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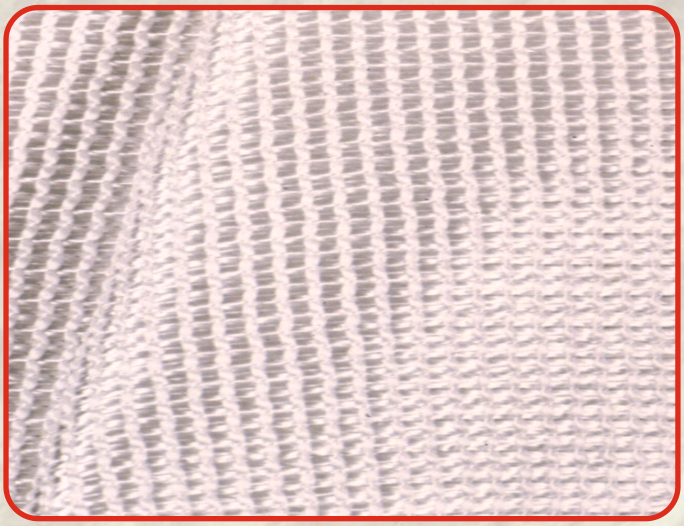
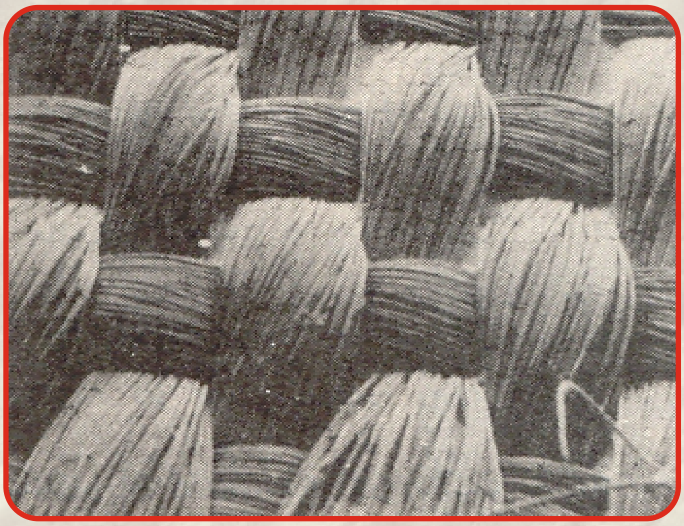
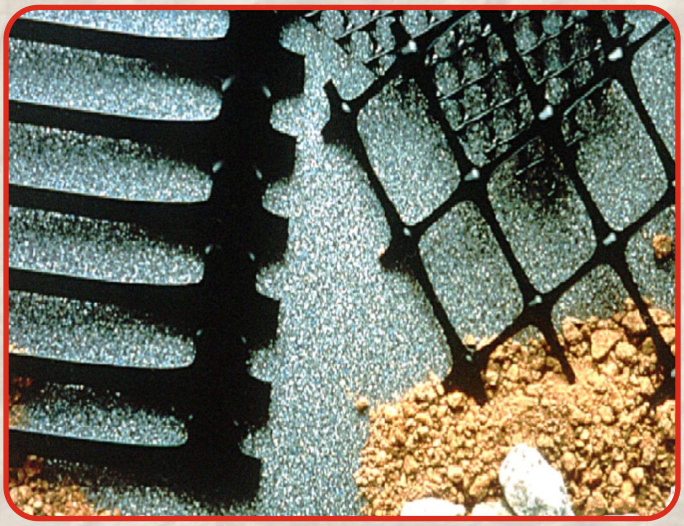
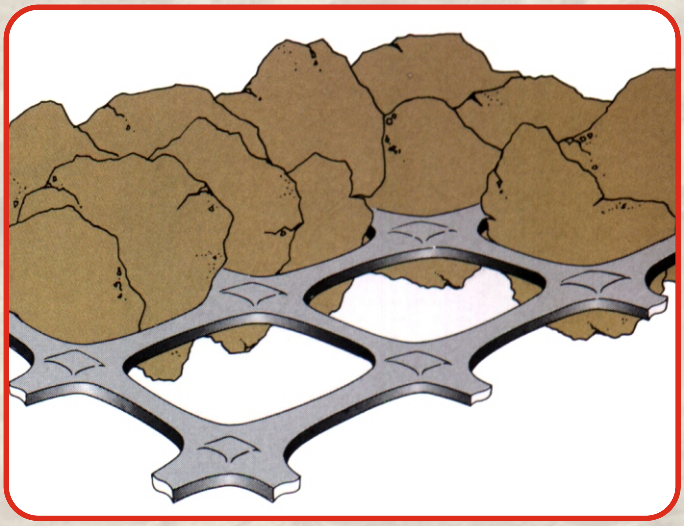
IGS INDIA

# Indian Journal of Geosynthetics and Ground Improvement

Half Yearly Technical Journal of Indian Chapter of International Geosynthetics Society

Wish you a Very Happy & Prosperous New Year 2021

## 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 The manuscripts must be unpublished and should not have been submitted for publication elsewhere.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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All communications to be addressed to :
*The Member Secretary*
Indian Chapter of IGS
CBIP Building, Malcha Marg, Chanakyapuri, New Delhi 110 021

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# FROM THE EDITOR'S DESK

First of all, I take this opportunity to wish all the members and readers a Very Happy and Prosperous New Year.

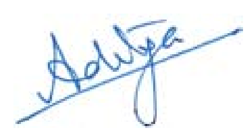
With the support of all of you, the journal has entered into 10th year of its publication, and the Nineteenth issue of the journal is now in your hands. I thank all the readers for their feedback about the journal. The feedback from all the quarters has given us the encouragement to our initiative and to bring out a quality journal.

I am very pleased to inform that Mr. Vivek P. Kapadia, Vice President of the Indian Chapter has been unanimously elected as President of the Chapter for the term 2020-2022 by the General Body in its 19th Meeting held on 15th September 2020 through Virtual Mode. I am sure under the able guidance of Mr. Vivek P. Kapadia, and re-elected/elected Vice Presidents, namely Dr. (Mrs.), R. Chitra, Scientist E, Central Soil and Materials Research Station and Dr. Jimmy Thomas, Geotechnical Consultant and the members of the Executive Board, Indian Chapter will achieve new heights in achieving its objectives of improving the communication and understanding Geosynthetics products, among the designers, manufacturers and users and especially between the textile and civil engineering communities.

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 of divergent multiple uses.

Roads built on soft and expansive soil subgrades suffer from many problems and deteriorate early. Investigation on failure of such roads reveal that one of the major causes of failure could be attributed to penetration of fine grained soils in base course of the pavement structure leading to improper drainage and loss of support. On the other hand, in the hilly areas of the country, erosion of slopes often leads to catastrophic landslides, disrupting road communication network. To overcome problems associated with soft ground and soil erosion, 'Geosynthetics', both polymeric as well as agro based variety like Jute/Coir, etc., have become an increasingly important construction material. Its use is long term cost effective and generally replaces scarce raw material resources like steel/cement/aggregates.

Considering the applications of geosynthetics in infrastructure projects, Indian Chapter is planning Online Training Courses on "Design & Construction of Pavements with Geosynthetics" and "Geosynthetics Reinforced Soil Slopes and Walls".




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

# GEOSYNTHETIC STABILIZED FLEXIBLE PAVEMENTS – A CRITICAL APPRAISAL FOR INDIAN SCENARIO

**Kolli Mohan Krishna*, Amit Prashant**, Guda Venkatappa Rao†**

** PhD Scholar, ** Professor, †Visiting Professor*

*Indian Institute of Technology Gandhinagar, India*

**ABSTRACT**

*The Guidelines of Indian Roads Congress IRC:SP:59-2019 provide the design methodology for the use of geosynthetics in flexible pavements for the first time in India. The design methodology is based on a Mechanistic-Empirical (M-E) design method and the concept of Modulus Improvement Factor (MIF) for the reinforcement effect in granular layers. The design concepts of M-E design procedure and a brief history of the mechanical stabilization of flexible pavements have been presented in this article to benefit Indian pavement engineers. A parametric analysis has been conducted using the M-E design method for different subgrade strengths to quantify the effects of stabilization of granular layers in flexible pavements. The Base Course Reduction (BCR) values attained for geogrid and geocell stabilization of the granular layer is presented. It is observed that both geogrid and geocell stabilization have resulted in considerable BCR values for all the subgrade strengths but with higher reduction attained for low subgrade strengths and higher traffic. The reductions obtained for stabilization with geocell appears to be higher due to its high MIF values, but designers need to evaluate the cost optimization possibilities for specific projects.*

**Keywords:** *Geogrid, Geocell, Glass Grid, Asphalt Interlayer Composite, Geotextile, Subgrade Stabilization, Mechanistic-Emperical Design Method, Modulus Improvement Factor, Base Course Reduction, CBR.*

## 1. INTRODUCTION

The highway infrastructure is growing rapidly in recent years in India, which has drawn closer attention of geotechnical engineers towards the design of flexible pavements. The use of mechanically stabilized granular layers around the globe from the past few decades allowed engineers to minimize the granular layer thickness and enhance the performance of pavements. With continually evolving design methods and introducing new concepts like mechanical stabilization needs a thorough background and insights over design concepts for engineers to perform flawless and practical designs. In India, IRC guidelines are followed to design the flexible pavements, and the Ministry of Road Transport and Highways (MoRTH) specifications act as construction guidelines. The recently released IRC:SP:59-2019 allowed flexible pavement designs with stabilized base and subbase courses. The potential benefit of IRC:SP:59-2019 in terms of advantages of stabilized pavements over unreinforced pavements in terms of performance and cost reduction is yet to be realized by various engineering departments concerned. This article provides insights to provide concepts in such aspects.

In this article, the design of mechanically stabilized flexible pavements is discussed in detail as per IRC:37-2018 and IRC:SP:59-2019. Potential applications of geosynthetics and a review of design methods of mechanically stabilized pavements have also been given attention. The design insights on the potential advantages of stabilization have been discussed with the parametric study data. The minimum effective subgrade CBR specified for national expressways and highways is 5% (IRC:37-2018). The possible benefits of utilizing geogrid and geocell stabilization for lower subgrade CBR is discussed. One of the challenges faced by engineers is the design of overlay for distressed pavements due to heavy rutting. Generally, engineering departments opt for bitumen overlays for all kinds of distressed pavements. Such designs may not be sufficient for pavements build on black cotton soils/soft soils, which can be heavily distressed from the subgrade level. Hence, a flow chart for designers is provided for the design approach in such conditions. Finally, specifications of geosynthetics for pavement applications as per MoRTH (2013) and BIS guidelines have been summarized.

## 2. APPLICATIONS OF GEOSYNTHETICS IN FLEXIBLE PAVEMENT

Geosynthetics of various kinds have been used for several years in flexible pavements for overall performance enhancement. The different functions in flexible pavements include filtration, drainage, reinforcement and moisture barrier. The Geosynthetic used for a particular application can perform multiple functions, which can be hydraulic, mechanical, or both as well.

Figure 1 shows the typical schematic, demonstrating the use of geosynthetics in a pavement section. Table 1 summarizes typical applications of Geosynthetics and their functional requirements for a given situation in pavement sections.

### 2.1 Hydraulic and separation functions:

The early application of Geosynthetics was as a separator in unpaved roads to prevent loss of aggregates into soft subgrade (Rankilor, 1981). The Geosynthetic fabric (Geotextiles – Woven / Non-Woven) placed at the interface of soft subgrade and granular layers also acts as a filter by preventing migration of fines into the granular layers. If provided with sufficient in-plane drainage capacity, it also acts as a drain by allowing excess pore pressures to dissipate. The filter-drainage function allows soft subgrades to gain strength through consolidation and improve with time, which is an additional advantage provided to the system. The woven geotextile provided as a separator can also act as reinforcement.

### 2.2 Mechanical functions:

The mechanical stabilization of pavements refers to the use of geosynthetic reinforcement in the granular layers or at their interfaces to enhance the mechanical response of pavement structure. It can be provided either by a Geogrid or by a Geocell or a combination thereof.

