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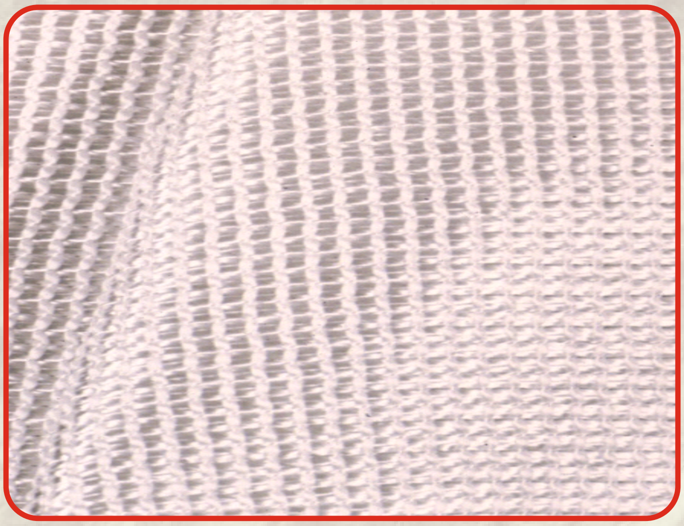
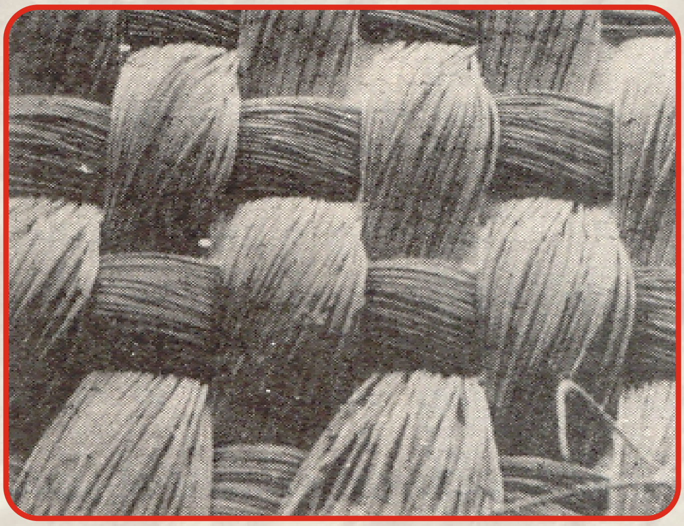
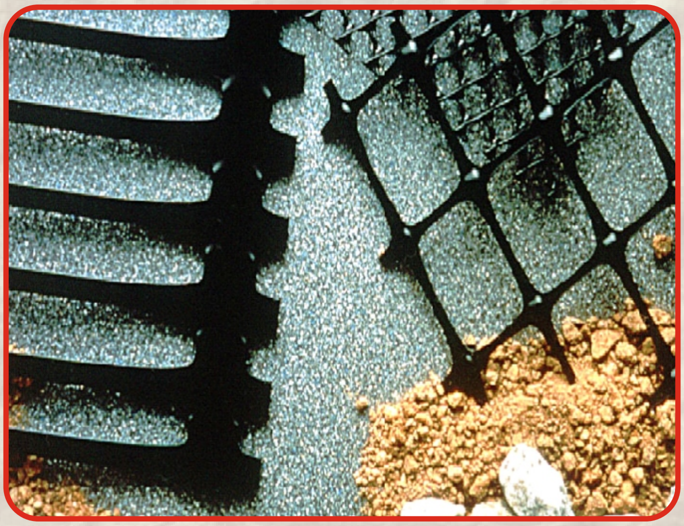
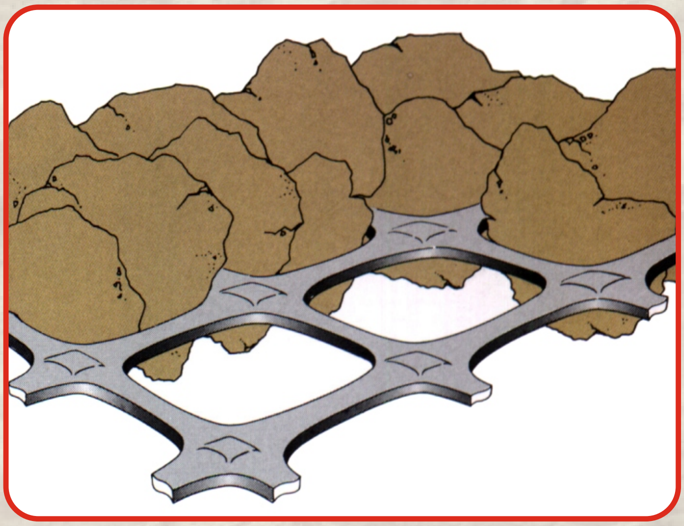

ABOUT JOURNAL

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 The manuscripts must be unpublished and should not have been submitted for publication elsewhere.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 CHAPTER OF INTERNATIONAL GEOSYNTHETICS SOCIETY

INDIAN JOURNAL OF GEOSYNTHETICS AND GROUND IMPROVEMENT

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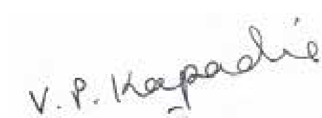
FROM THE PRESIDENT DESK

International Geosynthetics Society has been engaged in dissemination of knowledge on geosynthetics and India Chapter i.e. IGS - India has been a part of the same. India has been emerging as a manufacturing hub of quality products of a large range of geosynthetics. Though recent years have been known for some landmark projects in India using geosynthetics, a lot of scope is yet there to be explored. India is striving to develop quite interesting and innovative applications in coming years. This issue of the Indian Journal of Geosynthetics and Ground Improvement encompasses enlightening material on testing of geosynthetics and on membrane applications of geosynthetics as well. It also contains a case study on rockfall mitigation for safe and economical execution of a prestigious road project. Very complex problems in the field of dam engineering and seepage control in reservoirs are successfully addressed in India which are described as case studies in this issue. In short, this issue focusses on practical aspects narrated by renowned authors who have attempted to underline the importance and contribution of geosynthetics in meeting the present-day challenges. I am sure, it would invoke a great interest amongst engineering fraternity and establish another milestone in line of the past accomplishments. My earnest request to all practicing engineers to kindly spread the knowledge about geosynthetics for a sustainable development and for a greener world.



Vivek P. Kapadia
President
Indian Chapter of
International Geosynthetics Society

FROM THE EDITOR'S DESK

Dear IGS India Members,

I am reaching out to highlight a particularly valuable journal that has recently come to our attention. This journal comprises insightful papers on diverse topics within civil engineering, with a focus on cutting-edge research and case studies in the field.

Of particular note are the papers that delve into test methods for the evaluation of the benefits of geosynthetics reinforcements in flexible pavement design. These contributions offer a comprehensive exploration of the latest testing methodologies and their implications for optimizing the use of geosynthetics in enhancing the performance and longevity of flexible pavements.

Additionally, the journal features papers on the rehabilitation of ageing masonry dams, presenting innovative approaches and techniques. Given the critical importance of dam infrastructure worldwide, the insights provided in these papers could prove instrumental in shaping best practices for the preservation and modernization of these essential structures.

Furthermore, a notable case study on the application of HDPE geomembranes for commercial water reservoirs is included. This study presents a practical and detailed examination of the use of HDPE geomembranes in real-world scenarios, shedding light on their effectiveness, durability, and economic feasibility.

I believe the findings and recommendations presented in this journal could significantly contribute to advancements in civil engineering practices, infrastructure rehabilitation, and the utilization of geosynthetics in construction projects. I recommend that this journal be given the attention it deserves, as the information contained within could have a positive impact on industry standards and decision-making processes.

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

TEST METHODS FOR EVALUATION OF BENEFITS OF GEOSYNTHETIC REINFORCEMENTS FOR FLEXIBLE PAVEMENT DESIGN – A CRITICAL APPRAISAL FOR INDIAN SCENARIO

Guda Venkatappa Rao[1], Kolli Mohan Krishna[2], Amit Prashant[3] and Anil Dixit[4]

ABSTRACT

The Indian roadway construction has been in a golden period in the present decade. To optimize the cost of projects, Geosynthetics are widely used to save quantity of conventional flexible pavement materials and enhance the life of pavements. The cost optimization is majorly obtained by using Geosynthetic reinforcement products in granular layers in new pavement construction. In overlays, the asphalt reinforcement is in use to enhance the life of pavement by delaying the reflective cracking. For proper design and application of reinforcement materials in pavement sections, the design parameters that define the performance benefits in the overall system need to be obtained from proper testing. The basic material testing of Geosynthetic is carried out routinely in a few laboratories for quality control, but performance tests are not widely adapted in the country. However, the need and application of these materials are at a rush. The present performance test methods adapted in projects till now appear to be generally not as per specified protocols. This paper summarises test methods to quantify the benefits of reinforcements for each type of application and elaborates the important aspects not discussed directly in the relevant Indian Guidelines/Manuals. A general discussion on the present practice of test methods, analysis and design of reinforcements for flexible pavement along with recommendations is brought forth.

Keywords: Traffic Benefit Ratio, Modulus Improvement Factor, Base Course Reduction, Layer Coefficient Ratio, Cyclic plate load test, Full-scale traffic tests, Mechanistic-Empirical Design Method,

1. INTRODUCTION

The major initiative of the Government of India, Bharatmala Pariyojana Phase-I, envisages the development of about 26,000 km length of Economic Corridors in the present decade. It also involves around 8,000 km of Inter Corridors and about 7,500 km of Feeder Routes. The programme also envisages the development of Ring roads/bypasses, elevated corridors and Multi-Modal Logistics Parks. The cost of more than Rs. 6,92,324 crores are estimated for this scheme. (MoRTH, 2023). With the above vision, the road network in India is constructed at a speed of more than 30 km per day. By 2022, the National Highways have reached a total length of 1,44,955 km. Geosynthetics have been widely used in recent highway and expressway projects to optimize the cost and achieve life enhancement of flexible pavement sections. The Ministry of Road Transport and Highways (MoRTH), Government of India also encourages the use of geosynthetics in highway projects through various circulars (e.g., MoRTH, 2018).

The geosynthetics generally used in pavement applications are geotextiles, geogrids, geonets, geocomposites and geocells. Their major functions are reinforcement, stabilization, separation, filtration, drainage, erosion control and as moisture barrier. In the optimization of cost and life enhancement, reinforcement function is the key. However, other functions should accompany the reinforcement/stabilization in soft subgrades to provide a complete solution. The reinforcement applications in flexible pavements are of three types:

(a) Base/subbase stiffening reinforcement,

(b) Subgrade stabilization, and

(c) Asphalt reinforcement for life enhancement and prevention of reflective cracking.

The granular layer reinforcement is widely used and designed as per IRC:SP:59-2019 guidelines. The design for asphalt reinforcement is not available, and most of the applications are based on past experience.

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Apart from basic material testing, these reinforcement products must be tested for performance in the whole pavement system. The evaluation of the Modulus Improvement Factor (MIF) and Layer Coefficient Ratio (LCR) for granular layer reinforcements is the key performance testing requirement to use in the designs. Field tests with actual/control traffic or laboratory tests with simulated traffic loading are widely accepted tests around the world to evaluate these parameters. However, with the rapid phase of construction of highways in the country, the use of Geosynthetic reinforcements for the economic benefits of the project are pushed by construction agencies and these performance tests are generally not conducted as per accepted protocols, probably because of time constraints. Even though design methodology is not available for asphalt reinforcement, performance tests at the system level may be used to evaluate different products before application in a given project.

This paper discusses and summarises test methods to quantify the benefits of reinforcements for each type of application. Details which are not directly presented in IRC:SP:59-2019 were elaborated and summarized. Critical aspects of the determination of the modulus improvement factor and layer coefficient ratio were discussed. Critical discussions on the present practice and recommendations there off.

2. SUMMARY OF REINFORCED FLEXIBLE PAVEMENT DESIGN AS PER IRC GUIDELINES

2.1 Design of Unreinforced Flexible Pavement

The flexible bitumen pavements are presently designed as per the Indian Road Congress Guidelines (IRC:37-2018), which are based on the Mechanistic-Empirical Design (M-E) Method. By name, the M-E design method comprises two key components: A Mechanistic component and an Empirical component. The mechanistic component involves multi-layer elastic analysis of pavement layers under uniform circular loading. IRC:37-2018 recommends IITPAVE software for performing multi-layer elastic analysis. The elastic analysis requires resilient modulus and poisson's ratio as input for each layer. The values of the resilient modulus of the structural layers are obtained from correlations provided in the IRC:37-2018. Using the mechanistic model, one can determine radial/tensile and vertical strains at required pavement structure interfaces. The empirical component is necessary to estimate the traffic life of the pavement from the mechanical response. IRC specifies two empirical damage models, viz., rutting criteria and fatigue criteria. Rutting criteria require vertical strain at the subgrade level, and fatigue criteria require the tensile strain at the bottom of bituminous layers. Further details can be found in Krishna et al. (2021) and IRC:37-2018.

2.2 Base/Subbase Reinforcement: Functions and Design

The major function of base/subbase reinforcement is lateral restraint of the granular course (Bender and Barenberg, 1980; Kinney and Barenberg, 1982; Perkins et al., 1998). The lateral restraint leads to the prevention of lateral spreading of aggregate, increase in effective confinement and reduction in shear stress bottom subgrade layer. Overall, for the range of deformations of highway applications, base/subbase reinforcement provides “stiffening” to the reinforced aggregate layer. Biaxial polypropylene and polyester geogrids are generally used as base reinforcements in India. Woven polypropylene geotextiles are also used worldwide as base/subbase reinforcement. Geocells effectively provide 3D confinement to the base/subbase layer and make another option for base/subbase stiffening.

The major benefits envisaged from base/subbase stiffening are:

1. Reduction in aggregate layer thickness, and
2. Increased life for the same design rut criteria.

They are designated as Base Course Reduction (BCR) and Traffic Benefit Ratio (TBR). The BCR and TBR values can be directly used in design as per AASHTO (1993) method. However, the M-E method, as per IRC:37-2018, requires improved resilient modulus values of reinforced aggregate layers. Berg (2000) summarized these benefits from various studies and reported that TBR values range from 1.5 to 70 for different reinforcement products. The TBR values/traffic capacity obtained from experiments can be used to calculate the improved modulus of the reinforced layer and use in M-E design. The ratio of the improved resilient modulus to the original resilient modulus of the aggregate layer is termed the Modulus Improvement Factor (MIF). IRC:SP:59-2019 uses the Modulus Improvement Factor (MIF) concept to capture the benefits of geosynthetic stabilization of granular layers. The typical range of permissible MIF values of geogrid and geocell recommended by IRC:SP:59-2019 are given in Table 1. IRC:SP:59-2019 also allows using the Layer Coefficient Ratio (LCR) concept which was originally adopted from AASHTO (1993). The values of LCR represent the improvement/enhancement provided by a specific geogrid to the layer coefficient of the layer in which the geogrid is placed. The improved resilient modulus of the geogrid-enhanced pavement layer has to be determined using LCR and the layer coefficient of the layer. The typical range of LCR values of geogrid recommended by IRC:SP:59-2019 are given in Table 1.

Table 1 : Indicative range of MIF and LCR values for Geocell and Geogrid (As per IRC:SP:59-2019)

S. No.	Subgrade CBR	Geocell	Geogrid	
		MIF	MIF	LCR
1	<3%	2-2.75	1.2-2.0	1.2-1.8
2	>3%	1.4-2.0		1.2-1.6

These values are the indicative range of improvement ratios. These values may differ from product to product, subgrade and granular layer properties. However, actual certified values shall be used in the design subject to the maximum value in the table.

2.3 Subgrade Stabilization: Functions and Design

Under soft subgrade conditions, where large deformations are expected and a reinforcement material placed between granular base/subbase – subgrade interface provides a platform for construction equipment. The function of Geosynthetic reinforcement under such conditions is "stabilization" which increases the bearing capacity and also mobilizes the lateral restraint and the tension membrane effects (Haliburton et al., 1981; Giroud, 1981, 1985, Holtz 1998). Along with stabilization, such situations must also be designed for separation and filtration mechanisms. The increased strength of the subgrade can be taken into account in the pavement design process.

It is clear that the reinforcement stiffening and stabilization functions are quite different and needed in different scenarios. The original design section of the pavement needs to be constructed over the stabilized subgrade, which has to be designed separately. Several design methods based on tensioned membrane and bearing capacity theory exist for the design of subgrade stabilization as the design of reinforced unpaved roads (Steward et al., 1977; Giroud and Noiray, 1981; Giroud and Noiray, 1981; Holtz, et al., 1998; Holtz and Sivakugan, 1987). The details of these methods were summarized in Krishna et al. (2021). The paved flexible pavement needs to be designed using the M-E method of IRC over improved subgrade.

