members and a maximum of 5 additional co-opted members. These Officers and Council members are responsible to the General Assembly of members which elects them and decides on the main orientations of the Society.

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The IGS Chapters are the premier vehicle through which the IGS reaches out to and influences the marketplace and the industry. Chapter activities range from the organization of major conferences and exhibits such as the 10th International Conference on Geosynthetics in September 2014 in Berlin, Germany and its predecessors in Guaruja, Yokohama, Nice and Atlanta to the presentation of focused seminars at universities, government offices and companies. Chapters create the opportunity for the chapter (and IGS) membership to reach out, to teach and to communicate and they are the catalyst for many advances in geosynthetics. Participation in an IGS chapter brings researchers, contractors, engineers and designers together in an environment which directly grows the practice by informing and influencing those who are not familiar with our discipline.

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Membership of IGS is primarily organised through national Chapters. Most individual members (94%) belong to the IGS through Chapters. Chapter participation allows members to be informed about, and participate in, local and regional activities in addition to providing access to the resources of the IGS.

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INDIAN CHAPTER OF IGS

In the year 1985, Central Board of Irrigation and Power, (CBIP) as part of its technology forecasting activities identified geosynthetics as an important area relevant to India's need for infrastructure development, including roads. After approval of IGS Council for the formation of Indian Chapter in October 1988, the Indian Chapter of IGS was got registered under Societies Registration Act 1860 of India in June 1992 as the Committee for International Geotextile Society (India), with its Secretariat at Central Board of Irrigation and Power. The Chapter has since been renamed as International Geosynthetics Society (India), in view of the parent body having changed its name from International Geotextiles Society to International Geosynthetics Society.

The activities of the Society are governed by General Body and Executive Board.

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The Executive Board of the IGS (India) consists of President, elected by the General Body, two Vice-Presidents and 16 members. The Secretary and Director (WR) of the CBIP are the as the Ex-Officio Member Secretary and Treasurer, respectively, of the Society.

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Past Presidents

The presidents of the society in the past were:

- Dr. R.K. Katti, Director, UNEECS Pvt. Ltd. and Former Professor, IIT Bombay
- Mr. H.V. Eswaraiah, Technical Director, Karnataka, Power Corporation Ltd.
- Dr. G.V. Rao, Professor, Department of Civil Engineering, IIT Delhi
- Dr. D.G. Kadade, Chief Advisor, Jaiprakash Industries Ltd.
- Dr. K. Rajagopal, Professor, Department of Civil Engineering, IIT Madras

Indian Representation on IGS Council

- Dr. K. Rajagopal, Professor, Department of Civil Engineering, IIT Madras
- Dr. G.V. Rao, Former Professor, Department of Civil Engineering, IIT Delhi
- Mr. M. Venkataraman, Geotechnical and Geosynthetic Consultant
- Mr. Vivek P. Kapadia, Secretary to Government of Gujarat and Director, SSNNL

IGS Student Award Winners from India

The IGS has established Student Paper Award to disseminate knowledge and to improve communication and understanding of geotextiles, geomembranes and associated technologies among young geotechnical and geoenvironmental student engineers around the world. The IGS student award consists of US$1,000 to be used to cover travel expenses of each winner to attend a regional conference.

Following from India have been honoured with IGS Student Paper Award:

- Dr. J.P. Sampath Kumar, National Institute of Fashion Technology, Hyderabad
- Dr. K. Ramu, JNTU College of Engineering, Kakinada
- Mrs. S. Jayalekshmi, National Institute of Technology, Tiruchirappalli
- Dr. Mahuya Ghosh, IIT Delhi
- Dr. S. Rajesh, Department of Civil Engineering, IIT Kanpur
- Mr. Suresh Kumar S., Department of Textile Technology, Dr. B.R. Ambedkar National Institute of Technology, Jalandhar

Publications/Proceedings on Geosynthetics

In addition to the proceedings of the events on Geosynthetics, following publications have been brought out since 1985:

1. Workshop on Geomembranes and Geofabrics (1985)
2. International Workshop on Geotextile (1989)
3. Use of Geosynthetics – Indian Experiences and Potential – A State of Art Report (1989)
4. Use of Geotextile in Water Resources Projects - Case Studies (1992)
5. Role of Geosynthetics in Water Resources Projects (1993)
6. Monograph on Particulate Approach to Analysis of Stone Columns with & without Geosynthetics Encasing (1993)
7. 2nd International Workshop on Geotextiles (1994)
8. Directory of Geotextiles in India (1994)
9. An Introduction to Geotextiles and Related Products in Civil Engineering Applications (1994)
10. Proceedings of Workshops on Engineering with Geosynthetics (1995)
11. Ground Improvement with Geosynthetics (1995)
12. Geosynthetics in Dam Engineering (1995)
13. Erosion Control with Geosynthetics (1995)
14. Proceedings of International Seminar & Techno Meet on “Environmental Geotechnology & Geosynthetics” (1996)
15. Proceedings of First Asian Regional Conference “Geosynthetics Asia’1997”
16. Directory of Geosynthetics in India (1997)
17. Bibliography – The Indian Contribution to Geosynthetics (1997)
18. Waste Containment with Geosynthetics (1998)
19. Geosynthetic Applications in Civil Engineering- A Short Course (1999)
20. Case Histories of Geosynthetics in Infrastructure Projects (2003)
21. Geosynthetics – Recent Developments (Commemorative Volume) (2006)
22. Geosynthetics in India – Present and Future (2006)
23. Applications of Geosynthetics – Present and Future (2007)
24. Directory of Geosynthetics in India (2008)
25. Geosynthetics India’08

26. Geosynthetics India' 2011
27. Geosynthetic Reinforced Soil Structures - Design & Construction (2012)
28. Applications of Geosynthetics in Infrastructure Projects (2013)
29. Applications of Geosynthetics in Railway Track Structures (2013)
30. Silver Jubilee Celebration (2013)
31. Directory of Geosynthetics in India (2013)
32. Applications of Geosynthetics in Infrastructure Projects (2014)
33. Geosynthetics India 2014
34. Three Decades of Geosynthetics in India – A Commemorative Volume (2015)
35. History of Geosynthetics in India - Case Studies (2016)
36. Proceedings of 6th Asian Regional Conference on Geosynthetics (2016)
37. Coir Geotextiles (Coir Bhoovastra) for Sustainable Infrastructure (2016)
38. Proceedings of the Geosynthetics Applications for Erossion Control and Costal Protection (2018)
39. Geosynthetics Testing – A Laboratory Manual (2019)

Indian Journal of Geosynthetics and Ground Improvement

The Indian Chapter of IGS has taken the initiative to publish Indian Journal of Geosynthetics and Ground Improvement (IJGGI), on half yearly basis (January – June and July-December), since January 2012.The aim of the journal is to provide latest information in regard to developments taking place in the relevant field of geosynthetics so as to improve communication and understanding regarding such products, among the designers,manufacturers and users and especially between the textile and civil engineering communities.The Journal has both print and online versions.

Events Organised/Supported

1. Workshop on Geomembrane and Geofabrics, September 1985, New Delhi
2. Workshop on Reinforced Soil, August 1986
3. International Workshops on Geotextiles, November 1989, Bangalore
4. National Workshop on Role of Geosynthetics in Water Resources Projects, January 1992, New Delhi
5. Workshop on Geotextile Application in Civil Engineering, January 1993, Chandigarh
6. International Short Course on Soil Reinforcement, March 1993, New Delhi
7. Short Course on Recent Developments in Design of Embankments on Soft Soils, Nov./Dec. 1993, New Delhi
8. 2nd International Workshop on Geotextiles, January 1994, New Delhi
9. Short Course on Recent Developments in the Design of Embankments on Soft Soils, January 1994, Kolkata
10. Workshop on Role of Geosynthetics in Hill Area Development, November 1994, Guwahati
11. Workshop on Engineering with Geosynthetics, December 1994, Hyderabad
12. Short Course on Recent Developments in the Design of Embankments on Soft Soils, May 1995, New Delhi
13. Seminar on Geosynthetic Materials and their Application, August 1995, New Delhi
14. Short Course on Recent Developments in the Design of Embankments on Soft Soils, October 1995, New Delhi
15. Short Course on "Ground Improvement with Geosynthetics", October 1995, New Delhi
16. Workshop on "Environmental Geotechnology", December 1995, New Delhi
17. Workshop on "Role of Geosynthetics in Hill Area Development", February 1996, Gangtok
18. Workshop on "Engineering with Geosynthetics", March 1996, Visakhapatnam