**Reinforcement:** Geosynthetics such as Geotextiles (Woven) and Geogrids (Punched-oriented or extruded Biaxial) have been used in flexible pavements as reinforcements. It is typically placed within the granular layers or at the interface of layers (base and sub-base, or sub-base and subgrade layers, or within the base or subbase layers). The primary mechanisms that contribute to enhancing mechanical performance are lateral restraint, increased bearing capacity, and tensioned membrane effect, as shown in Fig. 2 (Haliburton et al., 1981; Giroud, 1981, 1985, Holtz 1998). The granular layer stabilization results in a lateral restraint mechanism (Fig. 2a), which provides additional confinement by its frictional and interlocking interaction with granular material. The additional confinement provides enhanced modulus to the granular layers, which in turn improves the overall performance of the structure. In soft subgrades, the reinforcement forces the critical failure planes to develop along alternate planes, enhancing the bearing capacity (Fig. 2b). Reinforcement also offers lateral restraint to subgrade by its frictional interaction. The tensioned membrane effect (Fig. 2c) will come into the picture at larger deformations for unpaved roads, which improve the wheel load-carrying capacity by resisting membrane tension forces developed (Giroud, 1981, 1985). The reinforcement layer provided at the interface between sub-base and subgrade also lowers the stresses over the subgrade.

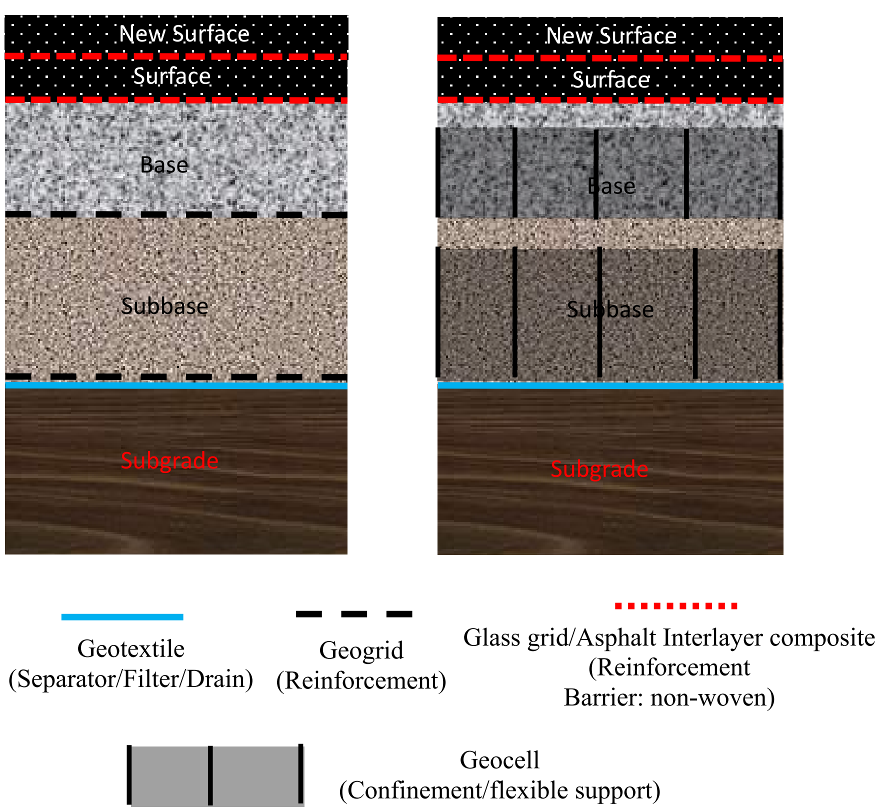



**Fig. 1** : Typical applications of Geosynthetics in Indian Flexible Pavements

Early studies conducted at the Indian Institute of Technology Delhi (Venkatappa Rao, 1996) have indicated that under triaxial testing of composite specimens as well as for unpaved pavement models, the inclusion of geosynthetics at the subgrade subbase interface reduces the permanent deformations and increases the modulus of resilience significantly. It was shown through the model studies conducted by Sheogopal (1995) using a perspex tank of 350 mm x 350 mm x 420 mm deep and subjecting the model to cyclic loading. The static loading behaviour of the models with saturated silty subgrade under a modelled WMM (100 mm or 60 mm thick) layer with a 100 mm diameter plate revealed that the inclusion of a geogrid or a geotextile over the subgrade significantly improved the load-bearing capacity. The un-reinforced models depicted a punching type of failure, whereas it was a general shear failure type for the reinforced model. On applying 3 kN cyclic load, it was found that for permanent deformation of 5 mm, the number of cycles carried by the un-reinforced, non-woven geotextile and geogrid reinforced models were 25, 55 and 80, respectively. Those values for a 10 mm permanent deformation, the number of cycles carried were 250, 400 and 1100, respectively. The Apparent Resilient Modulus also showed similar enhancement for the reinforced models up to 100 %. Similar results were obtained by Dixit (1995) for the model studies with soft kaolinitic clay as the subgrade reinforced with woven geotextile and geogrid inclusions.

In addition, Glass grid composite has been used to mitigate the propagation of cracks by sealing the asphalt layer when used in pavement overlays. The bitumen impregnated Non-Woven acts as a membrane to infiltrating water from the bitumen top. If vehicle overloading is expected, one can recommend asphalt interlayer composite at the interface of Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM) to further enhance the pavement life.

**b) 3-D Confinement Effect:** The other option to enhance the properties of granular layers is the provision of Geocells - a three-dimensional form of geosynthetic materials with interconnected cells filled with aggregates. The cells provide lateral confinement to the fill under lateral deformations (Fig. 2d) and enhance the resilient modulus of granular layers (Bathrust and Karpurapu, 1993). Geocell layers also act as stiff base to the pavement and allow only uniform settlements over soft subgrades (Al-Qadi et al., 2000; Han et al., 2008; Yang et al., 2012; Sitharaman et al., 2020).

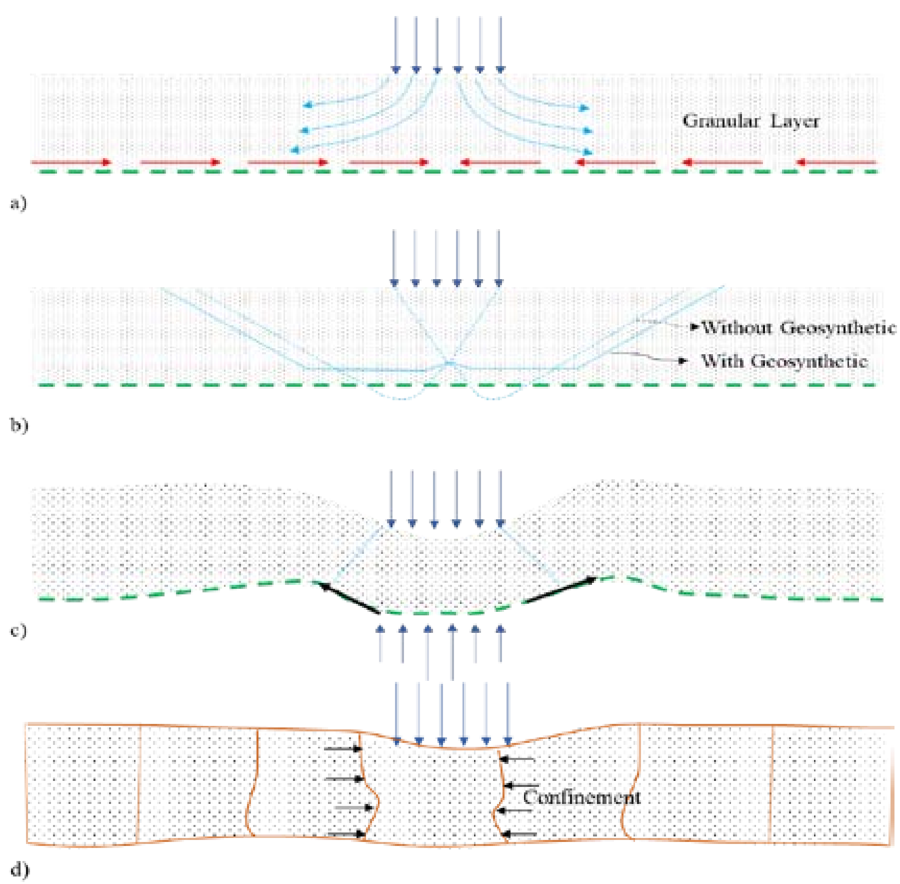



**Fig. 2** : Mechanical functions of Geosynthetic under a wheel load (a) Lateral restraint; (b) Bearing capacity improvement; (c) Membrane tension effect (Haliburton et al., 1981; Giroud, 1981, 1985); (d) 3-D confinement of geocell.

**Table 1** : Application and Associated Functions of Geosynthetics in Pavements (After Christopher, 2010)

| Application | Functions | Subgrade Strength | Qualifier |
|---|---|---|---|
| Separation | Primary: Separation<br>Secondary: Filtration | $3 \le CBR \le 8$<br>$90\ kPa \le c_u \le 240\ kPa$<br>$30\ MPa \le M_R \le 80\ MPa$ | Soils containing high fines (clayey and silty soils) |
| Stabilization | Primary: Separation, filtration and some reinforcement (especially CBR < 1)<br>Secondary: Transmission | $CBR < 3$<br>$c_u < 90\ kPa$<br>$M_R < 90\ MPa$ | Wet saturated fine-grained soils (i.e., silt, clay and organic soils) |
| Base Reinforcement | Primary: Reinforcement<br>Secondary: separation | $3 \le CBR \le 8$<br>$30\ kPa \le c_u \le 240\ kPa$<br>$10\ MPa \le M_R \le 80\ MPa$ | All subgrade conditions |
| Drainage | Primary: Transmission and filtration<br>Secondary: separation | — | Poorly draining subgrade |

$M_R$: Resilient modulus; $c_u$: Undrained shear strength; CBR: California Bearing Ratio

## 3. DESIGN METHODOLOGIES FOR MECHANICALLY STABILIZED FLEXIBLE PAVEMENTS

### 3.1 Unpaved Roads

Unpaved roads are generally low volume roads (access roads, project roads) constructed with granular layers alone without any bituminous base and surface layers. The use of Geotextiles began with unpaved road applications. The initial design procedures developed for it were based on the limit equilibrium bearing capacity theories (Barenberg et al., 1975) and Steward et al., 1978). Later, Tingle and Webster (2003) and Giroud and Han (2004) developed the solution for geogrid reinforcement. The Giroud and Han (2004) method is the most accepted design method for unpaved roads, a theoretically developed and experimentally calibrated design method. It can be utilized to analyze unreinforced and geogrid-reinforced unpaved roads.

#### 3.1.1 *Bender and Barenberg Method*

Bender and Barenberg (1978) conducted several laboratory model studies using aggregate and fabric over soft soils. They concluded that the allowable stress ($q$) on a soft soil under repeated loading could be predicted as $q = cN_c$, where c is the undrained shear strength of the soil and $N_c$ is the bearing capacity factor. Further, they developed a design curve using Boussinesq's theory. The design curve gives the thickness of the granular course required to maintain the stresses from the wheel loads to an allowable level of $cN_c$. Figure 3 shows a typical design chart developed for a wheel load of 45.4 kN.

#### 3.1.2 *U.S. Forest service Method*

Steward et al. (1978) provided a set of curves similar to Bender and Barenberg (1978) developed for single, dual, and dual tandem wheel loading over a broad range of loadings by following similar principles. A typical design chart for different single wheel loads developed for US Forest Service is shown in Fig. 4a. Figure 4b is extrapolated curve for 40 kN wheel load representing standard Indian wheel load provided by Venkatappa Rao and Suryanarayana Raju (1990).

Steward et al. (1978) recommended that 2.8 $c$ and 3.3 $c$ ($N_c$ values) are the stress level at which less rutting (less than 50 mm) with large traffic (>1000 passes of 80 kN standard axles) and deep rutting (greater than 100 mm) with less traffic (<100 passes), respectively, when no fabric is used. $N_c$ values of 5.0 $c$ and 6.0 $c$ are corresponding to the stress levels with a fabric layer. Tingle and Webster (2003) further modified the Steward et al. (1978) method and recommended using $N_c$ value of 5.8 for geogrids, which is applicable for rutting of 50mm-100mm for traffic > 1000 passes.