2.4 Asphalt Reinforcement: Functions and Design

The application of asphalt reinforcements in flexible pavements has been receiving attention in addition to subgrade/base/subbase stabilization/reinforcement. In general, three types of asphalt reinforcements are used:

1. Paving fabrics or geotextiles
2. Paving grids (glass grids and polymeric), and
3. Composites (Asphalt inter-layer composite/composite paving grid).

The major interest of designers and contractors in recent years has been mainly on glass grids and their composites due to their effective performance, reliability and cost-effective maintenance techniques. The stiffness of glass grids is compatible with the stiffness of bitumen layers (20 times greater than bitumen) and is thermally stable even at bitumen temperatures greater than 2000C. The ultimate tensile strength of commercially available glass grids/composite grids ranges from 50 to 200 kN/m with an ultimate strain <4%. The mesh sizes fall in the range of 12.5 mm to 50 mm. The Coatings are also thermally stable, include PVC or elastomeric polymer or polymer-modified bitumen or emulsions and allow good adhesion with bitumen.

The major function of asphalt reinforcement for distressed pavement or new bitumen layers includes reinforcement, moist barriers, stress relieving layer or a combination of them. The major applications are summarized as follows.

1. Overlays: To prevent reflective cracking or to act as a moisture barrier or combination of two functions for:
   (a) Overlay on PCC slabs or reinforced concrete roads
   (b) Overlay on fatigue/temp/block/top-down/bottom-up/edge/longitudinal cracked bitumen pavement.
   (c) Overlay on the old reflective cracked road: top of cracked asphalt on cement-treated bases.
2. New pavements: To improve fatigue/rutting life or reduce thickness of structural layers
3. Road widening: To provide transition of new-old pavements
4. Localised pavement repairs such patch repairs
5. Transition of bridge-road

For overlays, the primary function of asphalt reinforcement is to hold/modify the crack propagation. Three modes of cracking/fracture mechanisms are possible for overlays over cracked layer due to traffic and temperature-induced loads/stresses as shown in Figure 1 (SABITA, 2002; Roodi et al., 2023). Mode-1 is due to transient tensile stress at the bottom of bitumen overlay and results in cracks opening. Stresses are normal to crack planes. Mode-2 of cracking is due to transient shear stress parallel to the depth of crack propagation. Mode-3 is transient shear stress parallel to the length of crack propagation. The asphalt reinforcement holds the crack ends, reduces concentrated stresses at crack tips, and decreases the crack propagation rate (bottom-up). However, the literature (Thom, 2006; De Bondt, 2009; Brown, 2009; Reck, 2009) clearly

concludes that these reinforcements do not stop crack initiation in overlay but change the path of crack to parallel to reinforcement and reduce the propagation.

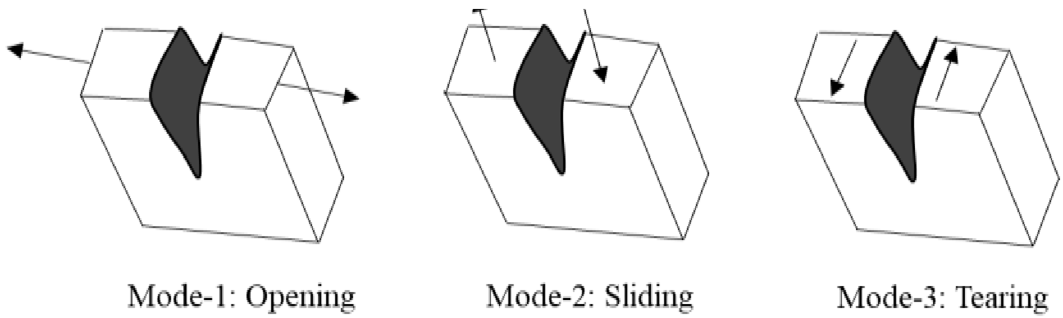

Fig. 1 : Failure modes of asphalt overlay (after SABITA, 2002; Roodi et al., 2023)

In the design of new pavement, the advantage of asphalt reinforcement is required to improve fatigue life and reduce rutting. The fatigue life of bitumen layers was observed to be increased significantly due to the use of asphalt reinforcement (De Bondt, 2009; Brown, 2009; Nguyen 2013). It was observed in some studies that the rutting of bitumen layers was reduced due to the incorporation of asphalt reinforcement at the mid-level of the bitumen layer (De Bondt, 2009; Brown, 2009; Nguyen 2013). No improvement in rutting was observed for asphalt reinforcement placed at the bottom of the bitumen layer (De Bondt, 2009; Brown, 2009; Nguyen 2013). However, it may influence rutting at the subgrade level; but from the various studies, this observation is not consistent throughout the literature. This aspect needs to be studied in detail.

Standard design methods applicable for asphalt reinforcement for overlay are not available. Similarly, design methods for the incorporation of the benefit of asphalt reinforcement in bitumen layers in new construction are also not available. IRC:SP:59-2019 enables the use of asphalt reinforcements within the recommended specifications to enhance the life of overlay/pavement. However, even though reduction of thickness is possible, it is not practiced due to lack of conclusive research findings. As such design in most situations is based on personal experience and sometimes on extrapolation from limited laboratory tests. Design models such as OLCRACK/THERMCR, BITUFOR and ARCDESO (based on specific commercial products) are used for design against reflective cracking for a few applications. However, a comprehensive verified design model for a wide range of field applications is not yet available.

3. TEST METHODS FOR QUANTIFICATION OF BENEFITS OF BASE/SUBBASE REINFORCEMENTS FOR DESIGN

Performance tests to quantify the benefits of Geosynthetic reinforcements in base and subbase layers of pavement structures are of three types:

1. cyclic plate load tests,
2. Moving wheel load tests, and
3. full-scale traffic tests.

Extensive research (Haas et al., 1988; Collin et al., 1996; Perkins and Ismeik, 1997a; Perkins and Ismeik, 1997b; Perkins, 1999; Perkins, 2002; Perkins et al., 2005; Thakur et al., 2012; Imjai et al., 2019; Abu-Farsakh et al., 2019; Schaefer, 2021) used these tests in an attempt to understand and quantify the performance of flexible pavements with geosynthetics. The test tracks/ sections/tanks for the above performance tests can be constructed indoors or outdoors, but outdoor facilities should be protected from water seepage into test sections during the testing process. Further, temperature difference should not be more than 100C during testing of comparative test sections (Berg, 2000). A brief summary of type of performance tests is presented in Table 2. The performance test procedures are equally applicable to quantify the benefit of geocells in base/subbase layers.

Table 2 : Summary of type of performance tests for base/subbase reinforcement

Laboratory tests Indoor	Test tracks Outdoor	Test section as part of actual pavement
- Cyclic plate load test in a tank. - Moving wheel load tests.	- Cyclic plate load test on a section in test track. - Moving wheel load tests. - Full-scale traffic using a loaded truck.	- Cyclic plate load test on a given section. - Measurements under controlled traffic.

These tests primarily enable the interpretation of the performance of reinforced and unreinforced pavement cross-sections. Comparison of performance with variation in material types, layer thickness, configurations, Geosynthetic reinforcement types and construction methodologies is possible with any of the above performance tests. For each load cycle/ wheel/axle passage, rutting on the surface is measured during these tests. For a given design rut criterion, the performance of the reinforced section is generally evaluated as an extension of life (TBR) or reduction in base/subbase material thickness (BCR) compared to the unreinforced section. Further, performance parameters such as modulus improvement or improvement in layer coefficient of reinforced base/subbase layer in terms of MIF and LCR can also be determined. Rutting in different layers can also be measured by an appropriate installation of displacement sensors in test sections (Christopher and Perkins, 2008; Abu-Farsakh et al., 2019). Instrumentation of test sections using pressure sensors in pavement layers and strain gauges on reinforcements is also possible to obtain additional data to evaluate performance and behavior (Christopher and Perkins, 2008; Abu-Farsakh et al., 2019).

3.1 Cyclic Plate Load Test

The cyclic plate load test is usually a laboratory test which simulates actual traffic in the form of cyclic load on the surface and accelerates rutting phenomena on cross-sections built in a controlled manner close to the actual design section. The cyclic plate load test is conducted in a test tank with load frames in the laboratory environment. These tests can also be conducted on test tracks and test sections of part of the actual roadway with appropriate loading and measuring arrangements. IRC:SP:59-2019 and AASHTO (2009) recommend a cyclic plate load test for evaluation of LCR and MIF of Geosynthetic reinforcement products for a given design section. The cyclic plate load test is also called the automated plate load test and is a type of accelerated pavement test.

The test tank with minimum tank dimensions is shown in Figure 2 (IRC:SP:59-2019). The photographs of the tank and cyclic loading facilities at Landmark Testing and Research Laboratory, Jaipur, are shown in the Figure 2. The minimum distance from the loading plate's centreline and the tank's edges should be 1 m. The minimum depth of the test tank should be 1.5 m. An actual design section, including all structural layers, has to be constructed in the tank with the same specifications as required for the project. Compaction of layers can be done using a vibrating plate, jumping jack or manual compaction hammers. Though not specified clearly in the IRC:SP:59-2019, the cyclic loading needs to be performed as per ASTM D8462 (2022) and Berg (2000), which is also referred in IRC:SP:59-2019. Loading may range from 0 to 40 kN with an equivalent applied pressure of 560 kPa. Load in the form of sinusoidal cycles shall be applied through a rigid circular loading plate having 300 mm diameter. To apply uniform pressure and to avoid the edge effects of a rigid plate, a waffled rubber pad should be placed between the plate and the surface of the test

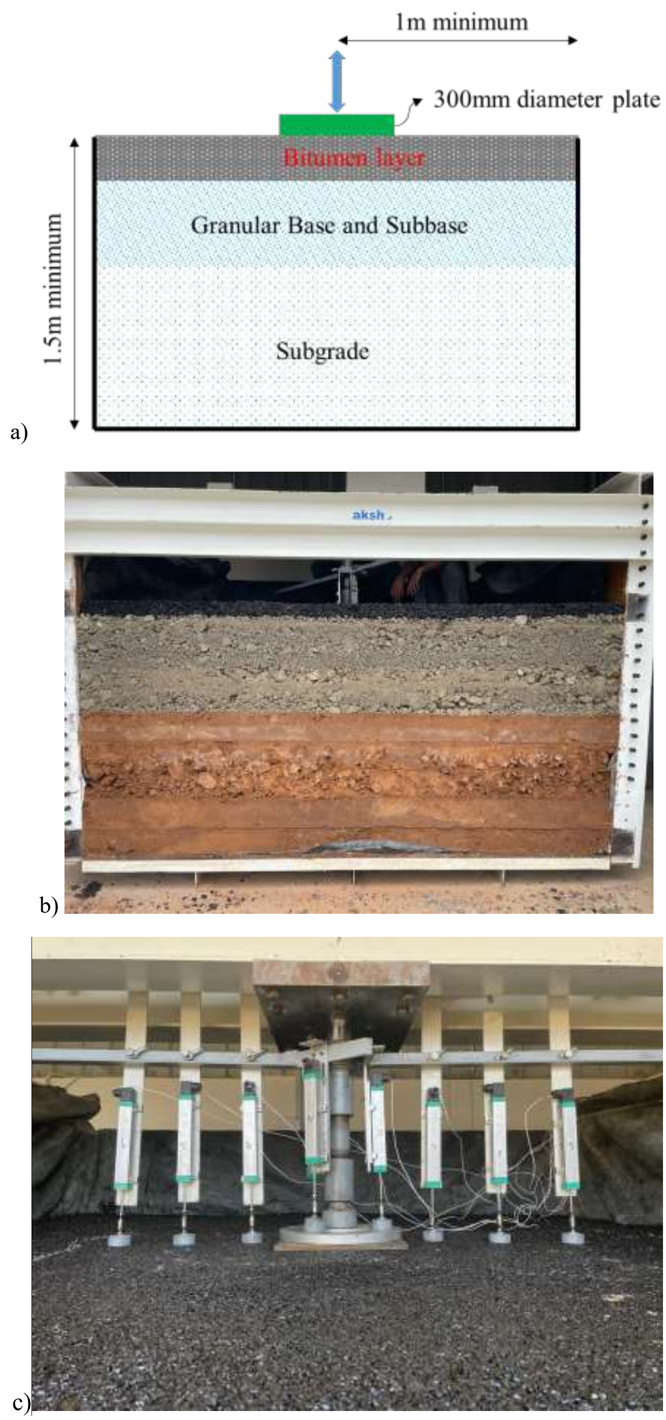

Figure 2 : (a) Schematic of cyclic plate load test (as per IRC SP 2019); (b) & (c) Pictures of test tank of cyclic plate load test at Landmark Material Testing and Research Laboratory Pvt. Ltd.

section. ASTM D8462 (2022) specifies using a 305 mm diameter plate, and it depends on the stress level one needs to simulate. Further, it specifies a seating load of 0.5 kN. Load cycle frequency shall not be greater than 1 Hz. Each cycle of load represents one standard axle passage. The loading –unloading pulse duration for each cycle should be between 0.1 to 1 second. ASTM D8462 (2022) recommends a conditioning step to simulate construction traffic on the base course layer before the construction of bitumen layers. The typical specified load cycles which need to be continued/repeated for target design criteria are depicted in the following Figure 3.

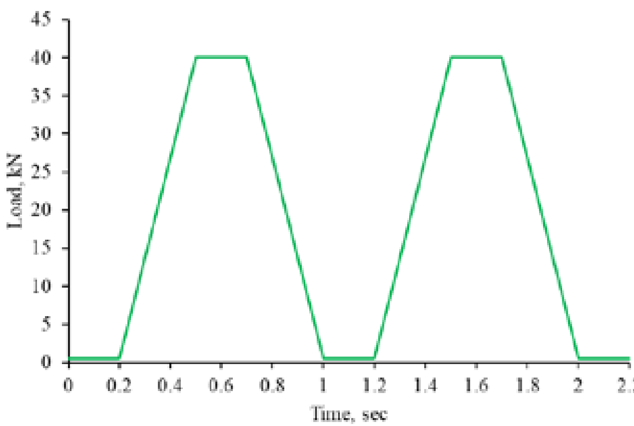

Fig. 3 : Typical cyclic loading for cyclic plate load tests (After ASTM D8462, 2022)

The permanent vertical deformations (ruts) at the surface are to be recorded as a function of the number of cycles at intervals chosen based on the requirements. Settlements and elastic rebounds of the asphalt layers shall also be measured during the tests. The rut measurements should be taken at two opposite points (minimum) of the loading plate, and their mean value should be considered a permanent rut value. The values of LCR and MIF are back-calculated from field/laboratory experimental results, as described in IRC:SP:59-2019.

Even though load application slightly differs from actual traffic, the results from these tests are accepted in literature and design guidelines to evaluate and compare the performance of various products or designs. Extrapolation of cyclic plate load test results to designs that deviate significantly from the materials and configurations tested is not recommended. Further, the performance parameter (TBR, MIF, LCR) needs to be calculated at the expected service requirement of actual pavement and a performance parameter calculated significantly away from design criteria is not recommended.

3.2 Moving Wheel Load Tests

In single/dual wheel accelerated pavement tests, a moving tyre/s connected to a loading frame is used to simulate traffic load over a test track. This is also an accelerated pavement testing method. The test track can be constructed outdoors/indoors in a long tank or excavated natural ground (Figure 4). The minimum depth of a test track should be 1.5 m, and the minimum distance between the wheel centerline and the edge of the test track should be 1 m. The minimum length of the test track should be 2 m. If a single wheel is used, it should apply a 40 kN load and should be inflated to 0.56 MPa. The speed of the wheel should be greater than 0.5 m/sec. Each passage of the wheel at a given point is considered as a standard axle passage. Permanent deformation/rut should be measured from a fixed datum as a function of the number of standard axle passages. The measurement intervals can be chosen based on the requirements (For example, measurements at passages 1, 2, 4, 8, 16, 32, 50, 100, and doubling thereafter). The mean of a minimum of 3 measurements across the width of the wheel path should be considered as rut depth at the measurement point. It is to be noted that IRC:SP:59-2019 does not discuss single/dual wheel accelerated pavement tests for determination of TBR/LCR/MIF.