19. Workshop on “Ground Improvement with Geosynthetics”, March 1996, Kakinada
20. Workshop on “Engineering with Geosynthetics”, May 1996, Chandigarh
21. International Seminar & Technomeet on “Environmental Geotechnology with Geosynthetics”, July 1996, New Delhi
22. Seminar on “Fields of Application of Gabion Structures”, September 1997, New Delhi
23. First Asian Regional Conference “Geosynthetics Asia’1997”, November 1997, Bangalore
24. Short Course on “Waste Containment with Geosynthetics”, February 1998, New Delhi
25. Symposium on “Rehabilitation of Dams”, November 1998, New Delhi
26. Training Course on “Geosynthetics and their Civil Engineering Applications”, September 1999, Mumbai
27. Seminar on “Coir Geotextiles-Environmental Perspectives”, November 2000, New Delhi
28. Second National Seminar on “Coir Geotextiles – Environmental Perspectives”, April 2001, Guwahati, Assam
29. National Seminar on “Application of Jute Geotextiles in Civil Engineering”, May 2001, New Delhi
30. International Course on “Geosynthetics in Civil Engineering”, September 2001, Kathmandu, Nepal
31. Workshop on “Applications of Geosynthetics in Infrastructure Projects”, November 2003, New Delhi
32. Geosynthetics India 2004 – “Geotechnical Engineering Practice with Geosynthetics”, October 2004, New Delhi
33. Introductory Course on Geosynthetics, November 2006, New Delhi
34. International Seminar on “Geosynthetics in India – Present and Future” (in Commemoration of Two Decades of Geosynthetics in India), November 2006, New Delhi
35. Workshop on “Retaining Structures with Geosynthetics”, December 2006, Chennai
36. Special Session on “Applications of Geosynthetics” during 6th International R&D Conference, February 2007, Lucknow (U.P.)
37. Workshop on “Applications of Geosynthetics – Present and Future”, September 2007, Ahmedabad (Gujarat)
38. International Seminar “Geosynthetics India’08” and Introductory Course on “Geosynthetics”, November 2008, Hyderabad
39. Special Session on “Applications of Geosynthetics” during 7th International R&D Conference, February 2009, Bhubaneswar (Orissa)
40. Seminar on “Applications of Geosynthetics”, July 2010, New Delhi
41. International Seminar on “Applications of Geosynthetics”, November 2010, New Delhi
42. Geosynthetics India’ 2011, September 2011, IIT Madras
43. Seminar on “Slope Stabilization Challenges in Infrastructure Projects”, October 2011, New Delhi
44. GEOINFRA 2012 – A Convergence of Stakeholders of Geosynthetics, August 2012, Hyderabad
45. Seminar on “Ground Control and Improvement”, September 2012, New Delhi
46. Workshop on “Geosynthetic Reinforced Soil Structures - Design & Construction”, October 2012, New Delhi
47. Seminar on “Landfill Design with Geomembrane”, November 2012, New Delhi
48. Seminar on “Slope Stabilization Challenges in Infrastructure Projects”, November 2012, New Delhi
49. Seminar on “Applications of Geosynthetics in Infrastructure Projects”, June 2013, Bhopal
50. Seminar on “Applications of Geosynthetics in Railway Track Structures”, September 2013, New Delhi
51. Silver Jubilee Celebration, October 2013, New Delhi
52. Seminar on “Applications of Geosynthetics in Infrastructure Projects”, July 2014, Agra
53. Geosynthetics India 2014, October 2014, New Delhi