#### 3.1.3 *Haliburton and Barron's Method*

Haliburton and Barron (1983) proposed a design method based on laboratory observations which involve the prediction of stresses at a depth of 0.5 $B$ tanΦ or 0.33 $B$ (where $B$ is the width of the tyre footprint) using Boussineq's solution and comparing 50% of this stress with allowable bearing capacity at the top of the subgrade. If the predicted stress is greater than allowable stress, the performance of the subgrade will be unsatisfactory, and an alternative design method will be required. Haliburton and Baron (1983) also provided design charts for determining the allowable tyre pressure for a given subgrade strength and aggregate thickness.

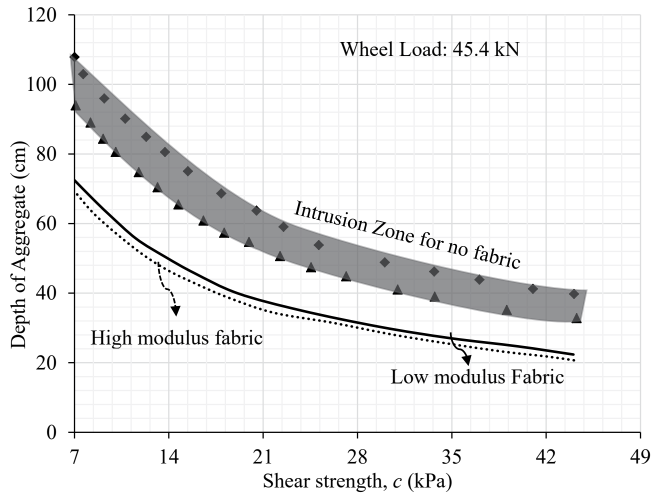



**Fig. 3** : Design chart for unpaved roads with and without geotextiles (After Bender and Barenberg, 1978)

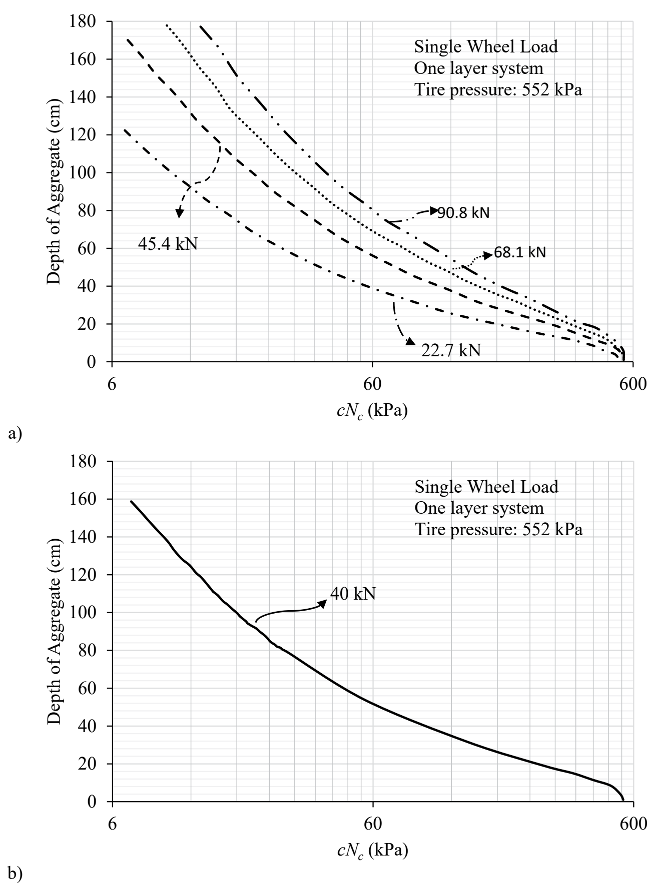



**Fig. 4** : (a) US Forest Service's design charts for unpaved roads (After Steward et al. 1978); (b) Extrapolated US Forest Service's design chart for Indian traffic loading (After Venkatappa Rao and Suryanarayana Raju, 1990)

### 3.1.4 *Giroud and Noiray (1981) Method*

Based on a semi-empirical formulation, Giroud and Noiray (1981) developed a set of design equations for determining the unpaved aggregate thickness with and without geotextile. The major assumption is that without geotextile, the maximum allowable pressure corresponds to the elastic limit of the soil, and with geotextile, the allowable pressure can be increased to the ultimate bearing capacity of subgrade. It also assumes a different load distribution angle of wheel load in case of geotextile stabilization. The reinforcement contribution is provided in the form of tension membrane support. The thickness determined by equating the stress determined from load distribution to allowable pressure gives the quasi-static thickness, i.e., thickness unaccounted with traffic. The additional thickness required for traffic effect in case of the unreinforced case can be added to obtain the thickness required with traffic effect in case of geotextile stabilization. Giroud and Noiray (1981) also provided design charts for easy utilization of the design method shown in Fig. 5 for a rut depth of 0.3 m. In the Figure, $h_o$' represents the thickness required without geotextile, and Δh represents thickness reduction attained by geotextile stabilization. Holtz (1987) later developed additional design charts using Giroud and Noiray (1981) theory for different rut depths.

### 3.1.5 *Giroud et al. (1985) Method*

The original method developed for Geotextiles was subsequently modified by Giroud et al. (1985) for geogrid stabilization by taking into account three mechanisms:

(a) Confinement of the subgrade soil;

(b) Improved load distribution; and

(c) Tensioned membrane effect.

A design chart was developed to determine the thickness reduction factor (R) on geogrid stabilization for given subgrade strength and allowable rut depth. The typical design chart for a single axle load ($P_s$) of 80 kN is shown in Fig. 6 for a rut depth (r) criterion of 75 mm and 150 mm. In Figure 6, $h_{os}$ represent the thickness required without reinforcement, $\alpha_0$ represents the load distribution angle for the unreinforced case, and the α represents the load distribution angle for the reinforced case represents. The dotted curve of SS1 in Fig. 6 is for vehicle passes (N) more than 1000 and SS2, and SS3 are for low traffic conditions, respectively. Also, SS1, SS2 and SS3 are obtained for Tensar range of geogrids (BX type). The reduction value (R) has to be obtained from Fig. 6b for given $h_{os}$ of unreinforced section and Geosynthetic type. The thickness of the reinforced section (h) is calculated by multiplying R with $h_{os}$.

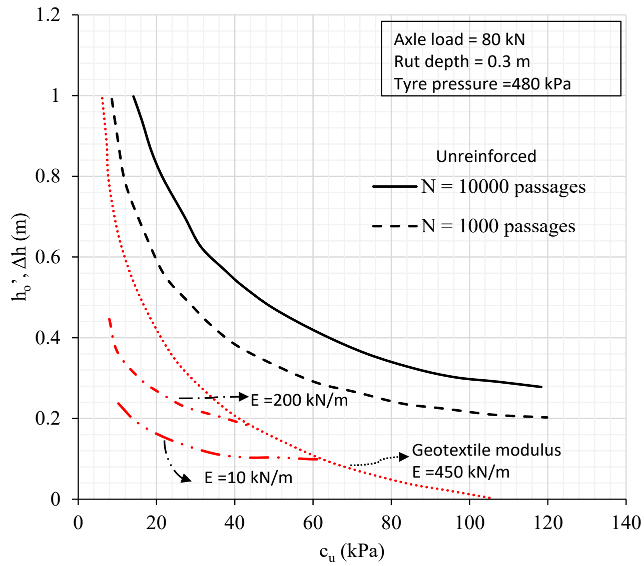



**Fig. 5** : Typical design chart for geotextile reinforced unpaved roads (After Giroud and Noiray, 1981)

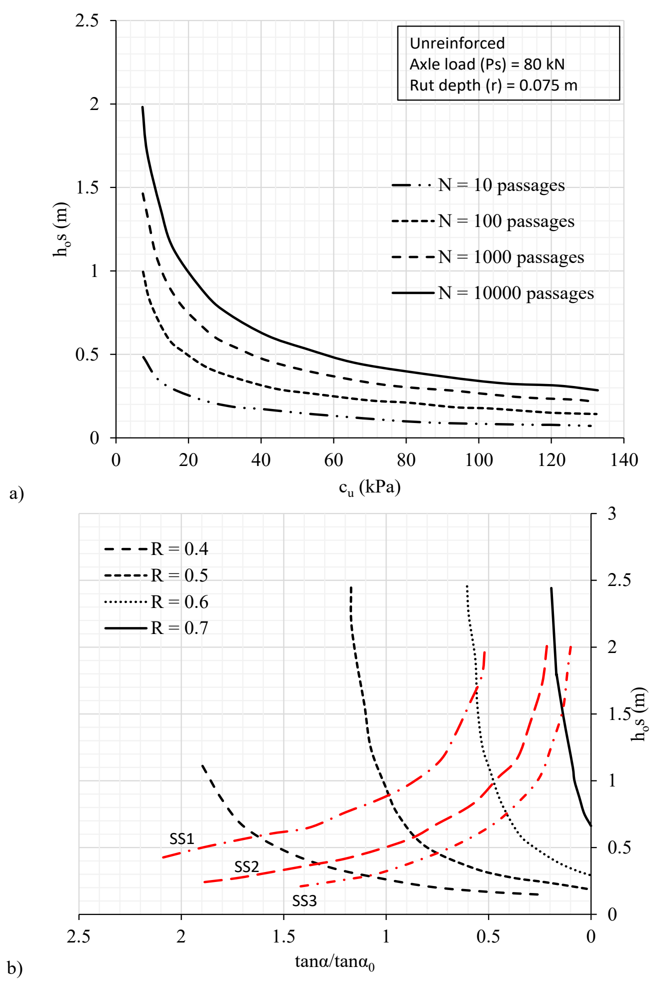



**Fig. 6** : Illustrative design charts for Geogrid reinforced unpaved roads (a) Unreinforced section thickness (b) Reduction factors for reinforced section (After Giroud and Noiray, 1985)

### 3.1.6 *Giroud and Han (2004) Method*

Giroud and Han (2004) extended the design methods proposed by Giroud and Noiray (1981) for geotextile reinforced unpaved roads and Giroud et al. (1985) for geogrid-reinforced unpaved roads. This method supersedes the earlier methods to account for physical parameters such as the ratio of resilient modulus values of subgrade and base course, in-plane aperture stability modulus of the geogrid (*J*), and interlock capability of geogrid with base layer aggregates. Uniquely, this method uses in-plane aperture stability modulus or in-plane torsional rigidity of the geogrid (J). Torsional rigidity is the resistance of a geogrid against torsion, which is related to the effectiveness against interlocking in general, and the stiffness is reported in units of N-m/degree (ASTM D7864). It is to be noted that the aperture stability modulus test of geogrids is not yet common in Indian practice.

The basic assumptions and parameters of the original theory, such as geotextile effect on failure, rut depth criteria, traffic volume, wheel loads, and tyre pressure, are also the basis for the modified method. A unique equation for determining the required aggregate layer thickness for a geogrid reinforced section was thus proposed by Giroud and Han (2004). The same equation can also be used for unreinforced and geotextile stabilized unpaved roads. The equation needs to be solved iteratively until the solution is converged. Figure 7 shows typical design charts provided for some specific cases.