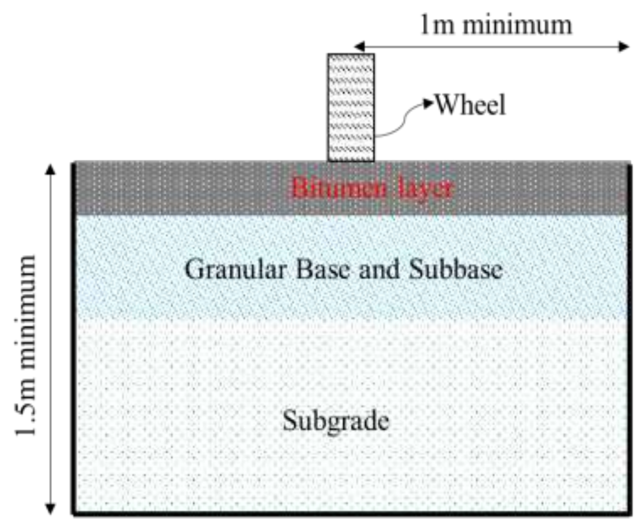

Fig. 4 : Schematic of moving wheel load test (After Berg, 2000)

3.3 Full-Scale Traffic Tests

IRC:SP:59-2019 and Berg (2000) specified full-scale traffic tests for quantification of the benefits of Geosynthetic reinforcements. These tests are performed on test tracks constructed outdoors and subjected to actual vehicle traffic and local environmental conditions (Figure 5). The minimum depth of a test track constructed close to the actual design section should be 1.5 m, and the minimum distance between the wheel centerline and the edge of the test track should be 1 m. The minimum length of the test track should be 8 m.

The loaded vehicle should be able to apply a load of 80-kN for each axle, and tyre pressure should be 0.56 MPa. Each axle load should be measured before testing so as to compare/convert to an equivalent standard axle load. The tyres shall be aligned from front to rear such that each wheel travels in the same path when the vehicle is driving straight. A typical loading vehicle (simple truck with two axles) used for traffic is shown in Figure 5. The truck tyres should be aligned from front to rear, and vehicle movement should be channelized. Each passage of one axle of the truck is one equivalent standard axle passage. The vehicle should run on the test track until the predetermined number of passes for surface rut depth measurements. The permanent deformation should be measured at 4 locations (3, 4, 5 and 6 m points of an 8 m-long section) along the length of the wheel path. For a given measurement location, the mean of a minimum of 3 measurements across the width of each wheel path of an axle (6 measurements for two-wheel axle; 12 for dual-wheel axle) should be reported as a rut depth. The mean of rut depth of 4 measurement locations should be plotted against the applied standard axle passages along with the standard deviation and coefficient of variation of these 4 mean values. The performance parameter (TBR, MCR, MIF, LCR) needs to be calculated at the expected service requirement (12.5/20/25/50/75 mm) of actual pavement.

3.4 Test on Sections Part of Actual Roadway

Cyclic plate load tests or controlled traffic can be used on test sections of the actual roadway to evaluate the performance of Geosynthetic reinforcements. The interpretation of measurements from actual traffic may be cumbersome. Hence, controlled traffic is preferred for such tests. However, these kinds of tests are limited in literature and less preferred in practice due to various challenges. Laboratory tests or separate test tracks are generally preferred.

3.5 General Quality Control Requirements During Performance Tests

Test section materials should be placed and compacted to achieve the required design properties. In addition, uniformity of material properties should be maintained between test sections of comparison. Hence, sampling and testing of each pavement layer material of reinforced and unreinforced test sections is essential to maintain uniformity of tests and interpretation. All materials should be tested appropriately as per relevant test standards for their characterization. Some of the quality control requirements recommended in ASTM D8462 (2022) and Berg (2000) are summarized in the following Table 2 and Table 3.

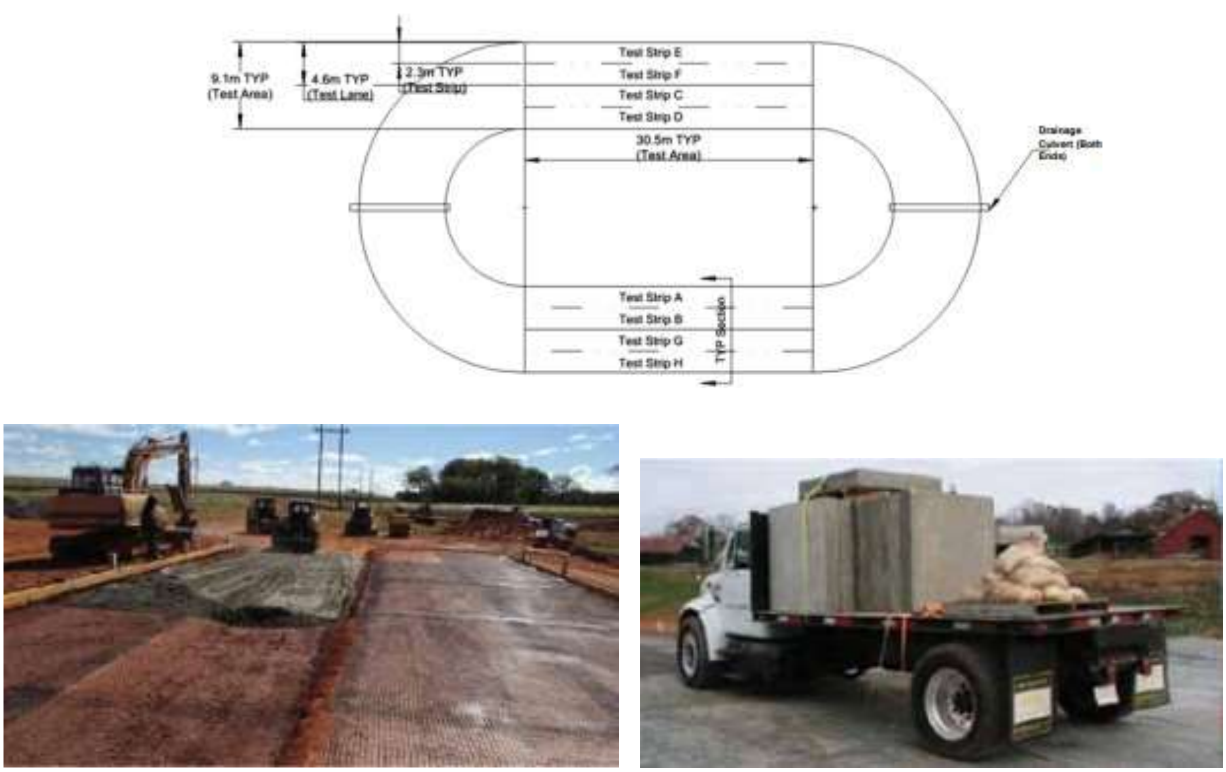

Fig. 5 : Schematic and pictures of full-scale traffic tests on a test track (After IRC:SP:59-2019)

Table 2 : Quality control measures during experiments suggested by GMA white paper-II (Berg, 2000)

Material	Quality control measure
Subgrade	The coefficient of variation (COV) of moisture content and dry density within the test section should be ≤3%
	The COV of mean dry density and moisture content between comparison test sections should be ≤2%
	$CBR_{in\text{-}place} = CBR_{design} \pm 0.1CBR_{design}$
	Measurement of dry density and moisture content should be made for every 0.1 m3 of compacted material placed.
Granular Subbase and base	The COV of mean thickness between comparison test sections should be ≤1%
	The COV of thickness within a test section ≤1%
	The COV of mean dry density between comparison test sections ≤2%
	The COV of Dry density within a test section ≤3%
	Compaction should be performed at:
	±1% of optimum moisture content
	±2% of 95% of maximum dry density
	A minimum of one thickness measurement for every 0.5 m^2 area should be made.
	Measurement of dry density and moisture content should be made for every 0.1 m^3 of compacted material placed.
Bitumen Layer	Bulk density within the test section should be ≤2%
	The mean bulk density between comparison test sections should be ≤1%
	A minimum of 1 measurement of thickness for every 0.5 m^2 area should be made.
	Approximately one bitumen core for every 1 m^2 area and far from the loading region should be taken. Bitumen content and air voids should be computed and reported. Marshal stability should also be determined and reported. A resilient modulus test should also be conducted on extracted core samples if required.
• The temperature difference should not exceed 10° C during loading of all test sections used for comparison. • The seeping of water into test sections should be prevented.	

Table 3 : Quality control measures during experiments suggested by ASTM D8462 (2022)

Material	Quality control measure
Subgrade	Strength (CBR) should be within ±5 % of the design target and between test sections.
	Final constructed thicknesses should be within ±2 % of the design target and between test sections.
Granular Subbase and base	Stiffness and density should be within ±5 % of the design target and between test sections.
	Final constructed thicknesses should be within ±2 % of the design target and between test sections.
Bitumen layer	Stiffness should be within ±5 % of the design target and between test sections.
	Final constructed thicknesses should be within ±2 % of the design target and between test sections.
• The construction time shall be within ±3 days between test sections within a series. • The elapsed time from construction to loading shall be within ±3 days within a series. • The ambient temperature during loading for test sections with bitumen layers should be within ±1 °C. • The reuse of bitumen is not recommended.	

4. CRITICAL ASPECTS ON THE USE OF TEST DATA AND DETERMINATION OF DESIGN PARAMETERS MIF/LCR

4.1 Calculation of MIF and LCR

The important criteria to be set for performance tests is the design rut criteria based on local project and code requirements. The resilient modulus of reinforced base/ subbase is back-calculated from the number of cycles/ passes of standard axles to reach the design rut criteria of IRC. The back calculation methodology should be consistent with the design methodology of IRC:SP:59-2019 and IRC:37:2018 for Indian practice. The improved resilient modulus of reinforced layers will be used to calculate MIF and LCR with comparison to unreinforced section properties. It is to be noted that LCR is the concept derived from AASHTO (1993). However, it is used to calculate the modulus of layers in IRC:SP:59-2019. The calculation of LCR should be made from the improved resilient modulus of the reinforced base/subbase layer. The improved resilient modulus, in turn, should be calculated as compatible with IRC:SP:59-2019, as discussed above. Hence, LCR back calculated as per the AASHTO (1993) method using the structural number concept may not yield compatible values with respect to IRC:SP:59-2019. The improved modulus value of the base/subbase layer due to geogrid reinforcement or geocell should be the same whether one uses MIF or LCR of a given product. If MIF and LCR are not compatible with IRC:SP:59-2019 and do not yield the same improved resilient modulus of the reinforced layer, the calculation procedure is incorrect. One should be aware of calculation compatibility and proper testing procedures in these cases. It is important as the design of reinforced pavement is highly dependent on the MIF/LCR values of Geosynthetic reinforcement/geocell to be used. It is also to be noted that the design traffic capacity of the unreinforced section and the traffic capacity obtained from the experiment can be different. This is attributed to the uncertainty of the design methodology used.

The other concept to notice is homogenization of the benefit of geogrid/geotextile for the full thickness of the reinforced base/subbase layer. It is established in the literature (Qamhia and Tutumluer, 2021) that reinforcement (geogrid/geotextile) has a zone of influence where its effective confinement will reduce far from it. A few studies (typically, Qamhia and Tutumluer, 2021) suggested dividing the reinforced base/subbase layer into different zones and using different MIF values for each zone, as shown in Figure 6. Extensive research is required to adopt such a methodology. However, as per the present design methodology of IRC:SP:59-2019, a uniform MIF value for the entire thickness of the reinforced layer is required, giving the averaged benefit. Hence, the MIF/LCR of the product is only applicable to the same or less thickness of the base/subbase layer it is tested for.

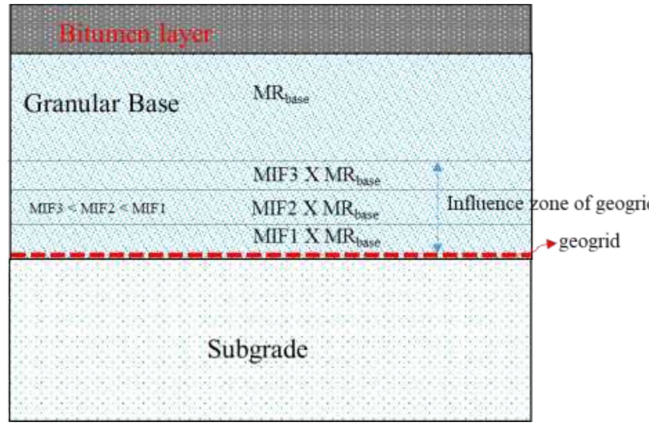

Figure 6 : Schematic of concept of using different MIF values in influence zone of geogrid (after Qamhia and Tutumluer, 2021)

4.2 Certification/Verification of MIF and LCR Values

The manufacturer normally provides LCR and MIF values based on their field and laboratory testing for specific sizes and materials. These factors may differ from product to product. Agency-specific evaluation to select appropriate MIF and LCR values is recommended. Such evaluation shall be tailored to local materials, practice, and costs.

In the absence of LCR and MIF value for a particular geogrid reinforced pavement system, a default value equal to the minimum value (Tables 1 and 2) may be taken for design. If the manufacturer/designer intends to use higher values in the design, then such values shall be based on appropriate testing/ evaluations. Such higher values obtained through testing shall be verified and certified by an independent third-party agency/institution. Ensuring correct LCR or MIF value is recommended for proper optimized design. The LCR or MIF value must be verified by appropriate testing for some trial patch before full fledged execution of the work. Further, only third-party validated MIF or LCR values must be used for the design. It may be appropriate to mention that no transportation department around the world recommended static plate load tests for the determination of LCR/MIF.

5. REVIEW OF TEST METHODS FOR PERFORMANCE ASSESSMENT OF BITUMINOUS REINFORCEMENT

Different test methods were developed for evaluating the performance of asphalt reinforcement over the past few decades to study the fatigue response, rutting response and reflection cracking phenomena caused by transient traffic or thermal loads. The tests can be mainly divided into the following types:

(a) Tests to study fatigue, thermal and reflective cracking response

(b) Tests to study rutting response

(c) Tests to study the adhesion of the bitumen-reinforcement interface

Most of these are element-level tests, and few are studied with a full system. For the Mode-1 mechanism (Figure 1) involving fatigue and reflective cracking response characterization, 3-point/4-point beam tests are widely performed (Ferrotti et al., 2011; Romeo and Montepara, 2012; Ferrotti et al., 2012; Ge et al., 2015; Canestrari et al., 2015; Saride and Kumar, 2017; Safavizadeh and Kim, 2017; Zofka et al., 2017; Sudarsan et al., 2019). ASTM D8237 (2021) also provides a general procedure for performing 4-point fatigue testing of bitumen mixtures. Slabs are also used in place of reinforced/unreinforced beams to conduct point load tests (Virgili et al., 2009; Romeo and Montepara, 2012; Fallah and Khodaji, 2015; Gonzalez-Torre et al., 2015a; Gonzalez-Torre et al., 2015b; Nejad et al., 2016). These point load beam tests induce tensile stress at the bottom of the beam/slab, initiating fatigue/reflective crack and propagation from bottom to top. Pre-notched beams/slabs were used to initiate cracking in a few tests. Plate load tests on bitumen slabs (reinforced/unreinforced) over rubber slabs and initiated cracks were also used to study fatigue cracking response (Brown, 2009; Khodalii et al., 2009; Gonzalez-Torre et al., 2015a; Gonzalez-Torre et al., 2015b). Further, these tests with bitumen slabs resting on rigid slabs with gaps to simulate reflective cracking were also carried out. Thermal cracking tests and combined thermal and transient tests are also developed in the literature to study the effect of thermal-induced stresses (Brown, 2009). Wheel track tests on a laboratory scale are used to study the rutting behavior of bitumen slabs (Komatsu et al., 1998; Kim et al., 2009; Correia and Zornberg, 2016; Correia and Zornberg, 2018; Nguyen et al., 2020a; Zhang et al., 2022). Recently, cross-shear tests were developed to simulate the Mode-II crack propagation under transient loads (Roodi et al., 2023).

Overall system response for fatigue/rutting/reflective cracks mechanisms can also be studied by performing cyclic plate load tests on actual design sections constructed in the tank. Such studies were performed in the literature to study the pre-notched bitumen layer and loading on the actual test section (Siriwardane et al., 2010). Similarly, test tracks were constructed outdoors in the excavated subgrade and performed large-scale wheel track APT (Van Gurp and Van Hulst, 1989; Austim and Gilchrist, 1996; Nguyen et al., 2020b). A few full-scale field studies were also conducted to study the performance of asphalt reinforcement (Chang et al., 1999; Sobhan et al., 2010; Pasquini et al., 2013; Kumar et al., 2022; Kumar et al., 2023).

In addition to performance/mechanism tests, interface adhesion tests were widely conducted for asphalt reinforcements, as reinforcement-bitumen adhesion is a major property that dictates the overall structural performance. The adhesion tests are different types:

Leutner shear test (Some et al., 2020; Correia and Mugayar, 2021; Sudarsanan et al., 2018),

Oblique shear test (Solatiyan et al., 2021; Li et al., 2022),

Direct shear test (Canestrari et al., 2013; Pasquini et al., 2014; Canestrari et al., 2015; Ferrotti et al., 2016),

Double shear test (Zamora-Barraza et al., 2010), and

Torque tests (Canestrari et al., 2013).