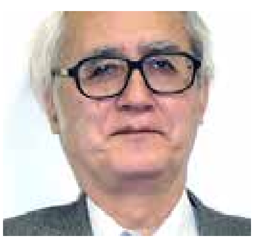
54. Seminar on Geotextiles: A Big Untapped Potential, September 2015, New Delhi
55. Three Decades of Geosynthetics in India – International Symposium Geosynthetics - The Road Ahead, November 2015, New Delhi, India
56. North Eastern Regional Seminar on “Applications of Geosynthetics in Infrastructure Projects”, June 2016, Guwahati
57. Workshop on “Applications of Geosynthetics in Infrastructure Projects”, June 2016, Thiruvananthapuram
58. Training Course on Geosynthethics, November 2016, New Delhi
59. Workshop on Coastal Protection, November 2016, New Delhi
60. 6th Asian Regional Conference on Geosynthethics, November 2016, New Delhi
61. Training Course on "Geosynthetic Reinforced Soil Structures", February 2017, New Delhi
62. Training Course on “Applications of Geosynthetics”, December 2017, Dharwad (Karnataka)
63. Workshop on “Design and Construction of Pavements using Geosynthetics”, January 2018, New Delhi
64. IGS Educate the Educators Program, February 2018, IIT Madras
65. Training Course on “Applications of Geosynthetics”, February 2018, Trichy (Tamil Nadu)
66. Training Course on Design and Construction of Pavements with Geosynthetics and Geosyntheics Reinforced Soil Slopes and Walls, 15 June 2018, New Delhi
67. Seminar on Slope Stabilization Challenges in Infrastructure Projects, 21-22 June 2018, New Delhi
68. Training Programme on “Applications of Geosynthetics in Dams & Hydraulic Structures”, August 2018, Bhopal
69. Training Course on “Slope Stabilization Challenges in Infrastructure Projects”, October 2018, Dehradun
70. Seminar on “Geosynthetics Applications for Erosion Control and Coastal Protection”, October 2018, Bhubaneswar
71. Workshop on Natural Hazard Mitigation with Geosynthetics, January. 2019, Thiruvananthapuram, (Kerala)
72. Symposium of International Association for Computer Methods and Advances in Geomechanics (IACMAG) – Special Session of Indian Chapter of IGS, March 2019, IIT Gandhinagar
73. Seminar on Geosynthetics for Highway Infrastructure with Marginal Materials and Difficult Soils, September 2019, Jaipur
74. Workshop on Testing and Evaluation of Geosynthetics, September 2019, Jaipur
75. Workshop on Best Practices for Implementation of Geosynthetic Reinforced Soil Walls. January 2020, Jaipur
76. Webinar on Challenges in Developing Codes of Practice for Geosynthetics for Durable Infrastructure Development, 14 September 2020
77. Webinar on Challenges in Geosynthetic and Geotechnical Testing, 15 September 2020
78. Virtual Training Sessions on Erosion Control, 28 July 2021
79. Virtual Training Programme on the Failure of Reinforced Soil Walls: Lessons and Remedies, 29 September, 2021
80. Workshop on “Geosynthetics for Infrastructure Development” 19-20 April 2023, New Delhi

IGS NEWS

IGS FOUNDATION WELCOMES NEW BOARD MEMBERS

The IGS Foundation (IGSF) has expanded its reach and abilities with three additional trustees.

The Board of Trustees has been boosted from five to seven members, welcoming Anant Kanoi from India, Yang Baohe from China and Peter Legg from South Africa. Mr Kanoi is Managing Director of TechFab India, Mr Baohe is President of BOSTD Geosynthetics in China, and Peter Legg heads Peter Legg Consulting based in South Africa.



The Board also says farewell to founding Trustee Professor Fumio Tatsuoka, who leaves after four years' service.