## 3.2 Paved Roads

In paved roadways, reinforcement is generally used for granular layer stiffening/improvement and subgrade stabilization to enhance the overall mechanical response. For subgrade stabilization, geogrid or geotextile is used to build a construction platform over soft subgrades, and the constructed platform acts as the improved subgrade. The design of such a platform is similar to the unpaved road design. In base/subbase reinforcement application, the geogrid placed at the interface or within granular layers improves the resilient modulus of granular layers and thus enhances the dynamic load-carrying capacity of the pavement traffic loading (Holtz et al., 1998; Berg et al., 2000; AASHTO, 2001; Perkins et al., 2005a; Gabr et al., 2006). The most common and widely used design method for base stabilized flexible pavements is based on Flexible Pavement Design Methodology of AASHTO (1993). It is an empirical design method (based on extensive field trials) using the concept the concept of Structural number (SN), which is the overall structural capacity to carry a certain amount of traffic load with pre-determined serviceability limits and statistical parameters. From AASHTO (1993), the structural contribution of geosynthetic reinforcement is considered as the improved structural number of the

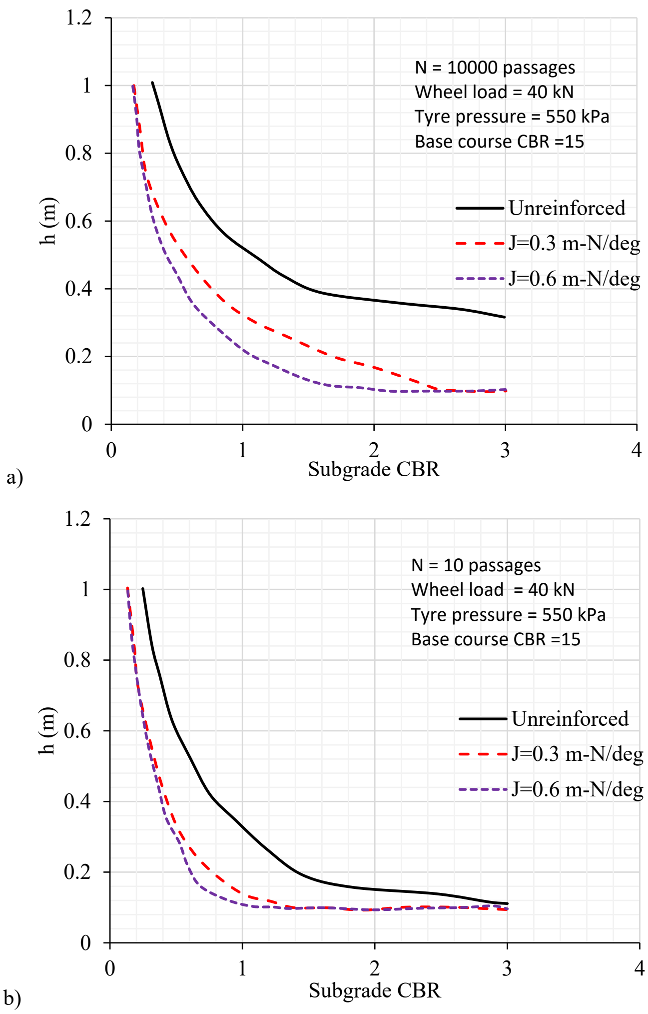



**Fig. 7** : Illustrative design charts for unpaved roads for (a) N = 10000 passages; (b) N= 10 passages (After Giroud and Han, 2004)

stabilized layer through Traffic Benefit Ratio (TBR) or Base Course Reduction (BCR). The TBR or BCR values are to be obtained from field/experimental results for a particular type of product. The recently evolving methods are more mechanics-based, referred to as mechanistic-empirical (M-E) design methods. Further details of the M-E method are given in the following sections.

### 3.2.1 *Mechanistic-Empirical (M-E) Design Approach*

In India, flexible pavements are presently designed as per the Indian Road Congress Guidelines IRC:37-2018 based on the Mechanistic-Empirical Design (M-E) Method. IRC adopted the M-E approach from Shell manual of pavement design, 1978. By name, the M-E design method comprises of two key components, viz., a Mechanistic component and an Empirical component. The mechanistic component involves utilizing the continuum approach of multi-layered homogeneous elastic layers under a uniform circular loading concept. The analysis can be non-linear by using non-linear material models, but IRC uses linear elastic analysis. Using the mechanistic model, one can determine radial/tensile and vertical strains at different pavement structure interfaces. The empirical component is required to estimate the damage/life of the structure. IRC specifies two empirical damage models, viz., rutting criteria and fatigue criteria. The damage models give the value of the allowable number of repetitions of standard axles for a given value of strain. Rutting criteria requires vertical strain at the subgrade level, and fatigue criteria requires the tensile strain at the bottom of bituminous layers. The empirical nature also lies in estimating the values of the Resilient Modulus of the structural layers. Subgrade resilient modulus can be obtained from a correlation with CBR in the absence of cyclic experimental data. The Resilient Modulus of granular layers is somewhat tricky. The granular base/subbase modulus is stress/pressure-dependent and needs to be obtained by cyclic loading experiments. Hence, a non-linear material model is required in the mechanistic model. But, IRC adopted an equivalent linear modulus for granular layers depending on subgrade modulus. It is because, from observations, it is known that the stress state depends on the type of support (bottom layer), and as such, the equivalent modulus can be 1~2-times the support modulus. Since it is adapted from a Shell Design Manual, it may have higher uncertainty in view of the granular layer selection and construction methodology under Indian conditions.

Hence, the M-E method involves the input of estimated pavement properties in mechanistic model and estimation of life by empirical damage models. IRC recommends IITPAVE software, which is based on a multi-layer elastic analysis for the mechanistic model. It also provides the required strains for given pavement thickness, properties, and loads.

National Cooperative Highway Research Program (NCHRP) also released a Mechanistic-Empirical Design Guide (MEPDG) for New and Rehabilitated Pavement Structures in 2004. This approach provides a more realistic characterization of in-service pavements and offers procedures for evaluating existing pavements and recommendations for rehabilitation treatments. It is different from IRC:37-2018 M-E method by its integrated analysis approach for predicting pavement conditions over time (like fatigue, rutting, and thermal cracking in asphalt pavements). It accounts for the interaction of traffic and climatic conditions with pavement performance. AASHTO (2008) falls in similar lines.

### 3.2.2 *Modulus Improvement Factor (MIF) Concept*

IRC:SP:59-2019 introduced the Modulus Improvement Factor (MIF) concept to capture the benefits of geosynthetic stabilization of granular layers. MIF is defined as the ratio of resilient modulus of the reinforced granular layer to the unreinforced granular layer. Geogrids and geocells stabilize the granular layers by providing additional confinement with their own mechanisms and improve the resilient modulus of granular layers. In literature, the benefits of geogrid stabilization in reducing permanent deformations have been studied and attempted to quantify MIF (Sprague et al., 2004; Rajagopal et al., 2014; Sun et al., 2017). The 3-D confinement effect of Geocell has also been studied in the literature (Bathurst and Karpurapu, 1993; Rajagopal et al., 2014). The M-E design approach with linear elastic analysis can capture pavement performance with the value of improved modulus of the granular layer. In a way, with the value of MIF in hand, one can define the equivalent homogeneous improved stabilized layer. The typical range of MIF values of geogrid and geocell recommended by IRC:SP:59-2019 are given in Table 2 and are similar to the typical values observed in the above mentioned literature.

**Table 2** : Indicative range of MIF values for Geocell and Geogrid (IRC:SP:59-2019)

| S. No. | Subgrade CBR | Geocell | Geogrid |
|---|---|---|---|
| 1 | <3% | 2-2.75 | 1.2-2.0 |
| 2 | >3% | 1.4-2.0 | |

## 4. DESIGN OF NEW PAVEMENTS WITH STABILIZED GRANULAR LAYERS USING IRC:37-2018 AND IRC:SP:59-2019

In this section, the design requirement and the step-by-step procedure is briefly elucidated. The multi-layer elastic analysis requires estimation of resilient modulus and Poissons ratio of each pavement layer, and IITPAVE software is used to perform the analysis. The strains obtained at critical interfaces will be converted into allowable traffic by using empirical failure models. The effect of geogrid or geocell stiffening of granular layers is incorporated as improved modulus of granular layers.

### 4.1 Effective modulus of subgrade

For the pavement system's design, first, an equivalent CBR or Resilient modulus of subgrade has to be established as in some cases subgrade is prepared in multi-layers. The following procedure, as per section-6.4 of IRC:37-2018, can be followed to get the equivalent CBR and resilient modulus:

Step-1: Find the CBR of all layers of subgrade. The resilience modulus of each layer of soil subgrade can be obtained from Section-6.3 of IRC:37-2018.

$$M_{RS} = 10.0 * CBR \text{ (for CBR < 5\%)} \quad ...(1)$$

$$M_{RS} = 17.6 * (CBR)^{0.64} \text{ (for CBR > 5\%)} \quad ...(2)$$

Poisson's Ratio, $\mu = 0.35$

- For design, $M_{RS}$ should be limited to 100 MPa.
- If traffic is greater than 450 commercial vehicles per day (two-way) in the construction year, it is required to have CBR > 5%.

Step 2 : Model the multi-layer Subgrade in IITPAVE and find the deflection of the heterogeneous profile due to the single wheel load of 40 kN as per Section-6.4 of IRC:37-2018.

Step 3 : Finding equivalent homogeneous modulus as per Section-6.4 of IRC:37-2018 as: $M_{Req} = (2*(1-\mu^2)*p*a)/(\delta)$. A schematic showing conversion of a multi-layer into a single homogeneous layer is shown in Fig. 8.

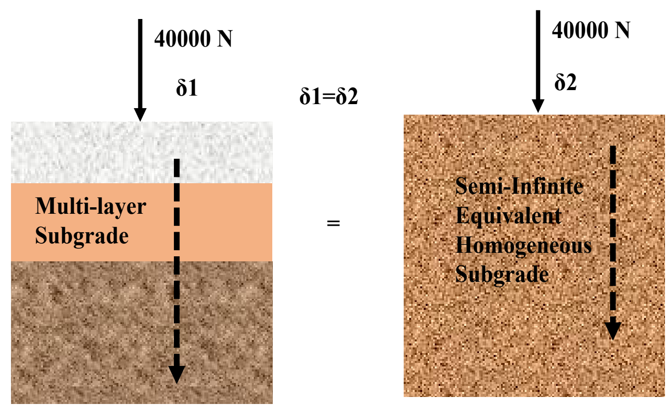



**Fig. 8** : Schematic showing the method for determination of effective modulus of Subgrade

### 4.2 Modulus of Granular Layers:

The following equation can estimate the resilient modulus of granular layers in the absence of experimental data, as per IRC:37-2018.

$$M_{RSB} = 0.2 * t^{0.45} * M_{Rsupport} \quad ...(3)$$

$$M_{RB} = 0.2 * t^{0.45} * M_{Rsupport} \quad ...(4)$$

The modulus is dependent on its thickness (t) and the modulus of supporting layers ($M_{Rsuppor}$). Poisson's Ratio ($\mu$) can be assumed around 0.35.

### 4.3 Modulus of Bituminous Layers:

The resilient modulus of bitumen layers can be assumed as given in Table 3, after IRC:37-2018, instead of performing the actual test. The provision also exists to determine the resilient modulus from indirect tensile tests.

**Table 3** : Indicative Values of resilient Modulus (MPa) of Bitumen mixes (IRC:37-2018)

| Mix Type | Average Annual Pavement Temperature $^0$C | | | | |
|---|---|---|---|---|---|
| | 20 | 25 | 30 | 35 | 40 |
| Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM) for VG10 bitumen | 2300 | 2000 | 1450 | 1000 | 800 |
| BC and DBM for VG30 bitumen | 3500 | 3000 | 2500 | 2000 | 1250 |
| BC and DBM for VG40 bitumen | 6000 | 5000 | 4000 | 3000 | 2000 |
| BC with Modified Bitumen | 5700 | 3800 | 2400 | 1600 | 1300 |
| BM with VG10 bitumen | 500 MPa at 35$^0$C | | | | |
| BM with VG30 bitumen | 700 MPa at 35$^0$C | | | | |
| RAP treated with 4% bitumen emulsion/ foamed bitumen with 2-2.5% residual bitumen and 1% cementitious material | 800 MPa at 35$^0$C | | | | |

### 4.4 Failure Criteria:

IRC:37-2018 adopted two failure models, viz.,

(b) Rutting model; and

(b) Fatigue Model.