In these tests, shear stresses were induced parallel to the reinforcement-bitumen interface. A summary of the list of tests is provided in Table 4.

Table 4 : Summary of test methods for evaluation of performance of asphalt reinforcement

Mechanical Response	Load type	Tests reported in literature
Fatigue Reflective Cracking	Traffic and thermal induced loads	3-point and 4-point bending
		Beam/slab tests with different boundary conditions
		Plate load test
		Cross shear tests
		wheel track tests
		APT
		Full-scale field tests with truck
		Field application and monitoring – case studies
Rutting	Traffic loads	Plate load test
		wheel track tests
		Full-scale field tests - APT
		Field application and monitoring – case studies
Interface adhesion	Interface shear stress	Leutner shear test
		Oblique shear
		direct shear
		double shear
		tensile test
		torque test
Specimen tests	Cylindrical samples	Indirect tensile test
		Bender element
		Monotonic/cyclic loading
		Thermal.

5.1 Assessment of the Use of Test Methods for the Design of Asphalt Reinforcement

One major drawback in applying asphalt reinforcement (popular designated for Geosynthetic used in bituminous layers) is the non-availability of standard, reliable design procedures for overlay or new construction. Even though different test methods are available to assess performance at the test level, one cannot merge the test method with the design methodology. Hence, the authors recommend the following process be followed to reach a reliable design and compatible testing methodology:

1. Overlays:
   (a) As IRC:SP:59-2019 suggested, use asphalt reinforcement for enhancement of life and life-cycle cost benefits. However, improved life should be verified from large-scale tank tests with cyclic plate load or test tracks with single-wheel or full-scale traffic. Similar test procedures, as explained in section-3 with appropriate measurements can be adopted for this purpose.
   (b) For reduction in thickness in reinforced overlay: The large tank or field test track test data can be used to obtain a reduction in thickness for a given project. Similar test procedures, as explained in section-3 with appropriate measurements, can be adopted. The data from different projects can be utilized to develop a design methodology.
2. In new construction:
   (a) For a given unreinforced design section, use asphalt reinforcement for life enhancement and life-cycle cost benefits. However, improved life should be verified from large-scale tank tests with cyclic plate load or test tracks with single wheel or full-scale traffic. Similar test procedures, as explained in section-3 with appropriate measurements, can be adopted.
   (b) For reduction in thickness of bituminous layers: Project-specific large scale tank or field test track tests should be performed to obtain a reduction in reinforced bituminous layer. Similar test procedures, as explained in section-3 with appropriate measurements, can be adopted. A general methodology should be developed from different test data to adapt to the M-E method of IRC.

However, for any new product, tests from element level to system level should be performed for its assessment. The 4-point beam tests can be utilized to assess the increased fatigue life of reinforced bituminous beams. However, logical extrapolation from several tests should be done to adapt to the actual project.

Further, the location of asphalt reinforcement within the bitumen layer is another question for designers. Generally, the reinforcement location should be at the bottom of the bitumen layer to reduce crack propagation from the bottom to top. However, based on the condition of the existing cracked layer, the location should be decided accordingly.

5. CONCLUSIONS

This paper presented a review of the test methods for quantifying the benefits of Geosynthetic reinforcements for flexible pavement applications. The base/subbase reinforcement design methods are available in IRC:SP:59-2019. The test methods to quantify MIF/LCR should be based on actual traffic load tests or cyclic load tests simulating the traffic. The static plate load tests should not be used to obtain MIF/LCR – instead cyclic plate load tests should be performed. The design methods for asphalt reinforcement are not available at present. It is advised to follow the IRC and MoRTH specifications strictly. Further, performance tests at system level need to be performed before applying an asphalt reinforcement product widely in new pavements or in overlays.

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REHABILITATION OF AGEING MASONRY DAMS : APPLICATION OF FLEXIBLE PVC GEOMEMBRANES FOR IMPROVING THE WATERTIGHTNESS AND INCREASING THE SERVICE LIFE OF THE DAM

Vinayagam Subramanian[1] & Jagadeesan Subramanian[1]

ABSTRACT

Gravity dams (Stone masonry / concrete) are designed to hold huge volumes of water only through their weight and their resistance against the foundation to withstand the horizontal pressure exerted by the water head. The ageing of these dams not just leads to loosing watertightness but, also loses the mass of the dam challenging the very purpose of its design. Deterioration and seepage cause by inadequate design /construction/operation, exceptional events or simple ageing can reduce the functional life of the dam. With recent advancements in the field of geosynthetics, their application in hydraulic structures is widely accepted and appreciated for the results and benefits attained. One such is the application of flexible geomembrane in masonry dam for rehabilitation purpose. The application of a well-designed anchorage system of the geomembranes in dams not just prevents water leakage but also ensures the integrity of these gravity structures are maintained. Geomembranes are used to waterproof all types of hydraulic structures, for dry and underwater rehabilitation and in the past few decades they are now one of the most sought after watertight element in many new dams construction. The present paper will focus on one of the major gravity dam – Upper Bhavani Dam (Stone Masonry) that was rehabilitated with flexible PVC geomembranes and how the results have benefitted the client.

INTRODUCTION

The paper is based on more than 5 decades history of application of impervious geomembranes on all types of hydraulic structures all over the world. The application of PVC Geomembranes on dams dates back to 1950's and they are the ones most prominently used as repair systems to restore imperviousness at the upstream face of all types of dams. Engineered and computer-controlled at manufacturing, their salient characteristics are >230% three-dimensional elongation at break, imperviousness two orders of magnitude inferior to that of traditional materials, small volume and light weight to facilitate transport and minimise environmental impact. In the early days of application of these systems, which can be considered a pioneer phase, all types of geomembranes were experimented, generally of very low thickness, and the manufacturing techniques were still not very sophisticated, so that service life was sometimes unsatisfactory. This may be true also nowadays, fortunately only in very few cases, where only cost dictated the choice. Modern PVC geomembranes can now be engineered for a service life exceeding 100 years when underwater or covered and more than half a century when permanently exposed.

The point to be considered here is that the experience of several decades on hundreds of dams, reservoirs, canals and hydraulic tunnels has shown that a geomembrane system being a system, to make a successful project all aspects must be taken into account:

(1) the soundness of the design,

(2) the characteristics and quality of the geomembrane, and

(3) the experience and good workmanship of the installer.

Improperly designed and installed liners may fail, but this is true also of concrete structures! Properly designed and installed liners may have a long service life, and, different from traditional materials, they do not require maintenance. In the segment below we will focus more on a specific case of Upper Bhavani Dam where the leakage has been controlled to a great extent and as a consequence the client is able to generate additional power.

BACKGROUND OF THE DAM AND ADVENT OF DRIP (DAM REHABILITATION AND IMPROVEMENT PROJECT)

Upper Bhavani is a stone masonry dam located in the state of Tamil Nadu. The dam is owned by TANGEDCO (Tamil Nadu Generation and Distribution Corporation) which is the state government entity responsible for generation and distribution of power in the state of Tamil

1. Carpi India Waterproofing Specialists, Chennai, Tamil Nadu, India

Nadu. The dam was built in the years from 1959-1965 across the river Bhavani on the Western Ghats of the Nilgiris Hills (a scenic location in this part of India). The dam is located in the border between Tamil Nadu and Kerala and located at an elevation of 2276.88 m. The dam acts as the major source of water for a series of power houses at its downstream side.

The dam stands tall at 80 m and is founded on hard granite rock and is 419 m long at crest. They key features of the dam is as below:

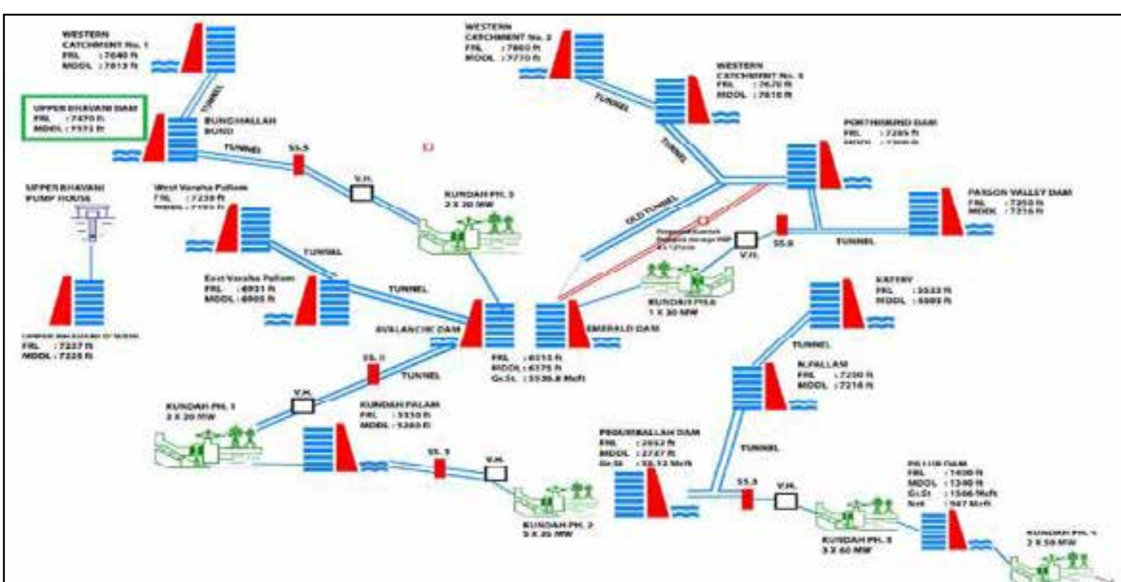
Spillway Length	19.81M
Scourvent Tower	1.52 X 2.13 M
No of Construction joints	13
No of gallery	1
MWL/MDDL/Sill level	EL 2276.88 M / EL 2240.42 / EL2221.99

Upper Bhavani Dam, considered a distressed dam in 2004/2005 was rehabilitated in 2019-2021 under the DRIP program. The Central Government of India through its Nodal Agency (Central Water Commission) partnered with the state government to execute this large scale rehabilitation work with funds from World Bank. The phase 1 of DRIP project had seen two large dams rehabilitated with Geomembrane system and both have reduced leakage by 99% thereby benefiting the client.

DETERIORATION IN THE MASONRY DAM

The masonry mortar joints showed signs of deterioration and withering. The dam being major source of water was never lowered beyond 15 meter and the condition of the mortar joints was very poor. It has been reported by the client that the water quality in this region is around 6 PH and little acidic in nature. The acidic quality of water

Picture 1: Google Earth image of the Upper Bhavani Dam



Picture 2 : Cascade Scheme of Kundah Basin (Upper Bhavani Dam indicate in green rectangle)

deteriorated the mortar joints and there was no bonding between the stones. This continued deterioration over the years, increased the permeability and the cavities in the rubble masonry pointing further increased the seepage through the dam, which emerged at the downstream face where the growth of small plants provided evidence of persisting leakage.

The total leakage measures in the gallery was around 8168 l/minute at El 2267 (9 m below FRL). The information from the client indicates the leakage is around 15,000 l/minute when the dam water reaches the FRL (Full Reservoir Level). The two shafts at the beginning and ending of the spillway contributed to the maximum discharge.

The client over the last 2 decades attempted several leakages arresting methods like

- Primary Body Grouting from Dam Crest
- Epoxy Pointing
- Shotcrete/ Guniting

Unfortunately, all efforts turned futile as the problem experienced in the dam needs large-scale repair works and not a localized repair solution. The extreme weather combined with the remote location of the dam made the selection of repair methods a challenge for the dam safety engineers.

Picture 3 : Water gushing from the 2 shafts near the spillway

Selection and Designing of the Geomembrane Waterproofing System

The Team of World Bank and consultants after inspection of the dam in 2017 and reviewal of the past repair methods attempted decided to go ahead with geomembrane waterproofing system. TANGEDCO with the experience of Kadamparai Dam immediately proceeded with the documentation and tender works. Carpi was awarded with the contract and began the designing of the waterproofing system. For effective designing and long durability and ensure the improvement in the structural integrity of the dam, dam mass improving works like grouting and re-pointing was suggested. Carpi executed these preparatory works before the installation of the geomembrane works. This ensure the grout entered in the dam body improves the dam mass and the geomembrane on the upstream barrier ensure no further entry of water through the upstream face thus retaining the mass of the dam body in tact.

The designing of the waterproofing system involves

- Selection of appropriate thickness of the geomembrane
- Selection of proper anchorages
- Selection of appropriate drainage system and the positioning of drain-pipes.

The following factor are considered before designing of the entire waterproofing system

Gravity Loads Heat

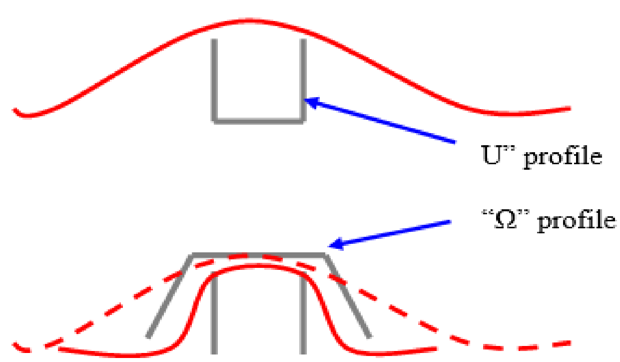
Puncture Loads Ultra violet Radiation

Wind Loads Water Ingredient

After careful study of the above parameters, Carpi chose a special anchorage made of Stainless Steel SS 304 grade

Several types of anchorages were used in Upper Bhavani

Face Anchorage : Made up of SS 304 Grade Profiles consisting of Lower U shaped Profile and Upper Omega Profile to resist the The face anchorage system will consist of tensioning profiles that avoid formation of folds that can be prejudicial to the longevity of the liner, and of flat profiles that will keep the liner taut and adherent to the face of the dam at concave corners.



Picture 4: Effect of the Carpi tensioning profile system. (Left) Winscar dam (UK, 2001) and (Right) Midtbotvatn dam (Norway, 2004).

Geomembrane Thickness : The waterproofing liner is a flexible composite geomembrane, SIBELON® CNT 4400, consisting of a 3.0 mm thick SIBELON® geomembrane heat-bonded during extrusion to a non-woven, needle punched 500 g/m2 polypropylene geotextile. Each sheet has a length such as to cover the dam section where it is placed and overlap on the geomembrane sheet below it.

INSTALLATION PROGRAM

The entire upstream face of the upper Bhavani dam is divided into 23 small areas to install the geomembrane on the face. The Installation of the geomembrane Waterproofing system was originally programmed for two seasons in 2019 and 2020 in 2 stretches a) Area < El 2254 and b) Area > El 2254. Subsequently, the delay in award of the contract combined with the power demand and monsoon impact, the installation program was shifted. The installation of the area Above El 2254 was performed first followed by installation below EL 2254. This necessitated one more design change and Carpi carefully modified the work program based on the new design.

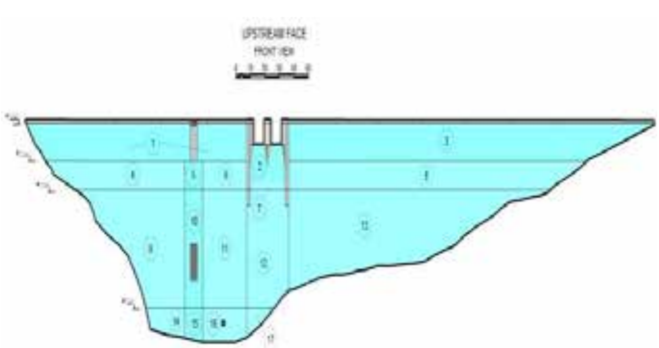


Fig. 5 : Planning of the division of the whole area into small areas for the execution of the work.

GEOMEMBRANE INSTALLATION

Before installation of the waterproofing liner, all anchorage lines was regularized by a layer of mortar. A strip of high-transmissivity drainage geonet was placed over the mortar and under the vertical tensioning profiles.

Face anchorage of the waterproofing liner is obtained by vertical stainless-steel tensioning profiles patented by Carpi and allowing continuous linear fastening and pre-tensioning of the liner. Figure 6 shows the preparation of the vertical strips to place the profile

The tensioning profiles were placed at 5.70 m spacing and waterproofed with a cover strip of SIBELON® C 3900 geomembrane (the same 3.0 mm thick material composing the SIBELON® CNT 4400 geocomposite, but

Fig. 6 : Preparation of mortar strips for placement of vertical anchorages

without geotextile) With rough and protruding stones, it was necessary to prepare a leveling mortar strip made with High Strength Mortar for fixing the stainless steel profiles.