Professor Fumio Tatsuoka

IGSF Chairman Jacques Côté said: "We're delighted to welcome Anant, Yang and Peter to our Board and gain from their vast and varied experience to further the goals of the IGSF. I would also like to thank Prof. Tatsuoka for his significant contribution to the development of the IGSF, including attracting many donors from Japan. It was a great pleasure for me and for all the members of the Board to have worked with this exceptional man of great wisdom."

Launched in 2019, the IGSF supports the educational, sustainability and diversity initiatives of the IGS, funding a range of activities aimed at widening awareness about the use and applications of geosynthetics, and improving young engineers' access to industry opportunities.

IGS ITALY DELIVERS 'UNFORGETTABLE' 12TH ICG

Attendees from 68 different countries descended on Rome for the 12th International Conference on Geosynthetics (12ICG) hosted by IGS Italy.

The event welcomed some 1,000 delegates (conference and exhibition) from five continents to explore the theme 'Geosynthetics: leading the way to a resilient planet' at the grand venue Auditorium Parco Della Musica, from September 17-21.

Hosted by IGS Italy, known as AGI-IGS, the conference programme included wide-ranging keynote lectures, short courses and site visits, with the prestigious Giroud Lecture given by Professor Ennio Palmeira on 'Geotextile filters: from idealization to real behaviour'. IGS Young Members also enjoyed several dedicated events including a networking dinner, and demonstrated their passion for geosynthetics at the IGS Young Member Contest.

IGS Italy President Daniele Cazzuffi, who was also chair of the 12th ICG's organizing committee, said: "The conference, exhibition and social events were really successful. There was immense satisfaction to observe that all areas of our industry were extraordinarily happy with our daily program. Delegates were impressed with the configuration of our venue, where event spaces were close to each other yet retained their own separate function."

Dr. Cazzuffi said he was delighted with the rich content offered by the conference, but the response to geosynthetics leader J.P. Giroud was particularly memorable.

"The standing ovation for J.P. Giroud in the Opening Session was a fundamental highlight of the 12th ICG, because it represented a real appreciation from the overall geosynthetics engineering community to a person who has dedicated almost his entire professional life to the growth and the outreach of our discipline," said Dr. Cazzuffi.

"For the first time in the history of the IGS international conferences, Dr. Giroud was not able to attend in-person but he followed the Giroud Lecture remotely, this time presented magnificently by Ennio Palmeira."

Dr. Cazzuffi thanked colleagues, AGI-IGS members and the I2th ICG organizing committee for helping to create such a successful conference, and singled out three individuals.

"Susanna Antonielli, secretariat of the Italian Geotechnical Society AGI and IGS Italy, and general manager of the 12th ICG, had a motorbike accident just 10 days before the event and despite this was able to follow the entire conference with competence, dedication and professionalism, even from a wheelchair," said Dr. Cazzuffi.

"Also, my longtime friend Nicola Moraci, who at the time as President of the Italian Geotechnical Society AGI, in 2017 encouraged IGS Italy to present the bid to host the 12th ICG and later co-chaired with me the conference organizing committee. His input was fundamental to the success of the conference.

"And finally my entire family who suffered a lot in the last years and months because of my limited spare time, in particular my wife Susanna, who also took the responsibility of accompanying delegates on site tours, and my children Anna, Lucia and Pietro who supported me throughout."

Montreal in Canada is set to host the 13th ICG in 2026. Did Dr. Cazzuffi have any tips for the organizers?

"It will be important to maintain the same high level of proceedings as in the 12th ICG, so it will be crucial to set up a group of efficient and reliable assessors and reviewers to guarantee an adequate level of the definitive version of the papers. They should also have open access publications from the beginning of the conference to ensure effective circulation of the various contributions among the worldwide geotechnical and geosynthetics engineering communities. This will cost money, but it will represent credibility of the event and our entire profession," he said.