The rutting criterion gives the allowable traffic to avoid rutting, and the fatigue criterion also provides the allowable traffic. These failure models are the empirical components of the M-E design method, which converts strains obtained from mechanistic analysis into allowable traffic. The critical locations for getting tensile strains and vertical strains are shown in Fig. 9. The equations for failure models are given as below:

***Rutting Criteria:***

$$N_R = 4.1656 \times 10^{-8}\left[\frac{1}{\varepsilon_V}\right]^{4.5337} \text{(for 80\% reliability)} \quad ...(5)$$

$$N_R = 1.4100 \times 10^{-8}\left[\frac{1}{\varepsilon_V}\right]^{4.5337} \text{(for 90\% reliability)} \quad ...(6)$$

***Fatigue Criteria:***

$$N_f = 1.6064 \times C \times 10^{-04}\left[\frac{1}{\varepsilon_t}\right]^{3.89} \times \left[\frac{1}{M_{RM}}\right]^{0.854} \text{(for 80\% reliability)} \quad ...(7)$$

$$N_f = 0.5161 \times C \times 10^{-04}\left[\frac{1}{\varepsilon_t}\right]^{3.89} \times \left[\frac{1}{M_{RM}}\right]^{0.854} \text{(for 90\% reliability)} \quad (8)$$

$C = 10^M$ ; $M = 4.84\left(\frac{v_{be}}{v_a + v_{be}} - 0.69\right)$

$N_R$ = Subgrade rutting life (cumulative number of 80 kN standard axle loads that can be served by the pavement before critical rut depth of 20 mm or more occurs)

$N_f$ = Fatigue life of bituminous layer (cumulative number of 80 kN standard axle loads that can be served by the pavement before the critical cracked area of 20% or more occurs)

C = Adjustment factor

$M_{RM}$ = Resilient modulus of bituminous layer

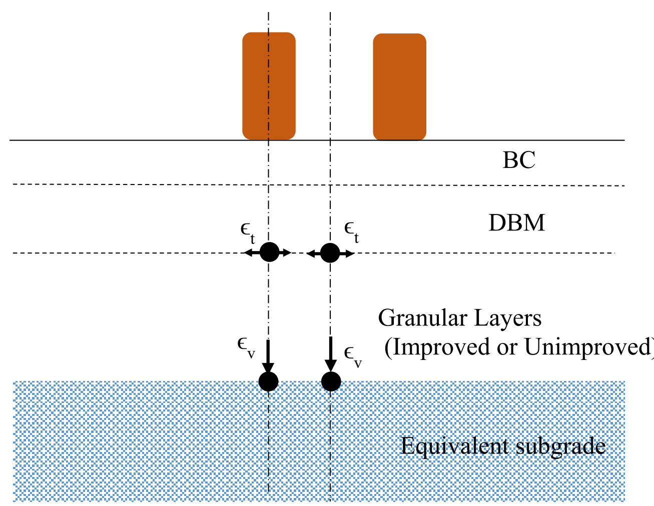



**Fig. 9** : Schematic showing the critical interfaces and corresponding strains to be estimated from multi-layer analysis

### 4.6 Design Procedure

Detailed design of new pavement stabilized with geogrid or geocells can be performed as per IRC:37-2018 and IRC: SP-59-2019 by the following steps.

1. The effective/equivalent modulus will be varying among different sections. Based on this, identify the number of sections to be designed.
2. Obtain the design traffic and standard axle loads.
3. Select the trial thicknesses of Granular Sub-Base (GSB), Base course (WMM), Dense Bituminous Macadam (DBM), and Bituminous Concrete (BC).
4. Find the resilient modulus of Subbase and Base courses.
5. Find the Resilient modulus of DBM and BC.
6. Find the strains in the pavement section using IITPAVE under design axle load.

7. Find the allowable traffic: The number of million axles allowable is calculated from the strains derived from avoiding rutting and cracking: The allowable traffic is the minimum of the two cases.
8. If the allowable traffic is less than the design traffic, increase the thickness of the layers provided.
9. In case the designer desires to introduce a geogrid/ geocell to improve subbase or base course layers, find the resilient modulus of the improved layer using the MIF values.
10. Reduce the thickness of base layer by using the improved properties and repeat steps 6-7 until design traffic is attained. A typical flow chart is shown in Fig. 10. In this way, a designer can obtain base course reduction by utilizing Geosynthetic stabilization.
11. Repeat the design for all design sections, and recommend the designed sections as per relevant chainages.

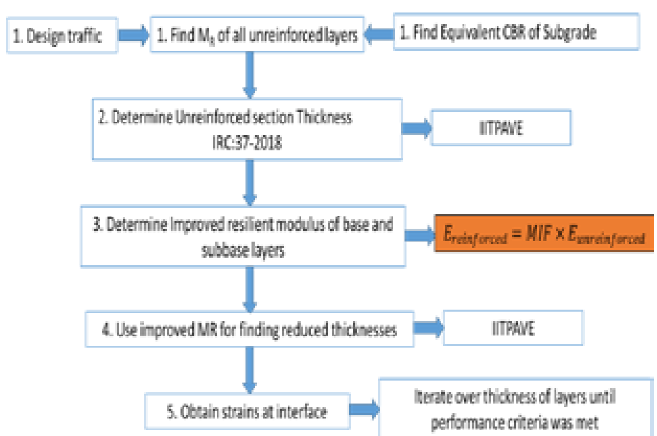



**Fig. 10** : Flow chart for the design of flexible pavement using IRC:SP:59-2019

### 4.7 Layer Coefficient Ratio (LCR) Approach

IRC:SP:59-2019 provides alternative method to MIF concept for determining improved modulus of stabilized granular layers by modifying AASHTO (1993) method. To determine the improved resilient modulus of granular layer, initially, structural numbers of unreinforced granular layers are needed to be determined by the following equations.

Structural number of unreinforced base layer:

$$a_2 = 0.249(\log_{10} M_{RB}) - 0.977 \quad ...(9)$$

Structural number of unreinforced sub-base layer:

$$a_3 = 0.227(\log_{10} M_{RSB}) - 0.839 \quad ...(10)$$

Where, $M'_{RSB}$ is the resilient modulus of unreinforced sub-base layer and $M'_{RB}$ is the resilient modulus of the unreinforced base layer.

The improved resilient modulus of granular layers can be determined by using the modified structural numbers with LCR values of particular product. The following equations are used to determine the values of the improved modulus:

$$LCR_2 \times a_2 = 0.249(\log_{10} M'_{RB}) - 0.977 \quad ...(11)$$

$$LCR_3 \times a_3 = 0.227(\log_{10} M'_{RSB}) - 0.839 \quad ...(12)$$

Where, $M'_{RSB}$ is the resilient modulus of the reinforced sub-base layer and $M'_{RB}$ is the resilient modulus of the reinforced base layer to be determined. The improved values of $M'_{RSB}$ and $M'_{RB}$ can be used to determine the reduced thickness of granular layer for the reinforced pavement section.

### 4.8 Geogrid and Geocell placement position in granular layers

The geogrid location is key to allow it to perform the desired functions of reinforcing effect and stabilizing effect. IRC:SP:59-2019 based on Haas et al. (1988) suggests that geogrid location has to be at the bottom of layer for lower thickness (<150 mm) layers and it has to be at 1/3~1/2 of thickness for higher thickness (>150 mm) layers. In practice, it is difficult to place a geogrid at the centre of the layer, and for ease in construction, geogrid is generally placed at the bottom of the granular layer to be stabilized. Haas et al. (1988) also reported that geogrid placed just below the bituminous layers will not provide any benefits, and for soft subgrades, it is advised that a geogrid layer just at subgrade layer and another layer at the center of granular layers is beneficial. Al-Qadi et al. (2012) based on field studied reported that for thick-base layers, geogrid placed at the upper one-third of the granular layer would improve the pavement performance and the geosynthetic stabilization layer at the subgrade-granular layer interface will improve the stability. Geocell on the other hand confines whole granular layer thickness; hence, it's location is not an issue. Design decision for location of geogrid should be taken according to the field situation.

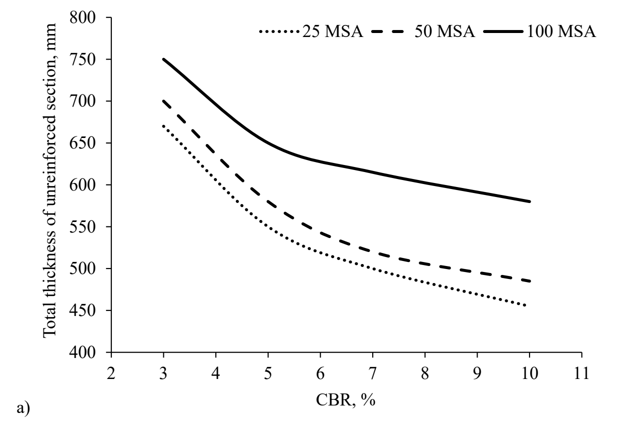
## 5. ADVANTAGES OF STABILIZATION OF GRANULAR LAYERS IN THE DESIGN

The use of granular layer stabilization can be realized only after quantifying the effects on design. The stabilization is done either with geogrids or with geocells. The granular layer stabilization increases the resilient modulus of the layer, which in turn allows decreasing the thickness of the layer for the same design traffic. The stabilization effects of geogrid or geocell on the design are quantified in two ways. One is in the form of Base Course Reduction (BCR), and the other is in the form of Traffic Benefit Ratio (TBR). The decision of how to optimize the design always rests with the designer. In this section, several designs have been carried out to quantify the effects of stiffening effect of granular layers on design sections using IITPAVE software by following IRC:37-2018; IRC:SP:59-2019 and MoRTH (2013) specifications. The reduction in the WMM layer is considered for optimizing as it is the costlier granular layer.

## 5.1 Geogrid stabilization

The geogrid can be used to stabilize either base course alone (1- layer stabilization) or base course together with a sub-base course (2 - layer stabilization), as shown in Fig. 1. In both cases, one can reduce the thickness of granular layers required for an unreinforced section designed for given traffic for the same strain levels. To investigate the effect of geogrid on final design in different conditions, different subgrade CBR values were chosen as 3%, 5%, 7% and 10%. It is to be noted that the minimum effective CBR required for subgrade is 5% for expressways and highways (IRC:37-2018). The bitumen mix properties were chosen from Table 3 for VG40 grade and a mean annual pavement temperature of 35 $^0$C. Initially, unreinforced sections were designed for design traffic of 100 MSA, 50 MSA and 25 MSA. Figure 11 shows typical unreinforced design requirements in terms of total pavement thickness and bituminous layer thickness, satisfying both rutting and fatigue criteria under different traffic conditions. The design sections consist of a Bituminous layer (BC and DBM), WMM layer and sub-base layer. Then geogrid was introduced in granular layers of unreinforced sections. The thickness of the wet mix macadam (WMM) base layer is iterated for satisfying the rutting and fatigue criteria for given design traffic. Reduction in the WMM layer is considered for reduction as it is the costliest granular layer. The resilient modulus of the stabilized layer is calculated using improved modulus values calculated by using MIF values. The typical MIF values suggested for geogrid by IRC:SP:59-2019 were in the range of 1.2-2.0. For a realistic case, the MIF for subgrade CBR of 3% is chosen as 1.75 and 1.2 for all other CBR values.

The total pavement thickness requirement for one-layer stabilization and two-layer stabilization is shown in Figs. 12, 14, and 16 for design traffic of 25, 50 and 100 MSA, respectively. It is evident that the requirement of total pavement thickness gets reduced with increasing subgrade strength. The reduction in the WMM layer thickness for single layer stabilization and two-layer stabilization is shown in Figs. 13, 15, and 17 for design traffic of 25, 50 and 100 MSA, respectively. It is evident from the results that the geogrid stabilization yielded a significant reduction in total thickness requirements by reducing the WMM layer, which was more at low CBR values. As expected, the reduction in pavement thickness due to two-layer stabilization was much more than one-layer stabilization for all CBR values. As may be expected, the reduction in thickness of pavement due to two-layer stabilization is much more than one-layer stabilization for all CBR values. It is to be noted that the analysis carried out for specific MIF values i.e. MIF value of 1.75 for subgrade CBR of 3% and 1.2 for all other CBR values. The influence of MIF value on design is discussed in a latter section.