After the installation of Vertical anchorages, a layer of 2000 g/m2 nonwoven geotextile is installed over the upstream stone masonry facings. This protects the geocomposite from puncture as well as provide some drainage capability

Fig. 7 : Thick 2000 gsm geotextile installed

The waterproofing membrane comes in 21 meters wide and several rolls of geocomposite are rolled one after the other as shown in Figure 8 and 9

Fig. 8 : Multiple rolls of geocomposites installed one after other

All welding of the waterproofing liner and geomembrane cover strips was done by “hot air” one-track welding guns. The waterproofing liner is confined at all peripheries by mechanical seals that are watertight against water in pressure where submersible (along bottom peripheries, scourvent, spillway, at connections between horizontal sections) and against rainwater and waves at crest Submersible perimeter seals are made with 80x8 mm flat stainless-steel profiles tied to the dam with anchor rods embedded in chemical phials.

Drainage system : The major advantage of having an upstream treatment with drainage layer is to ensure the water is properly drained into the gallery and is not allowed to enter to the dam body. This is achievable only with a loosely coupled system like the geomembrane system and not possible in any kind of permanently bonded system like the mortar or concrete septum.

The drainage system behind the SIBELON® geocomposite is made by

- The face drainage layer (it will consist of the gap between the liner and the dam face, of the geotextile backing the PVC geomembrane, and of the anti-puncture 2000 g/m2 geotextile)

- The vertical conduits formed by the tensioning system anchoring the SIBELON® geocomposite at the upstream face
- The bottom longitudinal collection conduit

Fig. 9 : Drainage Pipe from behind the geomembrane exiting into the gallery to collect any water that is accumulated behind the membrane

Drained water will travel by gravity to the bottom peripheral collector placed above the perimeter seal. The geonets will convey water to transverse discharge into the top gallery.

Perimeter Anchorages : The waterproofing geocomposite is anchored along all peripheries by a perimeter seal avoiding water by-passing the geocomposite.. Even compression is achieved with EPDM rubber gaskets and stainless-steel splice plates. The perimeter seal at the crest is made with 50 x 3 mm flat stainless-steel batten strips tied to the dam with mechanical anchors. The same profiles, waterproofed with SIBELON® C 3900 geomembrane cover strips, keep the waterproofing liner taut to the dam face at concave corners

Fig. 10 : Installation of Perimeter seal. Resins and bedding mortar seen before placing the perimeter seal

An Optical Fibre Cable system was installed like at Kadamparai dam, to implement the monitoring of the geomembrane system done by measurement of drained water.Figure11shows the Performance of the Geomembrane waterproofing system to be monitored using a special Optical Fiber Cable using the Heat Pulse Method (HPM).

Fig. 11 : Installation of Optical fiber cable and the control units

The entire work scheduled to be completed in 2 season got extended to three seasons due to extreme monsoon and two unpredictable events COVID 19 Wave 1 and Wave 2 between 2020 and 2021. Inspite of these challenges, the work was carried out with all the safety protocols.

RESULTS

The leakage from the two major shafts is now completely arrested and leakage which was in the order of 8200 l/m is now reduced to less than 60Lpm (99% Savings). The downstream of the dam appears dry and there is no major discharge of water inside the gallery. The quantum of water lost due to the leakage was alarming that the client as per mathematical calculation is able to generate around 30,000 MWatt* additionally each year. (*official data awaited from the client)

Fig. 12 : Upper Bhavani on June 30th 2021: fully lined

The result of the waterproofing was immediately seen with the water level raising fast, the leakage in the two shafts becomes negligible. Figure 13 shows the comparison of the area where there was leakage before and after installation of the geomembrane. Graph 1 shows the details of the quantity of the water leakage before and after installation of geomembrane.

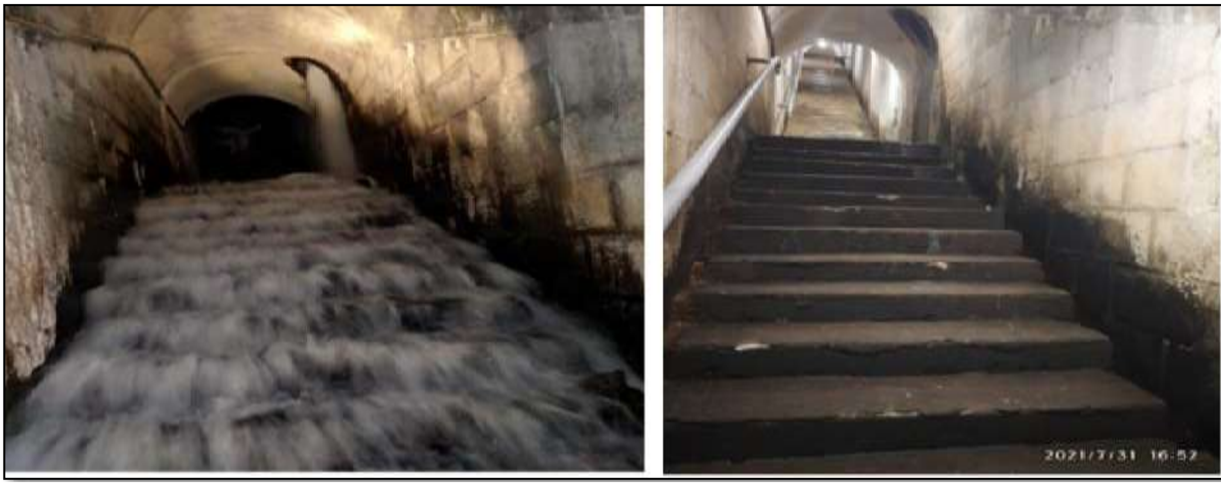
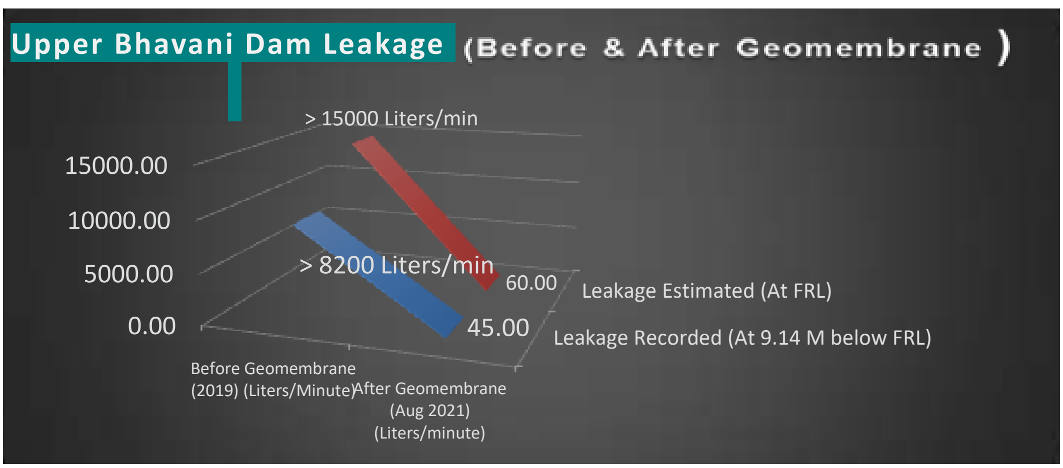


Fig. 13 : Shows the Vertical Drain Shaft (Right Spillway)Before and After GM Installation



Graph 1 : Shows the details of the quantity of the water leakage before and after installation of geomembrane

CONCLUSION

The paper emphasizes the fact that effective designing combined with proper selection of the waterproofing element helps to extend the service life of these ageing structures. Upper Bhavani considered a distressed dam is now the largest stone masonry dam lined with geomembrane and the expected design life of this system is more than 40 years. The initial grouting done to the dam body is now retained within the structure and the geomembrane barrier helps stopping of any further deterioration. The performance of the above applications has shown that exposed geomembrane systems, adequately designed and installed, provided a technically effective solution to restore imperviousness in the dam body by controlling the seepage of the dam.

The dam started impounding on 1st July 2021 and with the water level nearing Full Reservoir level (FRL) the results are very satisfying to the client TANGEDCO as well as Carpi.

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CASE STUDY: HDPE GEOMEMBRANE FOR COMMERCIAL WATER RESERVOIRS

Gaurav Jain[1], Sanjay Sharma[2] and Kantappa Halake[3]

ABSTRACT

Geomembranes are widely used in hydraulic applications as barrier liners for gas and fluids. The base materials include polyethylene (PE), polypropylene (PP), polyvinyl chlorides (PVC) and derivatives of them are regularly accommodating worldwide. The PE materials of different density are chosen for modifying the properties of geomembrane. The High-density polyethylene (HDPE) geomembranes are often preferred for hazardous waste landfills, water conservation, waste ponds, etc. Thermal and oxidative degradation of the base polymer changes the molecular level structures and in-service life of polymer. The present case study analyses the final condition of an exhumed HDPE geomembrane sample that was 1.5 mm thick for industrial water storage. The sample was collected after 7 years of service in the slope area water pond which was continuing in field exposure of stored water. The laboratory evaluation was performed based on physical and thermoanalytical performances according to global standard of GRI-GM13. GRI standards are very stringent and are mainly based on the standard certifications of American Standard Test Methods (ASTM). The reduced minutes of OIT demonstrated that the depletion of antioxidants had occurred. The carbon black content (CBC) is in the range of the required minimum standard. This study concludes that a certain number of antioxidants are still available to protect the geomembrane for further service.

***Keywords**: antioxidants, geomembrane, exhumed, in-service, pond liner, etc.*

1. INTRODUCTION

Geomembranes are impermeable liners used to control hydraulic barriers in human made projects. In decades, it has been envisaged that petrochemical based material typically PE of different grades are major starting materials to manufacture geomembrane (1,2). Typical geomembranes are manufactured through blown-film extrusion process with standard comply of geosynthetic institutes, GRI-GM13 and GRI-GM17 for high-density polyethylene (HDPE) and Low-density polyethylene (LDPE) polymers respectively. The geosynthetic research institute (GSI/GRI) specifications constitute the world's most stringent set of minimum technical requirements. The technical standards are completely based on the standard specifications of American Standard Test Methods (ASTM) certifications.

Megaplast India Pvt. Ltd. is manufacturer and exporter of geomembrane liners under the trademark of Megaliner® across India and over 20 countries worldwide. The liners are mainly manufactured through multilayered extrusion process from polyethylene granules. Polymers of different density are carefully chosen to alter the properties of geomembrane. The superior physical and mechanical properties of High-density polyethylene (HDPE) geomembranes have increased applications in various segments such as hazardous waste landfills, water conservation, waste ponds, etc. The state-of-art multilayer technology of blown film extrusion process having 3 and 7 layers has accommodated. The manufactured liners have maximum 8-meter wide in the roll form. The geomembrane product categories have variations such as in thickness, color, surface textures and flexibility. The final products are globally recognized through as standard specification from GRI. The specifications are measured with well calibrated equipment and testing conditions provided in ASTM standards. The high barrier film of seven layered liner has its barrier properties in very lower limit called ultra-barrier films. The barrier limitations can be controlled by varying the proper layer percentages and materials compositions and types. These are basically depending on the kind of barrier requirement for commercial applications (3).

Present case study focuses on analyses done on exhumed liner of HDPE of 1.5 mm thickness after 7-years. Usually, geomembranes are exposed to atmospheric conditions and the barrier contaminants during the service life. The service exposure of geomembrane causes thermal and oxidative degradation, changing the internal structure-property relationship of the material. The physical properties of sample were compared with the American Standard Test Method (ASTM) minimum values and their present conditions. The different physical properties such as thickness, MFI, OIT, density, carbon black content

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(CBC) and tensile properties were evaluated to understand the alteration in polymer properties being exposed over time. Additionally, thermal analyses such as melting, crystallization and OIT's were carried out to complement the understanding of the final condition of the geomembrane. The purpose of this study is to evaluate the material's performance for a water pond construction liner.

2. SAMPLING AND TESTING OF MEGALINER® HDPE

The HDPE geomembrane sample of thickness 1.5 mm was exhumed in water pond for industrial applications. The pond has been continuous in-service for 7 years for water storage. The sample named "exhumed sample" was cleaned with normal water and dried in atmospheric condition of sunlight. Fig. 1 shows the image of pond which is filled with water, it was located at BKT Bhuj, Gujarat, India. The HDPE geomembrane is used as a flow barrier system and piece of sample was collected from the pond's slope, which was in contact with the water and environmental conditions during exposure.

2.1. Physical tests

In this study the different physical analyses were performed to evaluate the exhumed liner. The sample thickness was determined directly by measuring with a precision of 0.001 mm and the difference between the specimen and the dead-weight loading gauge used 20 kPa. The density test uses the principle of Archimedes measuring with an analytical balance having 0.0001 g as precision before and after the immersion in a beaker with n-butyl acetate at room temperature. The carbon black content was measured gravimetrically, after and before burning the 1g specimen pieces at 600 ± 5°C 3 min in muffle furnace. The melt flow index (MFI) of exhumed liner was determined using a plastometer with a thermostatically controlled hot cylinder to extrude the material. The extruded mass after 10 min was noted directly by weighing on analytical balance.

2.2. Thermal analyses

The thermal behavior study was conducted in differential scanning calorimeter (DSC, model Q20, TA Instruments, New Castle, USA). The oxidative induction time (OIT) is measured with two configurations: the standard oxidative induction time (std.-OIT) and high-pressure oxidative induction time (HP-OIT) using ASTM D5885. The std. OIT was performed at 200 ± 2 °C with a constant oxygen flow rate of 50 mL min^{-1} and heating rate of 20 °C min^{-1}. The HP-OIT was conducted at 150 ± 0.5 °C with a constant oxygen pressure of 500 psi and heating rate of 20 °C min^{-1}. The OIT analyses were conducted in two stages. Initially, an endothermic reaction was performed in presence of nitrogen gas purge and subsequent oxidation in presence of oxygen gas. The melting and crystallization temperatures are determined by heating and cooling rate of 10 °C min^{-1} with a sample of 5 mg tightly punched in aluminum pan.

3. RESULT AND DISCUSSIONS

3.1 Physical analysis

Table 1 shows the comparative physical testing results of exhumed sample and the GRI-GM13 minimum required values for the reference. The evaluated average thickness and calculated density value are higher than the nominal values and which is related to the improvement in crystallinity. The similar results are also obtained in literature with lower

Fig. 1 : Industrial water pond with 1.5 mm HDPE Megaliner

Table 1 : Physical test result of exhumed sample and minimum standard requirement as per the standard GRI-GM13

Parameters	Test Methods	Units	Megaliner® HDPE	
			GRI-GM13 (min values)	Exhumed (7 yrs.)
Physical Testing Properties				
Thickness	D 5199	Mm	1.5	1.513
Density	D 792	g/cc	≤ 0.940	0.952
CBC	D 4218	%	2 to 3	2.47
MFI (190 °C)	D 1238	g/10 min	-	0.1434
Thermal Testing Properties				
std-OIT	D 5885	min	100	87
HP-OIT	D 5885	min	400	245
T_m	Megaplast test method	°C	-	128
T_g	Megaplast test method	°C	-	114

in MFI (4). The calculated carbon black content (CBC) is in the range of required minimum standard of 2 to 3%. The MFI of an exhumed sample is 0.14 g/10 min.

3.2 Thermoanalytical Analysis

The DSC evaluation as standard-OIT and HP-OIT demonstrated that the depletion of antioxidant in test temperature of 200°C. The resulted values of 87 mins and 245 mins for std-OIT and HP-OIT respectively. These lower minutes than required values clearly indicates the depletion of antioxidants was stated. However, the presented times for OIT also indicates the geomembranes is still well protected against the deterioration. The thermal behaviour of exhumed sample is illustration in Fig. 2 shows the heating and cooling curves.

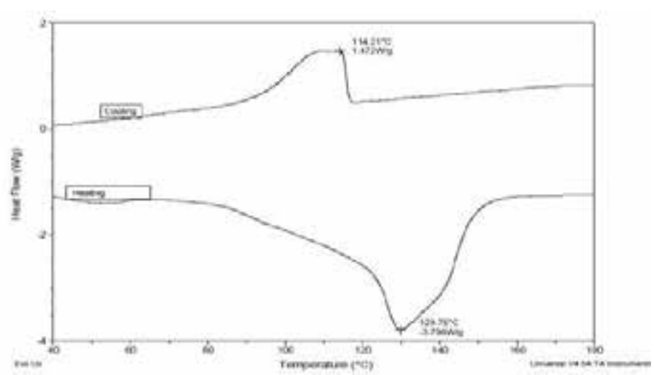

Fig. 2 : Heating and cooling thermograms of exhumed Megaliner®

The thermogram (Fig. 2) indicates the gradual heating and cooling profiles. The melting curve shows board peak which starts from temperature 87°C for melting phenomenon. The baseline change of the curve indicates a tendency of softening of the materials due to the continuous increase in temperature until it reaches the melting point of 129.75 °C. Then after, the sample was cooled with temperature rate, materials start crystallization and crystallization peak occurred at 114.21°C. In both melting and crystallization points, its observed that there is an indication of overlapped reactions which is attributed to the presence of foreign impurities in the material.