FOCACCIA, FRIENDSHIPS AND FINALS FOR IGS YOUNG MEMBERS AT 12TH ICG

Coffee, collaboration and competition kept the next generation of engineers busy at the 12th International Conference on Geosynthetics in Rome. An active program for IGS Young Members during the conference, which ran from September 17-21, included a delicious networking dinner, supporting friends and colleagues in the IGS Young Member Contest, and for some, benefiting from attendance scholarships thanks to the IGS Foundation.

Members got to know each other better with a group meal at Ristorante il Vignola, which was near the conference venue. Here they enjoyed delights including focaccia, mozzarella, focaccia, ham, aubergines, an entrée of rigatoni all'amatriciana, followed by millefoglie cake and plenty of coffee and wine.

But the young engineers couldn't relax for too long as the conference also included the exciting finals of the IGS Young Member Contest. More than 40 papers received from 19 different countries were filtered down to just 10 finalists, who presented their work live in a special session chaired by IGS Young Members Committee chair Dawie Marx and Dr Fernanda Ferreira. Judges Boyd Ramsey, Amir Shahkolahi, and Professors Richard Bathurst, Maria das Graças Gardoni, and Nicola Moraci, assessed the finalists on style and content.

The winner was Subramanian Sankaranarayanan, also known as Subu, whose paper explored pavement stability using geogrids. He received a $1,000 prize while runners up Viviana Mangraviti and Matheus Pena da Silva were presented with $600 and $300, respectively. Subu also had the chance to present his technical paper to the full audience.

IGS Young Members Committee chair Dawie Marx said: “We had great success at the 12th ICG and we are looking forward to building on the friendships formed and professional connections made during the conference.”

REGISTRATION LAUNCHED FOR 5th GEOAMERICAS CONFERENCE

The 5th Pan-American Conference on Geosynthetics will gather worldwide experts to discuss the appropriate use and positive impact of geosynthetics, this time via the theme ‘Connecting State of the Art to State of Practice’.

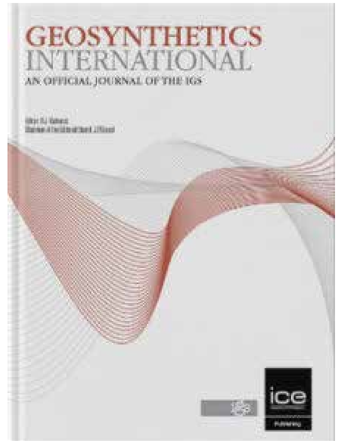
The conference, organised by IGS North America, takes place on April 28 to May 1, 2024, in Toronto, Canada, and is the first time the event has taken place in Canada.

There will be a particular focus this year on sustainability, energy, mining, and transportations infrastructure, while a regional focus will explore ‘hot topics’ in the Americas including engineering in different environments, geotechnical and civil software advances, and the standardization of geosynthetics. There will also be a technical tour of the Don River project in Toronto, and student teams will be able to take part in the GeoJeopardy technical quiz.

As well as technical sessions, Q&As, presentations, and networking opportunities, delegates will be able to hear the Zornberg Lecture, this time given jointly by Vinicius Benjamim and Victor Pimental. The Lecture was established in 2019 in honor of Dr Jorge Zornberg, for his significant contribution to geosynthetics and leadership in founding the first GeoAmericas conference.

The event will also be celebrating several significant milestones – the 40th anniversaries of the ASTM International Committee D35 on Geosynthetics, and the journal Geotextiles & Geomembranes, and the 30th anniversary of the journal Geosynthetics International.

GEOSYNTHETICS INTERNATIONAL REVEALS BEST PAPERS FOR 2022



The IGS’s official journal has announced its best papers for last year, featuring in Volume 29.

Geosynthetics International’s (GI) ‘Best Geosynthetics International Paper for 2022’ went to two papers:

- ‘Factors affecting geotextile filter long-term behaviour and their relevance in design’ by N. Moraci, S. Bilardi, and M.C. Mandaglio (2022). You can read this in Geosynthetics International, 29, No. 1, 19–42.
- ‘Factors affecting multicomponent GCL-geomembrane interface transmissivity for landfills’ by R.K. Rowe and F. Jabin (2022). It can be found in Geosynthetics International, 29, No. 5, 476–494.