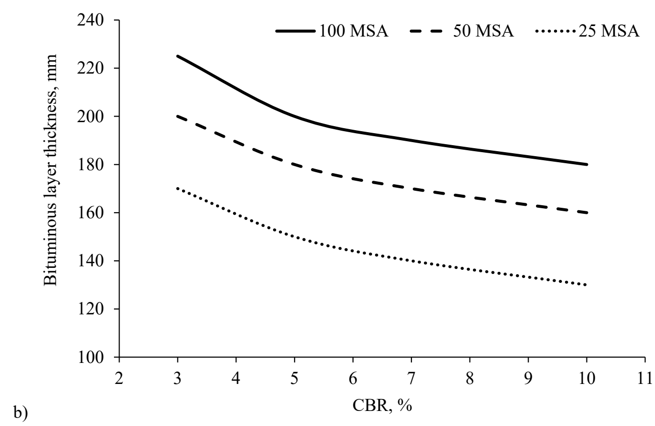




**Fig. 11** : Unreinforced section thickness requirements (a) Total thickness; (b) Bituminous layer thickness for different design traffic.

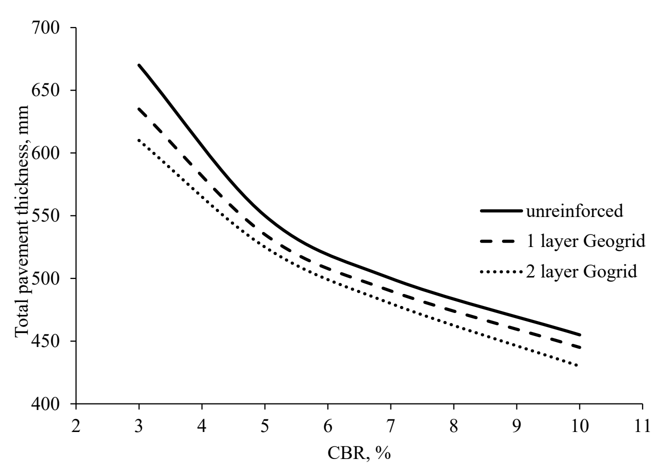



**Fig. 12** : Comparison of total thickness requirements for unreinforced and geogrid reinforced sections for design traffic of 25 MSA

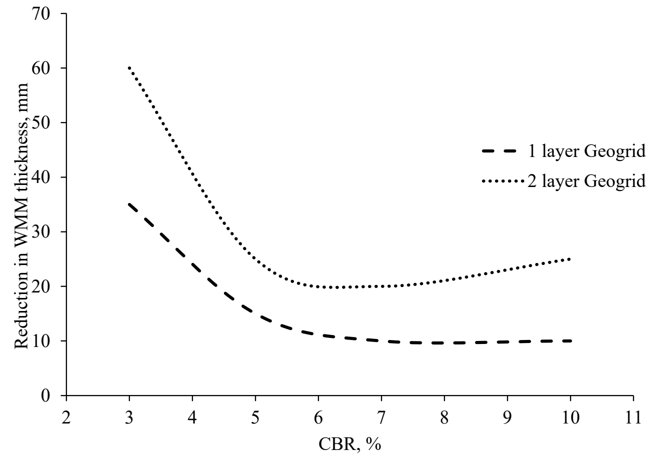



**Fig. 13** : Comparison of reduction in WMM thickness obtained for one-layer stabilization and two-layer geogrid stabilization for design traffic of 25 MSA

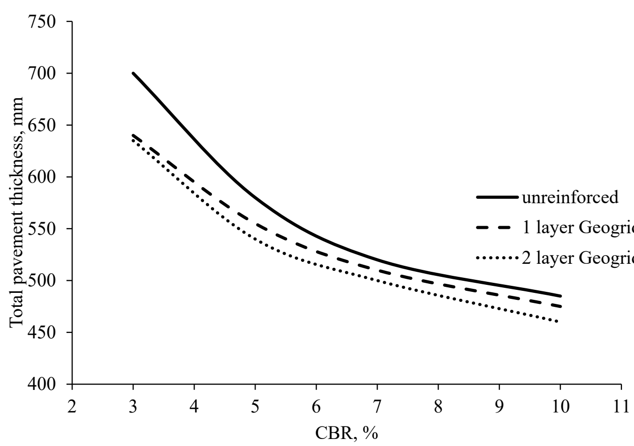



**Fig. 14** : Comparison of thickness requirements for unreinforced and geogrid reinforced for design traffic of 50 MSA

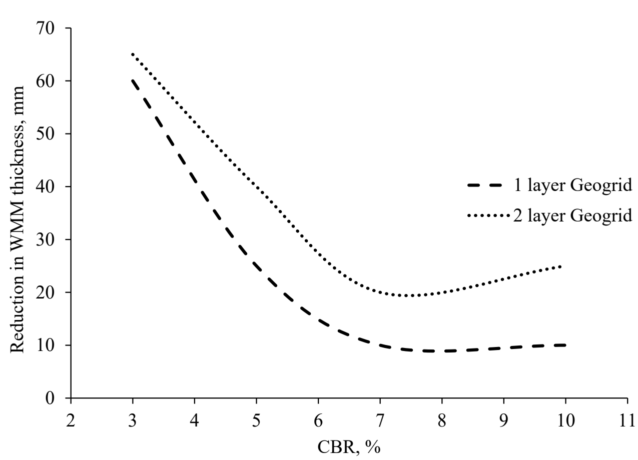



**Fig. 15** : Comparison of reduction in WMM thickness obtained for one-layer stabilization and two-layer geogrid stabilization for a design traffic of 50 MSA

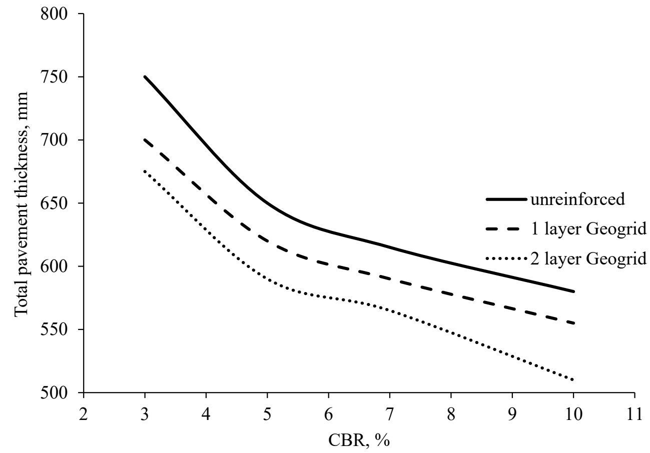



**Fig. 16** : Comparison of thickness requirements for geogrid reinforced and unreinforced sections for a design traffic of 100 MSA

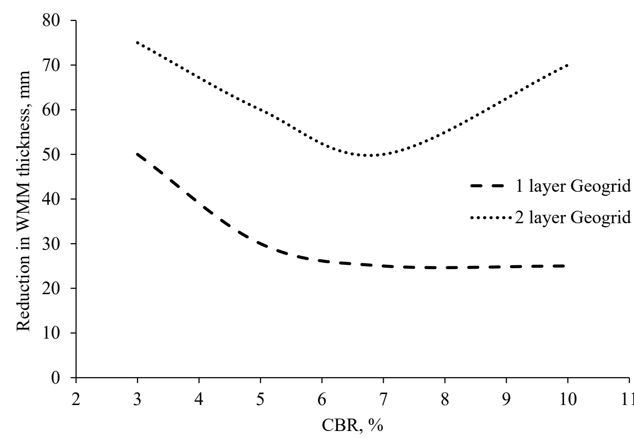



**Fig. 17** : Comparison of reduction in WMM thickness obtained for one-layer stabilization and two-layer geogrid stabilization for design traffic of 100 MSA

The design for National Expressways and National Highways is generally carried out for a minimum effective subgrade CBR of 5% (IRC:37-2018). Table 4 summarizes the reduced WMM thickness values obtained for different conditions. The reduction in case of one-layer stabilization for subgrade CBR of 3% is observed to be 35 mm, 60 mm and 50 mm for design traffic of 25 MSA, 50 MSA and 100 MSA, respectively. For subgrade CBR of 5%, these reduction values are about 15 mm, 25 mm and 30 mm, respectively. The reduction of thickness in case of two-layer stabilization for subgrade CBR of 3% is observed to be 60 mm, 65 mm and 75 mm for design traffic of 25 MSA, 50 MSA and 100 MSA, respectively. For subgrade CBR of 5%, these reduction values are about 25 mm, 40 mm and 60 mm, respectively. From these results, it is clear that a substantial advantage in pavement structural design can be achieved for low CBR values. It is also to be noted that the reduction in the WMM layer cannot be less than 75 mm (final layer thickness) as the minimum thickness of the WMM layer suggested by MoRTH (2013) is 75 mm.

**Table 4** : Summary of results for reduction in WMM layer obtained at different conditions with geogrid stabilization

| Subgrade CBR (%) | Reduction in WMM thickness (mm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | One-layer geogrid stabilization | | | | Two-layer geogrid stabilization | | |
| | Design Traffic (MSA) | 25 | 50 | 100 | 25 | 50 | 100 |
| 3 | | 35 | 60 | 50 | 60 | 65 | 75 |
| 5 | | 15 | 25 | 30 | 25 | 40 | 60 |
| 7 | | 10 | 10 | 25 | 20 | 20 | 50 |
| 10 | | 10 | 10 | 25 | 25 | 25 | 70 |

### 5.2 Geocell stabilization

The geocells like geogrids can be used to stabilize either base course alone (1-layer stabilization) or base course together with a sub-base course (2-layer stabilization), as shown in Fig. 1. The major difference in both the stabilizations is the mechanisms that improve the modulus of layers. A Geogrid enhances the modulus by confining by interface resistance and interlocking effect, whereas a geocell enhances the modulus by 3-D confinement. Also, it is to be noted that as per IRC, using geocells can provide higher MIF values compared to geogrid (Table 2). The specific thicknesses of commercially available geocells are 75 mm, 100 mm, 150 mm, 200 mm, 250 mm and 300 mm. It is to be noted that the thickness of the geocell stabilized layer should be at least 50 mm greater than geocell thickness for construction feasibility and to avoid damage to geocells during compaction.

For a comparative study, initially, unreinforced sections were designed for 100 MSA, 50 MSA and 25 MSA design traffic. The subgrade CBR values were chosen as 3%, 5%, 7% and 10%. The typical design requirements of the unreinforced section are already shown in Fig. 11. The design sections consist of a Bituminous layer (BC and DBM), WMM layer and sub-base layer. Then geocells were introduced in granular layers of unreinforced sections. The thickness of the wet mix macadam (WMM) base layer is iterated to satisfy the rutting and fatigue criteria for given design traffic. The resilient modulus of the stabilized layer is calculated using improved modulus values calculated by using MIF values. The typical MIF svalues suggested for geocells were 1.4-2.75, as suggested by IRC-SP-59. For a realistic case, the MIF for CBR of 3% is chosen as 2.5 and 1.75 for all other CBR values.

The total pavement thickness requirement for one-layer stabilization and two-layer stabilization is shown in Figs. 18, 20, and 22 for design traffic of 25 MSA, 50 MSA and 100 MSA, respectively. The reduction in the WMM layer for one-layer stabilization and two-layer stabilization is shown in Figs. 19, 21, and 23 for design traffic of 25 MSA, 50 MSA and 100 MSA, respectively. The results show that geocell stabilization yielded a greater reduction in total thickness requirements than geogrid stabilization for all CBR and design traffic conditions. It is because geocell stabilization provided greater MIF values compared to geogrid stabilization, hence, greater resilient modulus values of granular layers. Similar to geogrid stabilization, the reduction in pavement thickness due to two-layer stabilization is significantly more than one-layer stabilization for all CBR values. It is to be noted that the analysis carried out for specific MIF values i.e. MIF value of 2.5 for subgrade CBR of 3% and 1.75 for all other CBR values.

The reduction in case of one-layer stabilization for subgrade CBR of 3% is observed to be 60 mm, 90 mm and 70 mm for design traffic of 25 MSA, 50 MSA and 100 MSA, respectively. For subgrade CBR of 5%, the reduction values are about 30 mm, 40 mm and 75, respectively mm. The reduction of thickness in case of two-layer stabilization for subgrade CBR of 3% is observed to be 105 mm, 100 mm and 115 mm for design traffic of 25 MSA, 50 MSA and 100 MSA, respectively. For subgrade CBR of 5%, the reduction values are about 60 mm, 70 mm and 100 mm, respectively. These results indicate a substantial advantage in pavement structural design with geocell stabilization for lower CBR values.