4. CONCLUSIONS

The exhumed sample showed higher value of sample density and thickens. The improved density is related to the crystallinity and macromolecular chain alignment. During the in-service of geomembrane aging process molecular chains were relaxed and aligned more properly. The reduction in number of minutes for OIT study (std-OIT value of 87 min and HP-OIT values 245 min) indicates the antioxidant depletions has occurred. This indicated still enough amounts of antioxidants are available for further protection. The standard evaluation as per the GRI-GM13 this material is qualified for further services. Therefore, the analysed HDPE exhumed geomembrane showed changes in its properties due to aging mechanisms and the waste contact at the site.

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ROCKFALL MITIGATION WORKS FOR A NEWLY FORMED ROAD BY CUTTING INTO HARD ROCK

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ABSTRACT

A newly formed road by cutting into the rock was formed in the city of Hyderabad. During the monsoon prior to commissioning, some rock falls were seen that posed threats the users. After proper analysis of the stability, suitable measures to prevent any rockfall on to the moving traffic in the road formed by cutting the hill was implemented. The paper describes the process followed for selection of suitable products and the condition of the completed works after an year of implementation.

PROJECT BRIEF

Madhapur of Cyberabad Zone of TSIIC, a part of Hyderabad Knowledge City which falls under Industrial Area Local Authority has grown phenomenally in the last few years with many new offices / buildings coming up thereat. Many more buildings are under different stages of completion with noteworthy T-Hub's iconic building, a Government of Telangana's initiative for fostering innovation ecosystem. To meet the fast increasing demand of better connectivity for the increased traffic, Telangana State Industrial Infrastructure Corporation Limited (TSIIC) constructed a new carriageway of around 850 meter connecting internal roads of Hyderabad Knowledge City with the Old Mumbai Highway joining the same adjacent to Bio-diversity Park. This new road was constructed by drilling the hillock thereat to create a passage for the road. To mitigate the hazard for the carriageway users from loose boulders on the hilltop and rock slope falling on to the carriageway, TSIIC decided to take up slope stability and safety works and appointed IIT, Hyderabad to finalize a suitable scheme.

SITE STUDY AND STABILITY ANALYSIS OF THE SLOPE

IITH did studies on the cut slope to arrive at a suitable solution. The studies included drone study and the study of failure planes by a geologist. The rock mass was found to be granitic in nature. Horizontal bedding planes were observed along North-South direction. Vertical joints were also observed. Loose boulders were found near the hill top and along the rock slope. The rock in general was highly to moderately jointed and fractured. Cracks of 5-10cm wide were visible on the rock cliff surface. A series of cracks were seen on the slope which will facilitate the seepage of precipitation and may trigger further slope deterioration and ultimately trigger sliding of rocks. Some seepage was observed through the rock slope on the day of the visit. The site as per IS1893-2000 falls under Zone II. The seismic intensity for the zone is categorized as 'low'. (Figure 1)

Fig. 1 : Site photo prior to the protection works showing the loose rocks on the slope and top.

1. B Umashankar, Professor, IIT Hyderabad

2. Sudhakar M, TechFab India Industries Limited

3. Rama Krishna Ganga, Sree Rama Infra & Projects

Based on the elevation profiles from the drone survey, critical sections were considered to analyse the stability of the rock slopes. Needed parameters for the analysis of the slope were defined. A modelling software for geo-engineers and earth scientists, was used to perform the slope stability. Slope stability analyses were performed for the critical sections with maximum heights in the stretch. The factors of safety of rock slopes for the critical sections considered were found to be greater than 1.5. Hence, the rock slopes were considered safe. (Figure 2)

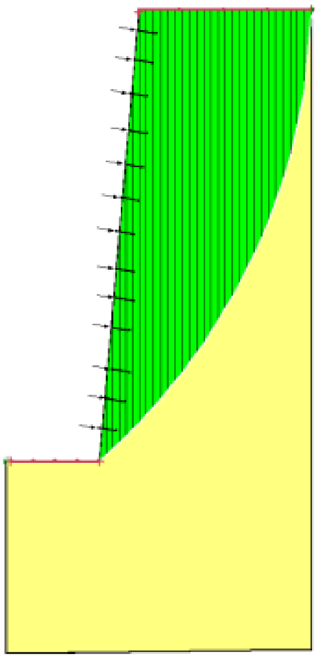

Fig. : Slope stability analysis of rock slope of height equal to ≈54m

SOLUTION AND RECOMMENDED

As the slope stability analysis using modelling software based on the survey and geology reports, showed there were no deep-seated global stability problems in the subject area. However, from the field observations the surficial instabilities near the face of the slope, it was evident that suitable measures were needed to prevent any damage to the users of the carriage way. So, a scheme was proposed to be implemented.

The scheme for the mitigation work consisted of the following:

LOOSE SCALING, REMOVING PLANTATIONS AND LARGE BOULDERS

The work started with doing preparatory work of taking down the loosed material from hill slope side and large boulders on top of the slope by using suitable mechanism.

All trees, bushes, shrubs, stumps, roots, grass, weeds, rubbish, top organic soil, etc., on the slope and at the edge of slope were removed. (Figure 3)

ROCK FACE STABILIZATION

The recommendation of IRC Highway Research Board Special Report 23 on 'State of the Art: Design and construction of rockfall mitigation systems' were followed for selection of suitable anchoring system, netting, and rockfall embankment. The rockfall netting has been adopted from IS 16014: 2018: 'Mechanically woven, double-twisted, hexagonal wire mesh gabions, revet mattresses and rock fall netting'.

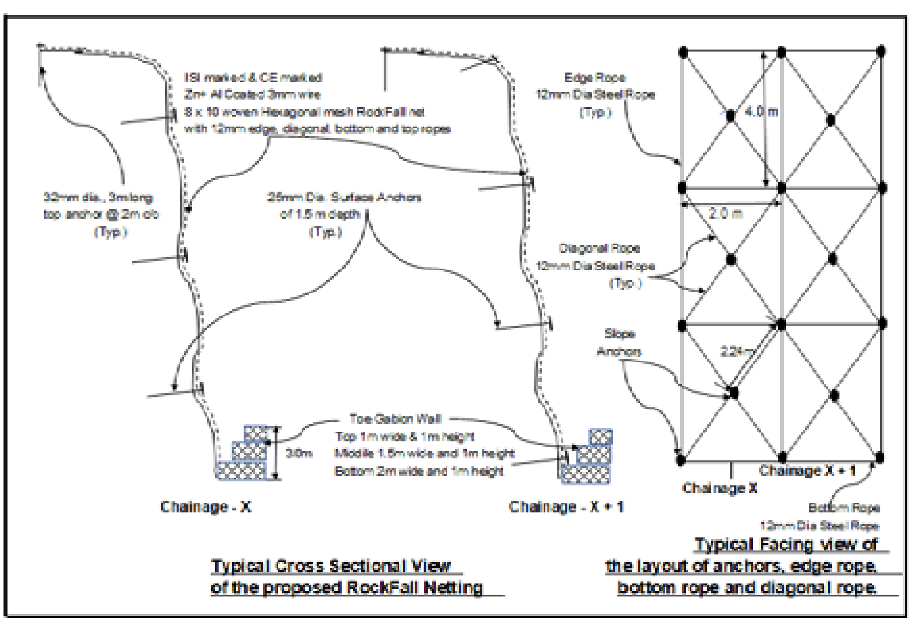

Fig. : Typical Cross Section for the RockFall Mitigation Works.

The IRC Highway Research Board Special Report 23, State of the Art, Design and construction of rockfall mitigation system Table 6.1 (Page 107), has recommended the depth and spacing of rock bolting and the same has been adopted. The rock bolt on the slope surface shall be made of Fe 500 grade steel of 25 mm diameter and up to depth of 1.5m along with the rockfall netting. The rock bolt shall have a tensile capacity of 220 kN. The spacing of the rock bolts required is 4.0 m c/c in vertical direction and 1.0 m c/c in horizontal direction. The location of the rock bolts at 1.0 m in horizontal direction should be such that the diagonals connecting the rock bolts from every 2.0 m horizontal interval pass through the rock bolts at 1.0 m. The rock bolts shall stitch the surface rock to the stable rock mass behind. (Figure 4)

The spacing and length requirement for certain locations of site were varied based on local conditions, especially where there is lot of unevenness in rock surface and also overhang at the top for some stretches. In such areas additional rock bolt installation were required to make the mesh adhere to rock surface.

On the surface, the rockfall netting were installed which provided stability against any local failures which may happen between the installed rock bolts. Rockfall netting comprised of double-twisted wire mesh with top, bottom, edge, and diagonal rope. The double-twisted wire mesh with the rope cable at edges and diagonals work as a composite shall effectively contain smaller and medium size particles on the slope surface. For severe areas with overhangs, rhomboidal wire rope panel needs to be provided to effectively take up load coming from any big-sized boulders. The depth of the rock bolts for the overhang portions were kept at 7m. (Figure 5)

Fig. 4 : Installation of Anchors on the slope.

Fig. 5 : Installation of RockFall nets of Double Twist Mesh on the slope.

The system consisting of rock bolting, rockfall netting, and cable wire rope at edges, top, bottom, and diagonals shall be provided at all locations except the severe areas with overhangs.

Only for the severe areas with overhangs the rock bolting, rockfall netting, and rhomboidal wire rope panel were to be provided. (Figure 6)

A Rockfall Protection Embankment was recommended at the toe of the slope. The rockfall protection embankment consisted of a 3 m high toe gabion wall with a vertical face towards the road and a trapezoidal section towards the cutting. This trench formed by the trapezoidal section towards the slope cutting shall also act as a rock trap ditch for any debris that may slides along the nettings.

The anchors were tested if they achieved the theoretical pull out capacities by doing filed pull testing on the installed anchors. (Figure 7)

Fig. 6 : View of the installed nets on the slope.

Fig. 7 : View of the completed work.

PERFORMANCE POST CONSTRUCTION

The work was completed in 2022. The site was visited again after an year of installation of the system. The nets were in position and performing as anticipated. Some stones did move but were entrapped within the nets. (Figure 8)

CONCLUSIONS

Safety of the users of the roads is of primary importance. Rock slope cut by blasting pose threat to the users of the roads. A case study is presented highlighting the design and implementation of suitable rockfall mitigation system that can minimize the threat to human life and resources. The details of the system consisting of rock bolting, rockfall netting, and cable wire rope at edges, top, bottom, and diagonals are detailed.

Fig. 8 : Site photos after one rain with stones entrapped in the nets

CALENDER OF UPCOMING EVENTS

Sl. No.	Event Name	Place	Date
1	TC-Barriers Webinar By Prof. Kerry Rowe: The Influence of Thickness Reduction and Squeeze-Out on Std-Oit Loss And Stress Crack Resistance of Hdpe Geomembrane Fusion	Virtual	Aug 29, 2023
2	Repeat Tc-Barriers Webinar By Prof. Kerry Rowe: The Influence of Thickness Reduction and Squeeze-Out On Std-Oit Loss and Stress Crack Resistance of Hdpe Geomembrane Fusion Seams	Virtual	Aug 30, 2023
3	12th International Conference on Geosynthetics: 12 ICG	Rome, Italy	September 17-21, 2023

PROTECTION & LINING OF RAIN WATER HARVEST RESERVOIR WITH GEOSYNTHETIC PRODUCTS AT GUMMUDIPOONDI, TAMIL NADU

Deeraj Kumar Reddy[1] and Sudhakar M[1]

ABSTRACT

Suryadev Alloys and Power Pvt. Ltd. planned to develop and harvest the rain water by creating a raw water reservoir at Gummudipoondi, Tamilnadu. The project aimed to prevent water loss due to seepage and to protect the slopes of the reservoir. To achieve this objective, a impermeable lining system with protective layers to the impermeable layer was designed and implemented on the entire surface area of the reservoir. The protection layer to the HDPE geomembrane impermeable lining system was sandwiched layers of non-woven geotextile layer, followed by a cement mortar layer, and a geocell layer filled with concrete. The anchoring mechanism for the lining system was also designed, which included an anchor trench and J-Hook made of MS bars. The lining system provided effective protection against seepage and ensured the durability of the reservoir.

INTRODUCTION

Water is a valuable resource that is essential for various industries, including power generation. Suryadev Alloys and Power Pvt. Ltd. recognized the importance of water and planned to develop a raw water reservoir in Gummudipoondi, Tamil Nadu to harvest the rainwater instead of allowing it to be wasted. The reservoir was designed to have outer dimensions of 73m x 90m and the dimensions of the reservoir bed of 66.5m x 49.5m with a 1V:1.5H slope angle. The finished bed level of the reservoir was -6.8m, and the finished crest level of the reservoir was -0.3m with a 2m horizontal berm at -3.8m level. The slopes of the reservoir were planned to be protected with precast RCC toe walls of total height 0.5m at the crest, berm, and the bed all along the slopes of the reservoir. The inner surface of the raw water reservoir was planned to be lined to prevent water loss due to seepage and provide suitable protection layers for the lining system.

RESERVOIR LINING SYSTEM

The lining system consisted of five layers: a non-woven geotextile layer, a HDPE geomembrane, another layer of non-woven geotextile layer, a cement mortar layer, and a geocell layer filled with concrete. (Figure 1)

The first layer was a non-woven geotextile layer, which acted as a protection layer for the subsequent HDPE Geomembrane lining system. The thick geotextile layer helped in reducing the potential for punctures or tears in the geomembrane layer due to any unevenness in the prepared soil base surface.

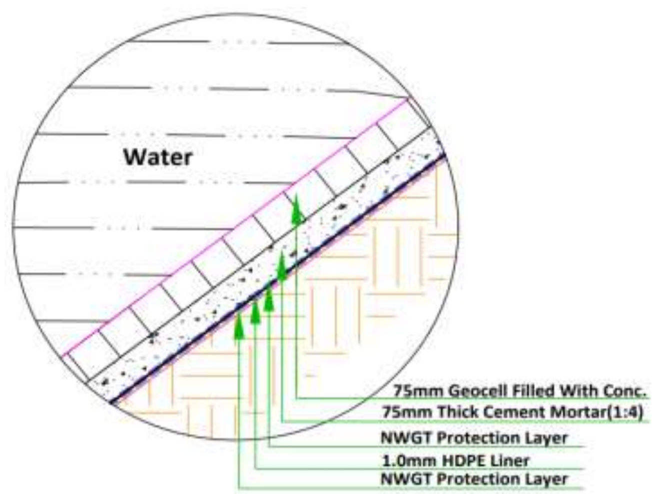

Fig. 1 : Components of Reservoir Lining System

The second layer was a HDPE geomembrane layer, which acted as a primary barrier to prevent water from seeping through the lining system. The HDPE geomembrane had excellent chemical resistance, tensile strength, and durability, making it ideal for the project's requirements. The geomembrane layer was also resistant to UV radiation, which helped to increase its longevity.

The third layer was another non-woven geotextile layer, which provided additional protection to the geomembrane layer. This layer helped to distribute the load uniformly over the geomembrane layer and prevented punctures or tears in the geomembrane layer due to any localised loads.

1. TechFab India Industries Limited

The fourth layer was a 75mm thick cement mortar layer with a 1:4 mix proportion. This layer provided an additional barrier against water seepage and helped to protect the geomembrane layer from any damage during backfilling operations.

The fifth and final layer was a geocell layer filled with M 15 Grade concrete. The geocell layer provided additional structural stability to the lining system and helped to reinforce the concrete lining and preventing the cracking and failure of the lining surface. The concrete-filled geocell layer also provided additional protection to the geomembrane.

All the geosynthetic layers i.e non-woven geotextile, geomembrane and the geocell layers were anchored inside an anchor trench at the crest of the slope. An 8mm MS bar was made to J-Hook of 200mm deep which was used to anchor these geosynthetic layers into the soil within the anchor trench as shown in Fig 2.

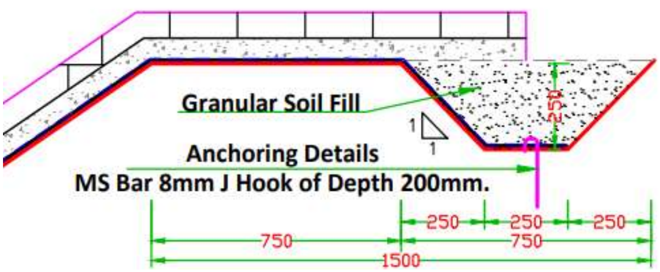

Fig. 2 : Typical detail of crest anchor trench.