Honorable mentions, regarded as among the best papers published in Geosynthetics International in 2022, were given to two runners-up:

- ‘A quantification of the short-term reliability of HDPE geomembrane seaming methods’ by A. Gilson-Beck and J.P. Giroud (2022). This can be found in Geosynthetics International, 29, No. 4, 337–341.
- ‘Influence of backfill type on the load-bearing performance of GRS bridge abutments’ by K. Hatami, and J. Boutin (2022). Read this in Geosynthetics International, 29, No. 5, 506–519.

Votes were cast by the Editorial Board Members, excluding the Editor-in-Chief and Editors who do not vote in this annual contest.

GI’s editor-in-chief Richard J. Bathurst said: “I speak on behalf of myself and Editors Ennio M. Palmeira and Patrick J. Fox to thank the members of the Editorial Board for participating in the best paper selection process and congratulate the authors of these excellent papers.

“Each paper reflects the high standards of the Journal and is an important contribution to our geosynthetics discipline. All IGS members have free access to these papers, as they have free access to all papers published in the Journal.”

INDIAN JOURNAL OF GEOSYNTHETICS AND GROUND IMPROVEMENT

GUIDELINES FOR AUTHORS

This journal aims to provide a snapshot of the latest research and advances in the field of **Geosynthetics**. The journal addresses what is new, significant and practicable. **Indian Journal of Geosynthetics and Ground Improvement** is published twice a year (January-June and July-December) by IndianJournals.Com, New Delhi. The Journal has both print and online versions. Being peer-reviewed, the journal publishes original research reports, review papers and communications screened by national and international researchers who are experts in their respective fields.

The original manuscripts that enhance the level of research and contribute new developments to the geosynthetics sector are encouraged. The work belonging to the fields of Geosynthetics are invited. **The journal is expected to help** researchers, technologist and policy makers in the key sector of Geosynthetics to improve communication and understanding regarding geotextiles, geomembranes and related products among designers, manufacturers and users The manuscripts must be unpublished and should not have been submitted for publication elsewhere. There are no **Publication Charges**.

1. Guidelines for the preparation of manuscripts for publishing in "Indian Journal of Geosynthetics and Ground Improvement"

The authors should submit their manuscript in MS-Word (2003/2007) in single column, double line spacing. The manuscript should be organized to have Title page, Abstract, Introduction, Material & Methods, Results & Discussion, Conclusion, and Acknowledgement. The manuscript should not exceed 16 pages in double line spacing.

Submission of Manuscript:

The manuscript must be submitted in doc and pdf to the Editor as an email attachment to **kamal@cbip.org.** The author(s) should send a signed declaration form mentioning that, the matter embodied in the manuscript is original and copyrighted material used during the preparation of the manuscript has been duly acknowledged. The declaration should also carry consent of all the authors for its submission to **Indian Journal of Geosynthetics and Ground Improvement**. It is the responsibility of corresponding author to secure requisite permission from his or her employer that all papers submitted are understood to have received clearance(s) for publication. The authors shall also assign the copyright of the manuscript to the Indian Chapter of International Geosynthetics Society.

Peer Review Policy:

Review System: Every article is processed by a masked peer review of double blind or by three referees and edited accordingly before publication. The criteria used for the acceptance of article are: **contemporary relevance, updated literature, logical analysis, relevance to the global problem, sound methodology, contribution to knowledge and fairly good English**. Selection of articles will be purely based on the experts' views and opinion. Authors will be communicated within Two months from the date of receipt of the manuscript. The editorial office will endeavor to assist where necessary with English language editing but authors are hereby requested to seek local editing assistance as far as possible before submission. Papers with immediate relevance would be considered for early publication. The possible expectations will be in the case of occasional invited papers and editorials, or where a partial or entire issue is devoted to a special theme under the guidance of a Guest Editor.