**Table 5** : Summary of results for reduction in WMM layer obtained at different conditions with geocell stabilization

<table>
<tr><th rowspan="3">Subgrade CBR (%)</th><th colspan="7">Reduction in WMM thickness (mm)</th></tr>
<tr><th colspan="4">One-layer geocell stabilization</th><th colspan="3">Two-layer geocell stabilization</th></tr>
<tr><th>Design Traffic (MSA)</th><th>25</th><th>50</th><th>100</th><th>25</th><th>50</th><th>100</th></tr>
<tr><td>3</td><td colspan="2">60</td><td>90</td><td>70</td><td>105</td><td>100</td><td>115</td></tr>
<tr><td>5</td><td colspan="2">30</td><td>40</td><td>75</td><td>60</td><td>70</td><td>100</td></tr>
<tr><td>7</td><td colspan="2">20</td><td>20</td><td>80</td><td>45</td><td>50</td><td>105</td></tr>
<tr><td>10</td><td colspan="2">20</td><td>30</td><td>90</td><td>50</td><td>50</td><td>125</td></tr>
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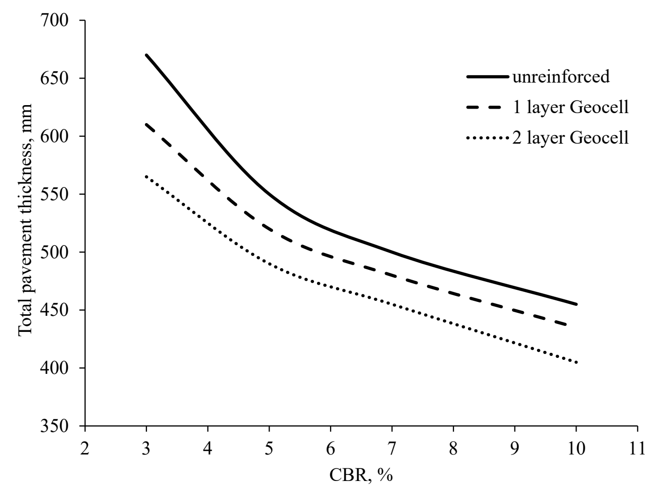


**Fig. 18** : Comparison of thickness requirements for unreinforced and geocell reinforced sections for design traffic of 25 MSA

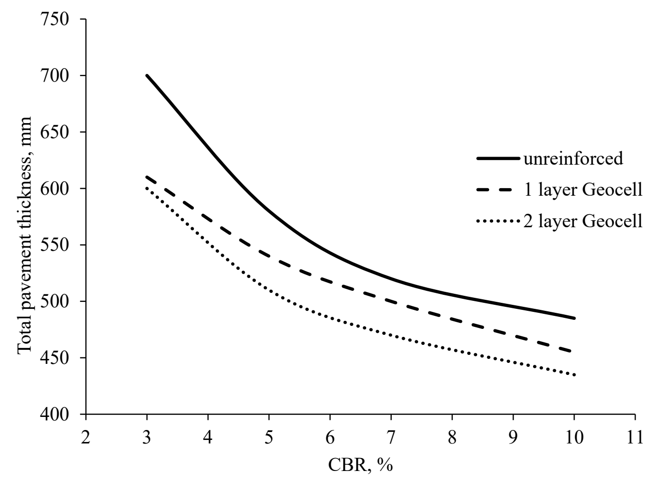


**Fig. 20** : Comparison of thickness requirements for unreinforced and geocell reinforced sections for design traffic of 50 MSA

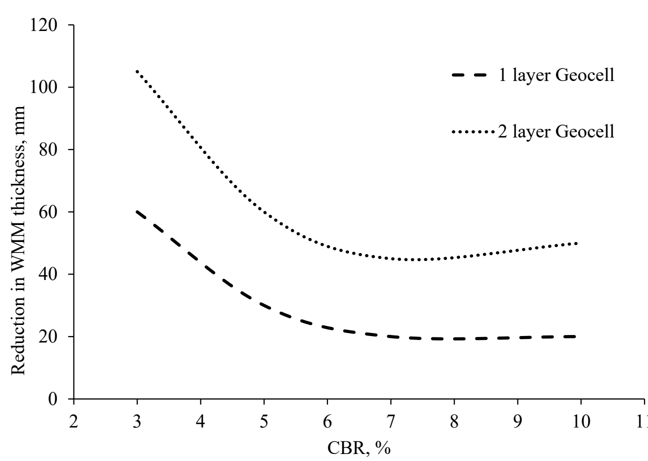


**Fig. 19** : Comparison of reduction in WMM thickness obtained for one-layer geocell stabilization and two-layer geocell stabilization for design traffic of 25 MSA

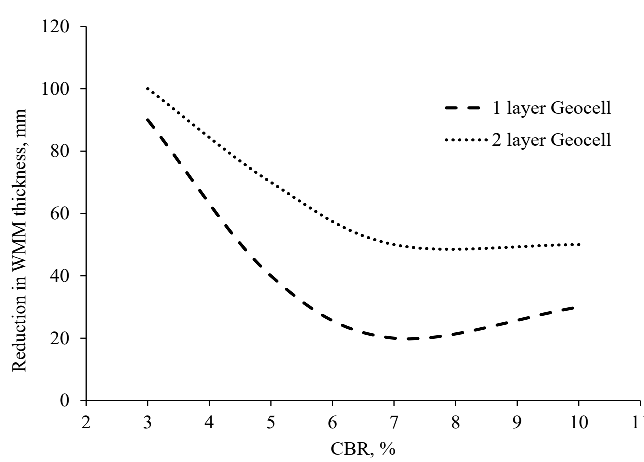


**Fig. 21** : Comparison of reduction in WMM thickness obtained for one-layer geocell stabilization and two-layer geocell stabilization for design traffic of 50 MSA

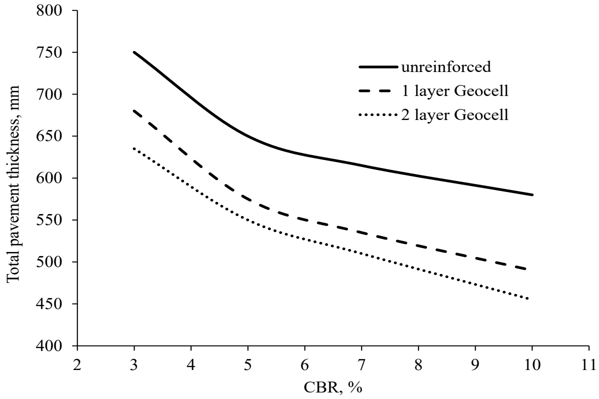


**Fig. 22** : Comparison of thickness requirements for unreinforced and geocell reinforced sections for design traffic of 100 MSA

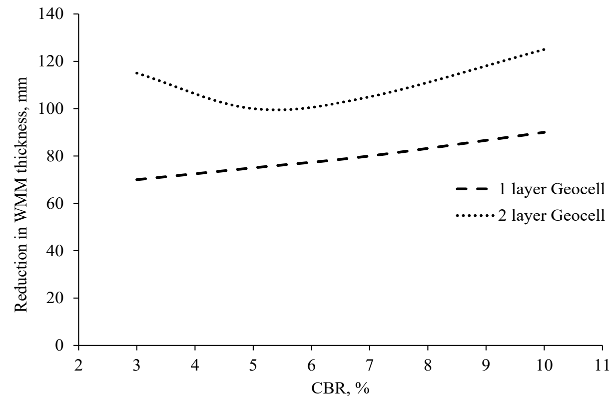


**Fig. 23** : Comparison of reduction in WMM thickness obtained for one-layer geocell stabilization and two-layer geocell stabilization for design traffic of 100 MSA

The stabilization effects on reduction of WMM layer discussed above are based on particular MIF values for corresponding condition. Further analysis is carried out to investigate the effect of MIF value on the design for a given subgrade and traffic conditions. Figures 24, 25, 26 and 27 illustrates the effect of MIF value on reduction of WMM layer possible for given subgrade condition. Higher the MIF values, the reduction attained is more. But due to the construction restrictions, the total WMM layer cannot be less than 75 mm as the minimum thickness of WMM layer suggested by MoRTH (2013) is 75 mm. Hence, after certain MIF values, reduction in base layer is not possible.

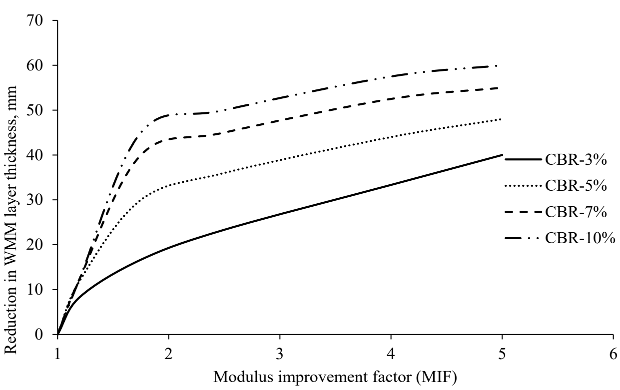


**Fig. 24** : Comparison of reduction in WMM thickness obtained for one-layer stabilization with different MIF values for design traffic of 100 MSA

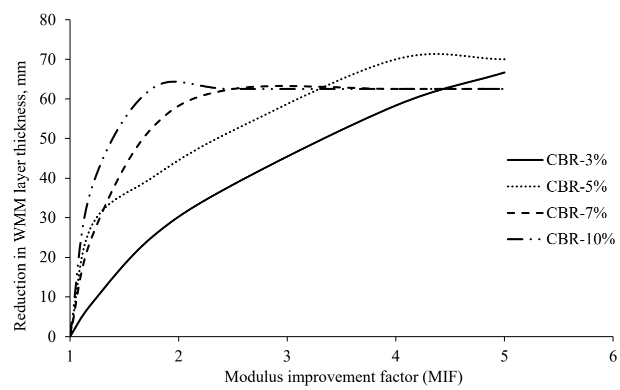


**Fig. 25** : Comparison of reduction in WMM thickness obtained for two-layer stabilization with different MIF values for design traffic of 100 MSA

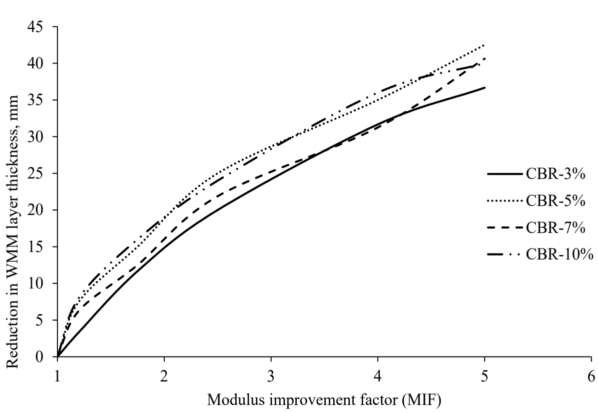


**Fig. 26** : Comparison of reduction in WMM thickness obtained for one-layer stabilization with different MIF values for design traffic of 25 MSA

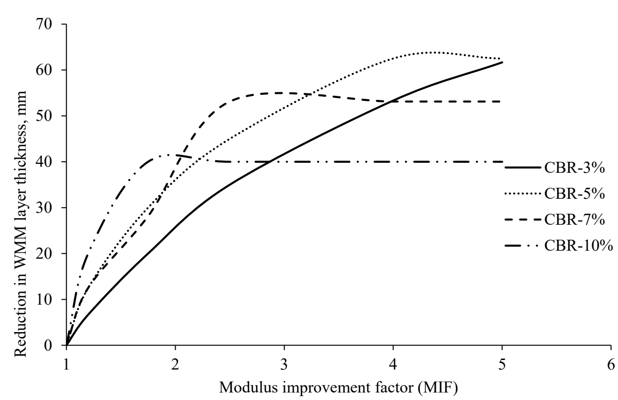


**Fig. 27** : Comparison of reduction in WMM thickness obtained for two-layer stabilization with different MIF values for design traffic of 25 MSA

## 6. SPECIFICATIONS FOR GEOGRID AND GEOCELL (REINFORCEMENT FUNCTION)

Minimum specifications are required to ensure the function of Geosynthetic to be served. MoRTH and BIS guidelines provided such specifications for the use of different geosynthetics in pavements. Tables 4 and 5 present the specifications of geogrid. Table 6 gives specifications for geocell to be used in granular layers for stabilization function. It is to be noted that specifications provided by MoRTH (2013) are presently under revision. In addition to above, for subgrade stabilization application, IS 16362:2015 provides specifications of geotextiles.