The lining system had several advantages, such as:

(a) Preventing water loss due to seepage

(b) Providing protection to the soil and preventing erosion

(c) Reducing maintenance and repair costs

(d) Increasing the longevity of the reservoir

CONSTRUCTION METHODOLOGY ADOPTED AT SITE

For the aforementioned raw water reservoir lining system, following construction methodology was adopted at site:

1. *Excavation* : A reservoir was created by excavation. The site was identified such the rain water could flow into the reservoir by gravity. (Fig. 3)

2. *Site preparation* : The site is prepared by clearing and levelling the ground where the reservoir is to be built. Any debris, rocks, or vegetation is removed from the site, and the ground is compacted to achieve a stable surface with slope angle of 1V:2H.

Fig. 3 : Excavation to create a reservoir

3. *Anchor trench excavation* : An anchor trench is excavated along the crest of the slope where the lining system is to be installed. The trench is excavated to a depth of 250mm and a bottom width of 250mm. The soil within the trench is compacted to achieve a stable slope.

4. *Installation of non-woven geotextile layer*: The first layer of non-woven geotextile is laid over the compacted soil on the slope and reservoir bed. The geotextile is laid in such a way that it extends up the slope and over the crest, providing a protection layer for the underlying layers. (Fig. 4)

Fig. 4 : First later of geotextile laid over the prepared surface

5. *Installation of HDPE geomembrane layer* : The HDPE geomembrane layer is laid over the non-woven geotextile layer. The geomembrane is unrolled and stretched out along the anchor trench, ensuring that it is free from any wrinkles or folds. The adjacent rolls of the geomembrane were welded together using specialized welding equipment. (Fig. 5)

6. *Installation of second non-woven geotextile layer*: The second layer of non-woven geotextile is laid over the HDPE geomembrane layer. The geotextile is laid in such a way that it extends up the slope and over the crest, providing additional protection to the geomembrane layer. (Fig. 6)

Fig. 5 : Installed geomembrane layer on the surface of reservoir

Fig. 6 : Installation of second layer of geotextile on the top of geomembrane

7. *Installation of cement mortar layer* : The cement mortar layer is applied over the second non-woven geotextile layer. The mortar is mixed to a 1:4 mix proportion and applied in a thickness of 75mm. The mortar layer is then allowed to cure for 7 days before proceeding to the next step.

8. *Installation of geocell layer filled with concrete*: The geocell layer is laid over the cured cement mortar layer. The geocell is filled with concrete, ensuring that it is compacted uniformly. The concrete-filled geocell layer is then allowed to cure for 28 days before proceeding to the next step. (Fig. 7)

9. *Anchoring of geosynthetic layers* : The geosynthetic layers, i.e., the non-woven geotextile layer, geomembrane layer, and geocell layer, are anchored inside the anchor trench using an 8mm MS bar made to a J-Hook of 200mm deep. The bar is anchored into

Fig. 7 : Filling of concrete on the installed geocell layer

the soil within the anchor trench, ensuring that the geosynthetic layers are held securely in place.

10. *Backfilling* : The backfilling operation is carried out by placing soil over the completed lining system. The soil is compacted in layers to achieve a stable and level surface.

11. *Quality control* : Quality control checks are carried out at various stages of the construction process to ensure that the lining system is built to the required specifications. Tests such as leak detection, pull-out tests, and thickness measurements are carried out to ensure that the lining system meets the required standards.

Fig. 8 : Finished raw water reservoir lining

By following this construction methodology, a robust and durable lining system has been constructed that provides long-term protection against water seepage and ensures the structural stability of the reservoir

OUTCOMES OF THE PROJECT

After the successful completion of the lining system installation, the raw water reservoir was filled with water and kept under observation. The seepage rate was measured for several days and found to be negligible. The lining system proved to be effective in preventing water loss due to seepage. The toe walls also proved to be efficient in protecting the slopes of the reservoir.

The project team conducted a final inspection of the raw water reservoir and found that the lining system and toe walls were intact and free from any defects. The reservoir was able to store water as per the desired capacity and there were no signs of any leaks or seepage. The project was completed within the scheduled time frame and budget.

CONCLUSION

The lining system and toe walls were essential components in the construction of the raw water reservoir. The lining system was able to prevent water loss due to seepage, which is crucial for the success of any reservoir project. The geotextile layer provided a protective barrier, while the geomembrane layer acted as the main barrier to prevent water from penetrating through the soil. The cement mortar layer and geocell filled with concrete provided additional support and protection to the geomembrane layer.

The toe walls played a critical role in protecting the slopes of the reservoir from erosion and maintaining their stability. The anchor trench and J-hook anchoring mechanism used to secure the lining system to the toe walls ensured its stability and effectiveness.

Overall, the lining system proved to be a successful solution in ensuring the effectiveness and longevity of the raw water reservoir at Gummudipoondi, Tamilnadu. This project can serve as a model for future reservoir projects, demonstrating the importance of proper lining systems in ensuring their success.

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Workshop on
GEOSYNTHETICS FOR INFRASTRUCTURE DEVELOPMENT

19-20 April 2023, New Delhi

(L-R) Shri K.K. Singh, Director (WR), CBIP; Dr. G.V. Rao, Visiting Professor, IIT, Gandhinagar; Dr. R. Chitra, Vice President, IGS (India) and Director, CSMRS; Dr. G.L. Sivakumar Babu, Professor, IISC Bangalore and Shri A.K. Dinkar, Secretary, CBIP during inaugural session

Geosynthetics are one of the most important materials in infrastructure construction today. This covers everything from natural fibers to polymer geomembranes. Internationally these materials play a major role in soil stabilization, landfill construction and landslide prevention, rock protection and soil erosion. Today the use of geosynthetics is increasingly being accepted as construction material in different fields of civil engineering not only in developed countries but also in the developing countries like ours. 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 anywhere close to recognitions. This is due to limited awareness of the utilities of this material and development taking place in its use.

Shri A.K. Dinkar, Secretary, CBIP & Secretary General, IGS (India), delivering Welcome Address

India is a fast developing economy requiring large scale infrastructures. Liberalization of economy has further facilitated planning and execution of many large scale

Dr. G.V. Rao, Visiting Professor, IIT, Gandhinagar, delivering keynote address

Dr. G.L. Sivakumar Babu, Professor, IISC Bangalore, addressing the participants during inaugural session

Dr. R. Chitra, Vice President, IGS (India) and Director, CSMRS, addressing the participants during inaugural session

Shri Vivek Kapadia, President, IGS (India), & Vice President CBIP & Director, SSNNL, addressing the participants during inaugural session (virtual mode)

Shri K.K. Singh, Director, CBIP & Treasurer IGS (India), proposing Vote of thanks

Shri Vishan Dutt, Chief Manager, CBIP, Master of Ceremony infrastructures in the field of roads, railways, power, water resources, land filling and other areas, which will further promote applications of Geosynthetics for civil engineering works. There is a need to enhance the awareness of this useful and versatile material amongst the various user agencies, engaged in infrastructure development.

Keeping in view the importance of the subject, The Indian Chapter of International Geosynthetics Society jointly with Central Board of Irrigation & Power, had organized Workshop on "Geosynthetics for Infrastructure Development" 19-20 April 2023, New Delhi at Conference Hall of CBIP, New Delhi. It was attended by about 40+ delegates from 13 organizations including Govt. & Pvt. Sector organizations, Research Labs & Manufacturers, etc.

The Workshop started on the 19 April 2023, with the inaugural session.

Shri Sudhakar M, Sector Head (Mining + Rockfall), TechFab India Industries Ltd., making presentation during technical session

INAUGURAL SESSION

Esteemed guests graced the inaugural session were:

- Shri Vivek Kapadia, President, IGS (India), & Vice President CBIP & Director, SSNNL – Addressed online
- Dr. R. Chitra, Vice President, IGS (India) and Director, CSMRS
- Dr. G.V. Rao, Visiting Professor, IIT, Gandhinagar
- Dr. G.L. Sivakumar Babu, Professor, IISC Bangalore
- Shri A.K. Dinkar, Secretary, Central Board of Irrigation and Power & Secretary General, IGS
- Shri K.K. Singh, Director, Central Board of Irrigation and Power & Treasurer IGS

Shri A.K. Dinkar delivered the welcome Address. He welcomed the dignitaries and the experts present on and off the dais. He briefed the gathering about the various activities of the IGS & CBIP.

The dignitaries on the dais and virtual Shri Vivek Kapadia, President, IGS (India) & Vice President CBIP & Director, Dr. R. Chitra, Vice President, IGS (India) and Director, CSMRS, Dr. G.V. Rao, Visiting Professor, IIT, Gandhinagar and Dr. G.L. Sivakumar Babu, Professor, IISC Bangalore addressed the audience one by one and highlighted the importance of the subject in present days.

The inaugural session was concluded with a Vote of thanks, proposed by Shri K.K. Singh, Director, CBIP. He expressed sincere gratitude to Dr. R. Chitra, Vice President, IGS (India) and Director, CSMRS, Dr. G.V. Rao, Visiting Professor, IIT, Gandhinagar, and Dr. G.L. Sivakumar Babu, Professor, IISC Bangalore for gracing the dais during inaugural session. He also expressed his special thanks to Shri Vivek Kapadia, President, IGS (India), Vice President CBIP & Director, SSNNL for addressing the participants through online mode during the inaugural session. He also conveyed his thanks to all the speakers, invitees and participants for joining this Workshop.

View of the audiance

TECHNICAL SESSIONS

There were Seven Technical Sessions conducted over two days. A total of 15 technical presentations were made by the following eminent experts on the subject:

1. Road Pavements - *Dr. G.V. Rao, Visiting Professor, IIT Gandhinagar*
2. RockFall Mitigation works for a newly formed road by cutting into Hard Rock- *TechFab India Industries Ltd.*
3. Railways - *Dr. G.V. Rao, Visiting Professor, IIT Gandhinagar*
4. Protection & Lining of Rain Water Harvest Reservoir with Geosynthetic products at Gummudipoondi, Tamil Nadu- *TechFab India Industries Ltd.*
5. The use of non-woven geotextile for formation and separation in railway formation- A case study - *Suntech Geotextile Pvt. Ltd.*
6. Ground Improvement - *Dr. G.L. Sivakumar Babu, Professor IISC Bangalore*
7. Reinforced Earthwalls - *Dr. G.L. Sivakumar Babu, Professor, IISC Bangalore*
8. Coastal and River Bank Protection- *Mrs. Dola Roychowdhury, Founder Director, Gcube Consulting Engineers LLP*
9. Geosynthetics in River Erosion Control – Case Studies- *Dr. R. Chitra, Director, CSMRS and Dr. Manish Gupta*
10. HDPE Geomembrane for Commercial Water Reservoirs- Case Study- *Megaplast India Pvt. Ltd.*
11. Geomembranes and Hydraulic Applications – *Mr. Jagadeesan Subramanian, Business Unit Manager, Carpi India Waterproofing Specialist*
12. Rehabilitation of Ageing Masonry Dams : Application of flexible PVC geomembranes for improving the water tightness and increasing the service life of the dam - *Carpi India Waterproofing Specialist*
13. Reinforced Application - *Mr. Saurabh Dhananjay Vyas, Head-Technical Services, Techfab (India) Industries Ltd.*
14. Geo membrane treatment upon hydraulic structure – *Dr. S. Christian Johnson, Professor, Erode Sengunthar Engineering College*
15. Presentation by *Dr. Satendra Mittal, Prof, IIT, Roorkee*

All the presentations were much focused, technical and to the point. Almost all aspects of the subject wokshop and allied topics deliberated during this workshop. The presenters made every effort to make it easy for the participants to grasp the subject. Further clarity was enabled by the Q&A opportunity in each session.

The workshop was closed with Vote of thanks to all the eminent experts, Speakers and participants and one and all associated for the success and usefulness of this Workshop.

Group Photograph

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.

IGS CHAPTERS

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.

MEMBERSHIP

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.

IGS Offers the following categories of membership:

Individual

Individual member benefits are extended to each and every individual member of the IGS including Chapter Members. Additional chapter benefits are provided to Individual Members who join the IGS through a chapter.

Individual Member Benefits include:

- a membership card
- an IGS lapel pin
- on-line access to the *IGS Membership Directory*
- the IGS News, Newsletter, published three times a year
- on-line access to the 19 IGS Mini Lecture Series for the use of the membership
- information on test methods and standards
- discount rates:
    - for any document published in the future by IGS
    - at all international, regional or national conferences organized by the IGS or under its auspices

- preferential treatment at conferences organized by the IGS or under its auspices
- possibility of being granted an IGS award
- Free access to the *Geosynthetics International* journal, now published electronically.
- Free access to the *Geotextiles and Geomembranes* journal, now published electronically.

Corporate

Corporate Membership Benefits include:

- a membership card
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- the IGS News newsletter, published three times a year
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- **advertisement in the *IGS Member Directory* and on the IGS Website**
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- **Company Profile in the IGS News**
- **right of using the IGS logo at exhibitions and in promotional literature**
- **priority (by seniority of membership within the IGS) at all exhibits organized by the IGS or under its "auspices"**
- **opportunity to join IGS committees in order to discuss topics of common interest.**

Student

Student Membership Benefits include:

- Electronic access to the IGS News, published 3 times a year
- Special Student discounts at all IGS sponsored/supported conferences, seminars etc.
- Listing in a special student members category in the IGS Directory
- Eligibility for awards (and in particular the IGS Young Member Award).

List of IGS Chapters

Algeria
Algerian Chapter 2018)
ZahirDjidjeli
https://jstgsba.wixsite.com/asag

Argentina
Argentinean Chapter 2009
Dr. Marcos Montoro
marcos_montoro@yahoo.com.ar

Australia and New Zealand
Australasian Chapter 2002
Mr. Graham Fairhead
gfairhead@fabtech.com.au

Austria
Austrian Chapter 2016
Prof. Heinz Brandl
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Belgium
Belgian Chapter 2001
Mr. Noel Huybrechts
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info@bgsvzw.be

Brazil
Brazilian Chapter 1997
Mr. Victor Educardo Pimentel
igsbrasil@igsbrasil.org.br

Chile
Chilean Chapter 2006
Mr. Francisco Pizarro
castillofernando072@gmail.com

China
Chinese Chapter 1990
Prof. Chao Xu
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Chinese Taipei
Chinese Taipei Chapter of the IGS
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Cga18241543@gmail.com

Colombia
Colombian Chapter 2013
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Czech Republic
Czech Chapter 2003
Mr. ZikmundRakowski
president@igs.cz

Egypt
Egyptian Chapter (2018)
Prof. FatmaElzahraaAlyBaligh
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Finland
Finish Chapter 2011
Mr. MinnaLeppänen
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France
French Chapter 1993
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Germany
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Ghana
Ghana Chapter 2012
Prof. Samuel I.K. Ampadu
skampadu.coe@knust.edu.gh
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Greece
HGS, Greek Chapter 2005
Mr. Anastasios KOLLIOS
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Honduras
Honduran Chapter – Hon-duran Society of Geosynthetics 2013
MSc. Ing. Mr. Danilo Sierra D.
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India
Indian Chapter 1988
Mr. Vivek P. Kapadia
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Indonesia
INA-IGS, the Indonesian Chapter 1992
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Iran
Iranian Chapter 2013
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AGI-IGS, the Italian Chapter 1992
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Japan
Japanese Chapter 1985
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Kazakhstan
Kazakhstanian Chapter 2012
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Korea
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Malaysia
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Mexico
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Dr. Rosember Reyes Ramirez
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Morocco
Morocco Chapter 2014
Mr. HoussineEjjaaouani
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Netherlands
Netherlands Chapter 1992
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North America
North American Geosynthetics Society (NAGS)
(Canada, USA) 1986
Dr. Richard Brachman
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Norway
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Pakistan
Pakistanian Chapter of IGS 2011
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Panama
Panama Chapter 2014
Mr. Amador Hassell
amador.hassell@utp.ac.pa

Peru
Peruvian Chapter 2001
Mr. Jorge Zegaree Pellanne
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Philippines
Philippine Chapter 2007
Mr. Mark Morales
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Poland
Polish Chapter 2008
Mr. Jakub Bryk
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Portugal
Portuguese Chapter 2003
Mr. Jose Luis Machado do Vale
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Romania
Romanian Chapter 1996
Mr. Laurentiu Marculescu
adiol@utcb.ro

Russia
Russian Chapter of IGS (RCIGS) 2008
Dr. Andrei Petriaev
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Slovakia
Slovakian Chapter of IGS 2011
Dr. Radovan Baslik
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South Africa
South African Chapter 1995
Mr. Johann Le Roux
secretary@gigsa.org

Spain
Spanish Chapter 1999
Mr. Angel LeiroLópez
pabad@cetco.es
aleiro@cedex.es

Switzerland
Swiss Chapter (2018)
Mr. ImadLifa
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Thailand
Thai Chapter 2002
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Turkey
Turkish Chapter 2001
Dr. Ayse Edincliler Baykal
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United Kingdom
U.K. Chapter 1987
Mr. Andrew Belton
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Vietnam
Vietnam Chapter (VCIGS) 2013
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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.