The Editor-in-Chief may be reached at: contact@geosyntheticsindia.org

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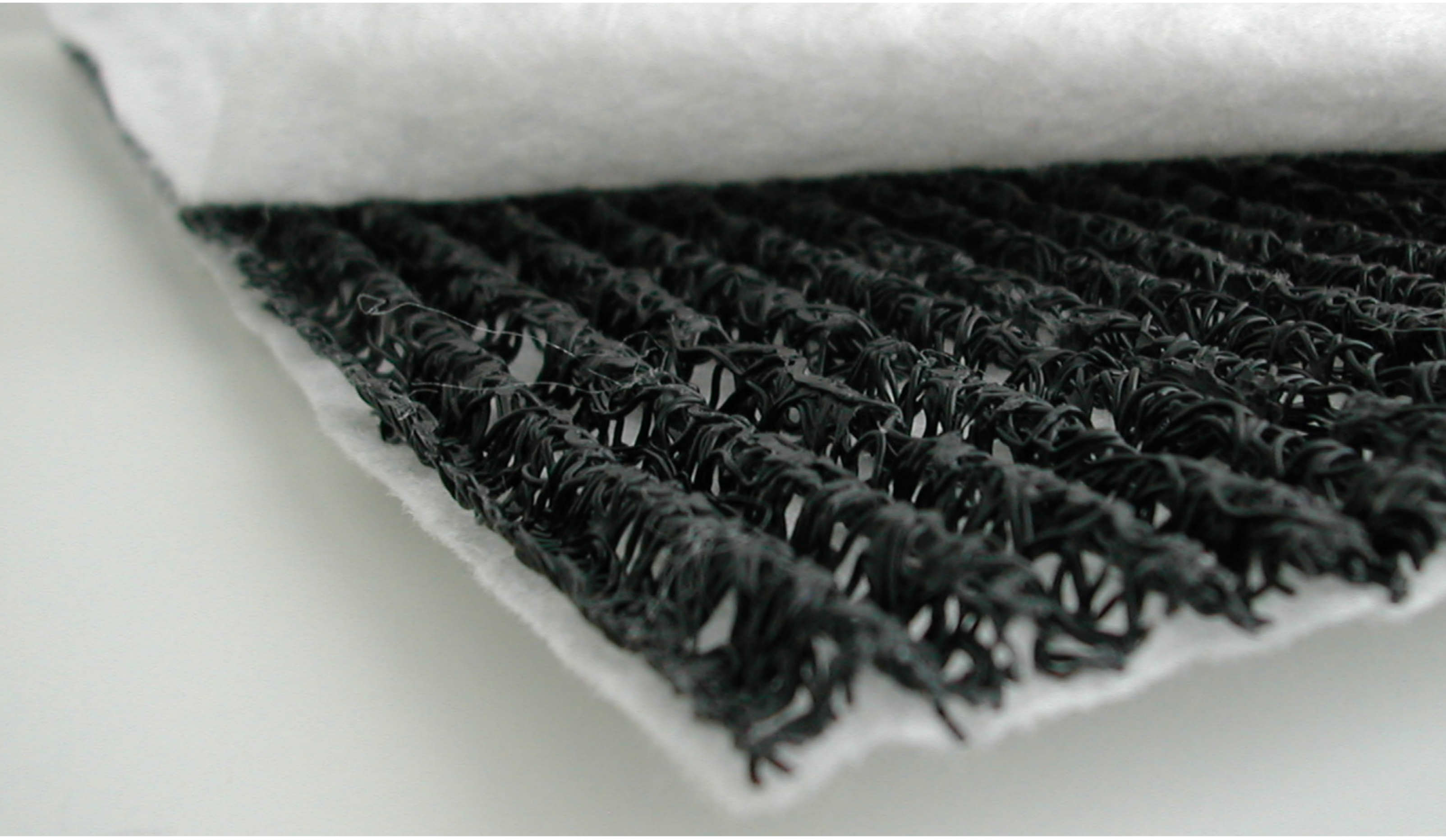

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