Executive Board of Indian Chapter of IGS 2020-2022

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.

The present Executive Board is as under:

President

- **Mr. Vivek P. Kapadia,** *Secretary to Government of Gujarat and Director*, SSNNL

Vice-Presidents

- **Dr. R. Chitra,** *Director,* Central Soil & Materials Research Station
- **Dr. Jimmy Thomas,** Geotechnical Consultant

Immediate Past President

- **Mr. M. Venkataraman,** *Chief Executive Officer,* Geosynthetics Technology Advisory Services LLP and Guest Professor, Department of Civil Engineering IIT Gandhinagar

Hon. Members

- **Dr. G.V. Rao,** *Former Professor,* Department of Civil Engineering, IIT Delhi and Guest Professor, Department of Civil Engineering, IIT Gandhinagar
- **Dr. K. Rajagopal,** *Professor,* Department of Civil Engineering IIT Madras

Member Secretary

- **Mr. A.K. Dinkar,** *Secretary,* Central Board of Irrigation & Power

Treasurer

- **Mr. K.K. Singh**, *Director (WR),* Central Board of Irrigation & Power

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

IGS COLOMBIA HOSTS GEOSYNTHETIC REINFORCEMENT TALK

IGS Ambassador Patricia Guerra-Escobar visited Bogotá recently to speak to members of IGS Colombia in the latest of their busy activities program.

Ms Guerra-Escobar, who is an IGS Council Member and chair of IGS UK, spoke on ‘Reinforced load transfer platform on piles using high strength geosynthetic’, at the event last month. Her talk was part of the chapter’s ‘IV International Course of Exploration, Characterization and Soil Improvement’ course.

Some 315 students, engineers and geotechnicians attended the program, which is staged every two years in Bogotá by the Colombian Society of Geotechnics (SCG). This year it was in collaboration with the National University of Bogotá.

Ms Guerra-Escobar’s participation was the latest in a series of activities hosted by a revived IGS Colombia chapter, which in 2019 began efforts to boost its initiatives, including improving training, increasing events, and devising new strategies for academic work, and standardization and regulation.

Previous events have included a course led by Professor Richard Bathurst, also an IGS Ambassador, on ‘Reinforced soil walls – design and performance’, in Cartagena in November, last year, and the first in-person IGS Educate the Educators (EtE) event for the Latin America region since the pandemic, in Bogotá in July, last year.

Francisco Pizarro, chair of the IGS Pan-American Regional Activities Committee, said: “We were delighted to welcome Patricia to speak. The course was part of a series of actions focused on strengthening our synergies with geotechnical societies in each country. It is one of the strategic aims of the IGS to help achieve a high level of dissemination between sister societies.”

Chapter President Mario Ramirez added: “It is very important to emphasize the importance of disseminating knowledge and good practices of the systems and technologies that include geosynthetics so we can achieve the best outcomes for Colombia’s infrastructure.”

JOB SHADOW PROGRAM LAUNCH FOR IGS MOROCCO

Three talented students from the National School of Mines of Rabat (ENSMR) got a taste of working life thanks to the IGS Job Shadowing Program.

The Program, funded by the IGS Foundation, launched in September 2022 as a means to give the next generation of engineers real world experience in a geosynthetics environment while offering companies access to fresh talent. With funding support from the Foundation, IGS Morocco was the latest Chapter to facilitate the scheme.

Second year engineering students Diae Saffi, Aichatou Dadoune and Ahmed Zarough, were hosted by Afitexinov Geosynthetics. It began with an introduction to geosynthetics followed by a site visit to a mechanically stabilized earth (MSE) retaining wall in Rabat.

Hamza Mridakh, senior committee member at IGS Morocco and assistant professor at ENSMR, said: “We started the day in the ENSMR classroom with a general overview presentation on geosynthetics, their application, benefits and some design tips. The students were also able to look through a product samplebook to bring the presentation to life.

"We then took a field trip to a project near Rabat to examine some construction aspects of an MSE wall. It was the students' first field trip so it was a unique opportunity for them to experience a new side in geotechnical engineering application, in addition to building their professional network for future opportunities.

"As chairman for the IGS Young Members Committee for the Africa and Middle East region, it was incredibly rewarding to see these students make the most of this opportunity, and our thanks must go to the IGS Foundation for providing funding support to help make it happen."

Student Diae said: "This invaluable experience provided me with practical insights into geosynthetic applications in my field. As a future geotechnical engineer I am confident that geosynthetics will play a significant role in my work."

Fellow undergraduate Aichatou said: "Job shadowing is an amazing opportunity to better understand geosynthetics and build your network. This experience has inspired me to do more research on geosynthetics so I can use them in the future."

Youness Bessam, Afitexinov Geosynthetics' chief technical and business development manager for Morocco, said the IGS Job Shadowing Program was a unique opportunity for the company to share their expertise.

He added: "We are keen to have more students visit us as part of the IGS Job Shadowing Program, to contribute to the development of geosynthetics applications in Africa. We will also invite Ahmed, Diae and Aichatou to return for a separate additional field visit in the future so they can continue to develop their knowledge on the use of geosynthetics."

SECOND CALL FOR YOUNG MEMBER 12TH ICG TRAVEL GRANT LAUNCHED!

igs Young Members | XII ICG

The IGS Young Members in collaboration with the IGS Foundation (IGSF) has launched a second call for Young Members to apply for the travel grant to attend the prestigious 12th International Conference on Geosynthetics (ICG).

Four engineers whose travel expenses (flight/train/bus) are expected to exceed $500 will receive up to $500 to assist with their attendance. The deadline to apply for the second call is the 31st of July.

The flagship 12th ICG takes place on September 17-21, this year, at the Auditorium Parco Della Musica in Rome, Italy. The conference, themed 'Geosynthetics: leading the way to a resilient planet', promises a fascinating program of lectures, technical sessions, short courses and a social program. Plus, delegates will hear the renowned Giroud Lecture, this time given by Ennio M. Palmeira, Professor of Civil Engineering at the University of Brasília and a Member of the Brazilian Academy of Sciences.

Young Members will also benefit from their own social and networking events including testing their knowledge at a fun Geosynthetics Quiz and the IGS Young Members Contest.

Young Members Committee chair Dawie Marx said: "Travel to Italy is exorbitant for many Young Members so we want to try and ensure young engineers have a fair chance to attend career-shaping geosynthetics events like this, regardless of location. We thank the IGSF for helping to support our important aims."

To apply, Young Members must:

- Be registered members of the IGS.
- Be a student or young professional aged 35 or under at the time of the conference.
- Have had a paper accepted for presentation at the 12th ICG

Grants will be awarded based on financial need, travel expenses and merit.

Successful applicants will be informed of their level of funding by mid-August and will be reimbursed after the conference. They must also submit a 450-word feedback report on their experience at the conference before reimbursement is processed.

To enter, submit using this Google Drive form (https://forms.gle/Q5XJ6N22tmbTdp9Z7) including:

- Proof of age
- Proof of registration to the 12th ICG
- PDF of paper being presented
- Quote or receipt for your flight ticket
- CV (no more than two pages)
- Letter of recommendation, preferably by an IGS member

Mr Marx added: "We are delighted to offer this opportunity and look forward to meeting our grant recipients and fellow members in Rome for the customary IGS YM networking dinner and the IGS Young Member Contest."

DID YOU KNOW?... GEOSYNTHETICS REMOVE MICROPLASTICS FROM TREATED WATER

Fig.1 Geotextile tubes used for capturing and further dewatering sludge for disposal in solid form

Sludge is a semi-solid slurry that can be produced from a range of industrial processes, from water treatment, wastewater treatment or on-site sanitation systems.

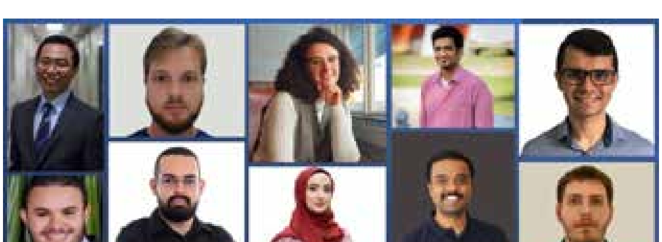
Geosynthetics are used to treat sludge, through collection, dewatering and disposal. This process filters water from the sludge, capturing and containing fine particles. In combined systems, more than 99% of microplastics can be removed.

Geosynthetic solutions should be fully investigated on every infrastructure project to ensure they meet the needs of the present without compromising the ability of future generations to meet their own needs.

FINALISTS ANNOUNCED FOR 12TH ICG YOUNG PAPER AWARD CONTEST

Young engineers shortlisted for the Best Young Member Paper prize at the 12th International Conference on Geosynthetics (ICG) have been revealed.

Ten Young Members will compete at the 12th ICG, which takes place on September 17-21 in Rome, where they will present their papers at the IGS Young Member Session on September 20. Open to all conference participants to watch, competitors will be rated on the content, style of presentation and delivery by a panel of judges.



Vinay Kumar, Matheus Pena da Silva; Bottom: José Wilson Batista da Silva, Lucas Paiva, Nesrin Omar Akel, Subramanian S., Paulo Victor de Carvalho Figueiredo

Those competing this year and their papers are:

- Viviana Mangraviti – 'Basal reinforced earth embankments on piled foundations: the role of embankment construction process'
- José Wilson Batista da Silva – 'GCL hydration by lateritic soils under isothermal conditions and simulated daily thermal cycles'
- Earl Marvin De Guzman – 'Numerical modelling of a reinforced embankment in cold regions environment'
- Subramanian S – 'Predicted performance of geogrid-stabilized unbound aggregate layers using confined soil-geosynthetic composite stiffness'
- Giovani Lombardi – 'Hyperbolic models to represent the effect of mechanical damage and abrasion on the short-term tensile response of a geocomposite'
- Lucas Paiva – 'Topology optimization of a junction in a biaxial geogrid under in-isolation tensile loading'
- V. Vinay Kumar – 'Evaluation of geosynthetic-asphalt interface characteristics using leutner shear tester'
- Matheus Pena da Silva – 'Interface shear bond analysis of different geosynthetic paving interlayers'
- Paulo Victor de Carvalho Figueiredo – 'Laboratory device to evaluate connection loads in segmental geosynthetic-reinforced soil walls'
- Nesrin Omar Akel – 'A micromechanical model of a PVC geomembrane'

As well as receiving a Best Paper certificate, the winner will get $1,000 and be featured on the IGS website. Second prize is $600 and third prize $300. The conference registration fee has also been waived for all 10 finalists.

Dawie Marx, chair of the IGS Young Members Committee said: "After a highly competitive first round of judging, with entries from 19 different countries, we have selected our top 10 competitors. Once again the topics from our young finalists are rich and varied. The audience is in for a treat at the 12th ICG where they will hear the cutting-edge work our young members are doing in the field of geosynthetics. Good luck to all of them."

IGS LAUNCHES SUSTAINABILITY BENEFITS CALCULATOR

A game-changing online tool to help compare the sustainability gains of using geosynthetics versus other materials is now live.

The IGS Sustainability Benefits Calculator offers a way to measure the environmental benefits of using geosynthetics materials in projects versus traditional materials. It uses real world scenarios that can be tailored to the user's specific enquiry and fit current industry and regulatory protocols.

Users can view some case studies and tailor them to their specific project needs, exploring the cradle-to-cradle implications. The software, provided by https://www.oneclicklca.com/ generates numerical values for the environmental impact of a design, such as the amount of CO2 that might be produced in a particular scenario. Detailed results can also be downloaded and used in presentations, bid documents and reports.

The search parameters also comply with EU regulations (other regulatory packages are available) and practices so it is a reliable tool for design engineers, site owners, regulators, government officials, contractors, as well as the wider public, to use. It will also help inform and enhance future IGS training materials, courses and educational programs.

Boyd Ramsey, of the IGS Sustainability Committee, said: "The Committee is delighted to finally see months of hard work come to fruition with this comprehensive tool for the benefit of our members, and the planet. For the first time users have at their fingertips a practical, factual way to measure the sustainability benefits of geosynthetics. It helps to demonstrate unequivocally how geosynthetics are the greener choice."

Similar to other software modelling used in the geosynthetic and engineering industry for slope and wall stabilization and other engineering calculations, these programs require user training to access the complete experience and benefits. These needs are due to be discussed within the IGS.

Users can explore the tool for free to view the case studies. However, purchase of a user license is needed if tailored calculations are required. Licenses are available for IGS members to buy at a discounted rate.

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 **c**ontribute new developments to the geosynthetics sector are encouraged. The work belonging to the fields of Geosynthetics are invited. **The journal is expected to help r**esearchers, 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 as per the following guidelines. 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.

Take margin as 1." (Left, Right, Top & Bottom) on A4 paper.

The **Title** of the paper should be in bold and in Title case .

The next item of the paper should be the author's name followed by the co-authors.

Name of the corresponding author should be highlighted by putting an asterisk, **with whom all the future correspondence shall be made.**

This should be followed by an affiliation and complete official addresses.

Providing e-mail id is must.

Please keep the title, author's name and affiliation center aligned.

Use the following font sizes:

Title: 14 point bold (Title Case), **Author's name(s):** 12-point bold, **Author's Affiliations:** 10-point normal, **Headings:** 11-point bold & caps, **Sub-headings:** 11-point normal & caps, **Body Text:** 10-point normal.

The manuscript must be in **English.**

Manuscripts are accepted on the basis that they may be edited for style and language.

Use **Times new roman** as the font.

Words used in a special context should appear between single quotation marks the first time they appear.

Lines must be double-spaced (plus one additional line between paragraphs).

Tables and figures must be included in the same file as the text in the end of the manuscript. Figures must be inserted into the document in JPEG or Tagged Image File Format (TIFF) format.

Abbreviations should be spelt out in full for the first time they appear and their abbreviated form included in brackets immediately after.

Communicating author will receive a soft copy of his/her published paper at free of cost.

Diagrams and Figures: Only black & white figures are accepted. Figures should be entered in one column (center aligned) and should not exceed 6-inch total width. A minimum line width of 1 point is required at actual size. Annotations should be in Times New Roman 12 point with only the first letter capitalized. The figure caption should be preceded by 'Figure' followed by the figure number. For example, 'Figure 10.

Photographs and illustrations: No color photographs are allowed. Image files should be optimized to the minimum possible size without compromising the quality. The figures should have a resolution of 300 dpi.

Equations: Using the appropriate editor, each equation should appear on a new line. The equations referred to in the text, should be numbered sequentially with their identifier enclosed in parenthesis, right justified. The symbols, where referred to in the text, should be italicized.

$$E = mc^2 \qquad (1)$$

References: The papers in the reference list must be cited in the text in the order in which they appear in the text. In the text, the citation should appear in square brackets "[]". References of Journals, Books and Conferences must be written as shown in the example below.

Jones B., Brown, J., and Smith J. 2005**,** The title of the book. 1st edition, Publisher.

Jones B., Brown, J., and Smith J. 2005 The title of the conference paper*. Proc Conference title* 6: 9-17.

Jones B., Brown, J., and Smith J. .2005 The title of the journal paper. *Journal Name*. 3(4): 101-121.

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**

INTERNATIONAL GEOSYNTHETICS SOCIETY (INDIA)

OBJECTIVES

- 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; and
- to improve communication and understanding regarding such products, e.g. between designers, manufacturers and users and especially between the textile and civil engineering communities.

MEMBERSHIP ELIGIBILITY

Membership is open to individuals/institutions, whose activities or interests are clearly related to the scientific, technological or practical development or use of geotextiles, geomembranes, related products and associated technologies.

Membership Categories and Subscriptions:

• Individual Members for 01 Calendar year	:	Rs. 3,000.00
• Individual Members for 05 Calendar years	:	Rs. 14,000.00
• Individual Members for 10 Calendar years	:	Rs. 26,000.00
• Institutional Membership for 01 Calendar year	:	Rs. 25,000.00
• Institutional Membership for 02 Calendar years	:	Rs. 45,000.00
• Institutional Membership for 03 Calendar years	:	Rs. 60,000.00

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