**Table 4** : Requirements of PP Geogrid (IS 17371:2020)

| S.No. | Characteristic | Requirement | | | Method of Test |
|---|---|---|---|---|---|
| | | 20/20 | 30/30 | 40/40 | |
| 1 | Ultimate Tensile strength (MD × CD) kN/m | $\geq 20 \times 20$ | $\geq 30 \times 30$ | $\geq 40 \times 40$ | IS 16635 |
| 2 | Tensile strength at 2% strain (MD × CD) kN/m | $\geq 6 \times 6$ | $\geq 9 \times 9$ | $\geq 12 \times 12$ | IS 16635 |
| 3 | Tensile strength at 2% strain (MD × CD) kN/m | $\geq 14 \times 14$ | $\geq 21 \times 21$ | $\geq 28 \times 28$ | IS 16635 |
| 4 | UV resistance, retained strength after 500 h exposure, % | $\geq 70$ | $\geq 70$ | $\geq 70$ | IS 13162 (Part 2) |
| 5 | Chemical resistance, retained strength after 72 h immersion, % | $\geq 70$ | $\geq 70$ | $\geq 70$ | IS 17363 |
| 6 | Junction strength, % of the original strength | $\geq 80$ | $\geq 80$ | $\geq 80$ | IS 17371 |
| 7 | Width, m | Tolerance +/- 10 mm | | | - |
| 8 | Roll length, m | Tolerance +1 m with no negative tolerance | | | - |
| MD: Machine Direction; CD: Cross Direction | | | | | |

**Table 5** : Minimum Requirements of Geogrid (Table 700-7 of MoRTH (2013))

| Property | Test Method | MARV |
|---|---|---|
| Stiffness at 0.5% strain | ISO-10319 | ≥ 35; both in the machine and cross-machine direction |
| Tensile strength at 2% strain | ASTM D 6637 | ≥ 15% of $T_{ult}$; both in the machine and cross-machine direction |
| Tensile strength at 5% strain | ASTM D 6637 | ≥ 20% of $T_{ult}$; both in the machine and cross-machine direction |
| Junction Efficiency for extruded geogrid | GRI-GG2-87/ASTM-WK 14256 | 90% of rib ultimate tensile strength |
| Ultraviolet stability | ASTM D 4355 | 70% after 500 hrs exposure |

**Table 6** : Minimum Requirements of Geocell for Granular layers of Flexible pavement (TXD-30-14682)

| Sl. No. | Characteristic | Requirement | Method of Test |
|---|---|---|---|
| 1 | Density, g/cm$^3$ | 0.9 | IS 13360 (Part 3)/ Section 10 |
| 2 | Environmental Stress crack resistance – Notched Constant Tensile Load (ESCR - NCTL), 400 h | Test specimen shall not fail | IS 16346 |
| 3 | Environmental Stress crack resistance (ESCR), 5000 h | Test specimen shall not fail | TXD-30-1468 Annex C |

| | | | |
|---|---|---|---|
| 4 | Carbon Black Content, percent | 2.0 | IS 2530 |
| 5 | Post texturing Strip/Cell wall thickness at a pressure of 2 ± 0.01 kPa, mm | 1.6 | IS 13162 (Part 3) |
| 6 | Seam Peel-Strength per 25 mm of cell depth, N | 350 | Method B of TXD-30-14600 |
| 7 | Seam weld hang strength for 100 mm of seam weld under constant dead weight of 72.5 kg for 7 days | Seam shall not break | TXD-30-1468 Annex D |
| 8 | Resistance to Oxidation, Retained tensile strength, percent | 90 | TXD-30-14602 |
| 9 | Retention of breaking strength after UV exposure of 500 h | 95 percent of the original actual value | TXD-30-1468 Annex E |
| 10 | Friction efficiency, percent | 85 | TXD-30-1468 Annex F |
| 11 | Standard Oxidative Induction Time, minutes | 100 | ISO 11357-6 |
| 12 | High Pressure Oxidative Induction Time, minutes | 400 | ISO 11357-6 |

## 7. DESIGN FOR REHABILITATION OF DISTRESSED PAVEMENTS

It is challenging to design overlays for rehabilitating a heavily distressed pavement due to heavy rutting. A pavement damaged due to rutting is due to subgrade failure, and opting for bitumen overlays for such kind of distressed pavements is not a good option. Such situations will be faced mainly for pavements built on black cotton soils/soft soils, which can be heavily distressed at the subgrade level. To prevent rutting, additional base layers can be provided on the existing distressed pavement, and thereafter, a bituminous layer can be placed.

Typical design steps for a distressed pavement at the subgrade level are explained in this section. To design new layers on the existing damaged pavement, one needs to find the equivalent resilient modulus or CBR of existing distressed pavement resting on the soft subgrade. The following procedure, as per Section-6.4 of IRC:37-2018, can be followed to get the effective modulus:

1. Obtain the CBR of natural subgrade below existing GSB from the samples taken from the pavement location. Calculate the modulus of resilience as per section-6.3 of IRC:37-2018.
2. Find the resilient modulus of the existing granular layer as per section-7.2.3 of IRC:37-2018. Sometimes, the GSB layer of the existing pavement gets mixed-up with soft black cotton soils. While taking field samples for the CBR test of subgrade, this phenomenon can be observed. In such cases, the GSB layer should also be considered as the subgrade.
3. Obtain the resilient modulus of the existing bituminous layer by testing core samples. The minimum value has to be taken to account for further damage from the date of testing to construction.
4. Find the deflection of the existing heterogeneous profile as per section-6.4 of IRC:37-2018 using IITPAVE.
5. Find the equivalent homogeneous modulus as per section-6.4 of IRC:37-2018. A schematic of obtaining equivalent support is shown in Fig. 28.

The effective modulus of existing layers can be taken as the modulus of support for new layers. The effective modulus will be varying among different sections. Accordingly, design sections/chainages are needed to be identified. The design of new layers can be done as a new pavement design, as already explained in Section-4. A typical solution for design traffic of 100 MSA and *"equivalent support"* CBR of 5% is shown in Fig. 29. The designer has the flexibility to opt for two-layers of geocell or one layer of geocell and one layer of geogrid for low support CBR values. For competent CBR values, even one layer geocell/geogrid reinforcement is sufficient. It is prudent to provide a non-woven geotextile over the distressed layer, which will serve both as drainage and separation layer. It is required because most of the time, the existing drainage layer, if any, would have got mixed with the soft subgrade soil and may not perform its function. It is also possible to provide an Asphalt Interlayer Composite like glass grid composite (as detailed in IRC SP 59-2019) at the interface of BC and DBM to enhance the life of pavement further since vehicle overloading by 20% is legally permitted. A general flow chart for designers is provided in Fig. 30 for the design of overlays over the distressed pavement.

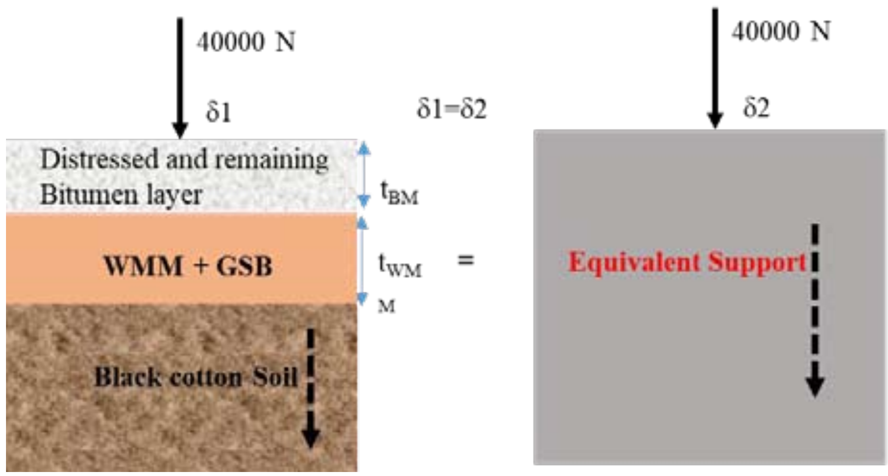


**Fig. 28** : Schematic showing method to obtain effective modulus of existing pavement

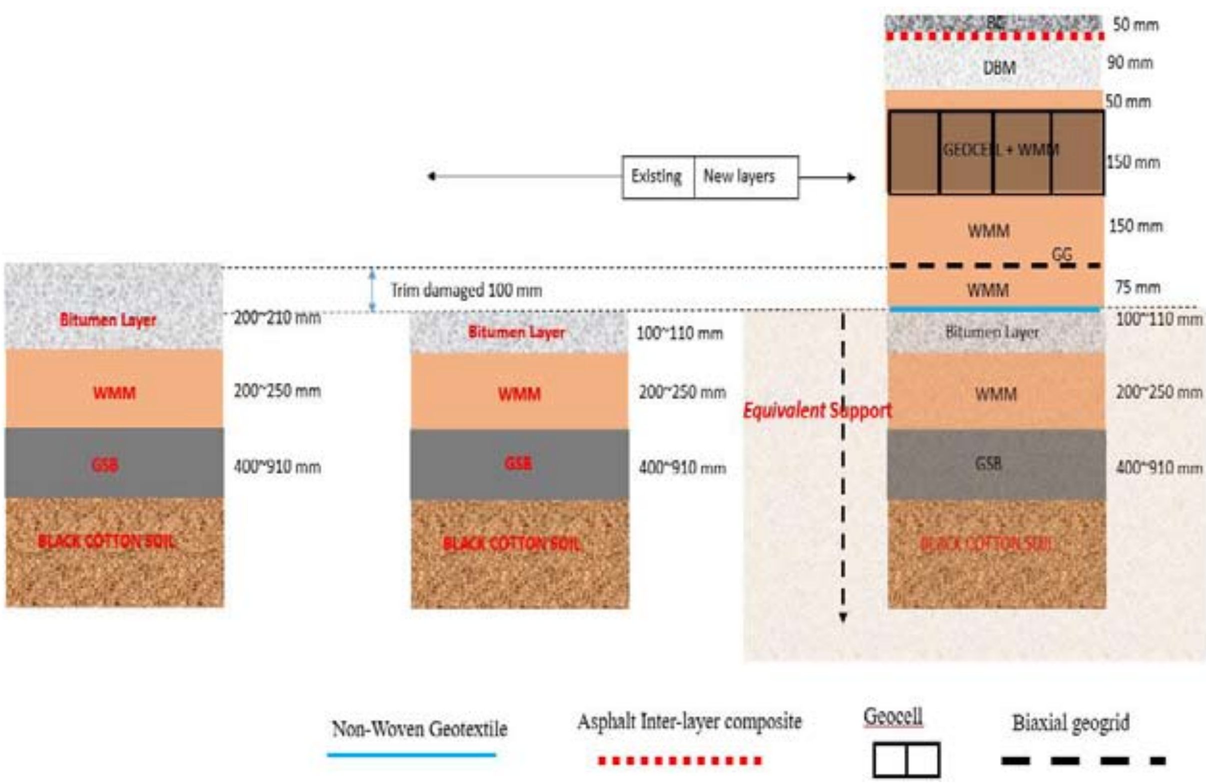


**Fig. 29** : Possible design solution for pavement distressed at subgrade level

## 8. SPECIFICATIONS FOR GEOTEXTILES (HYDRAULIC FUNCTIONS)

The minimum specifications of geotextile for separation function are given in Table 7 and Table 8. The construction survivability requirements are summarized in Table 9. The geotextile chosen should satisfy both criteria. It is to be noted that specifications provided by MoRTH (2013) are presently under revision.

Table 10 presents the specifications for geotextiles for minimum drainage requirements. Tables 11 and 12 give the minimum requirements of geotextile and core material used in drainage composite. Generally, a non-woven geotextile is used for drainage applications. It is designed by checking the drainage capacity of geotextile/geocomposite and satisfying the minimum design and survivability requirements. IRC:SP:59-2019

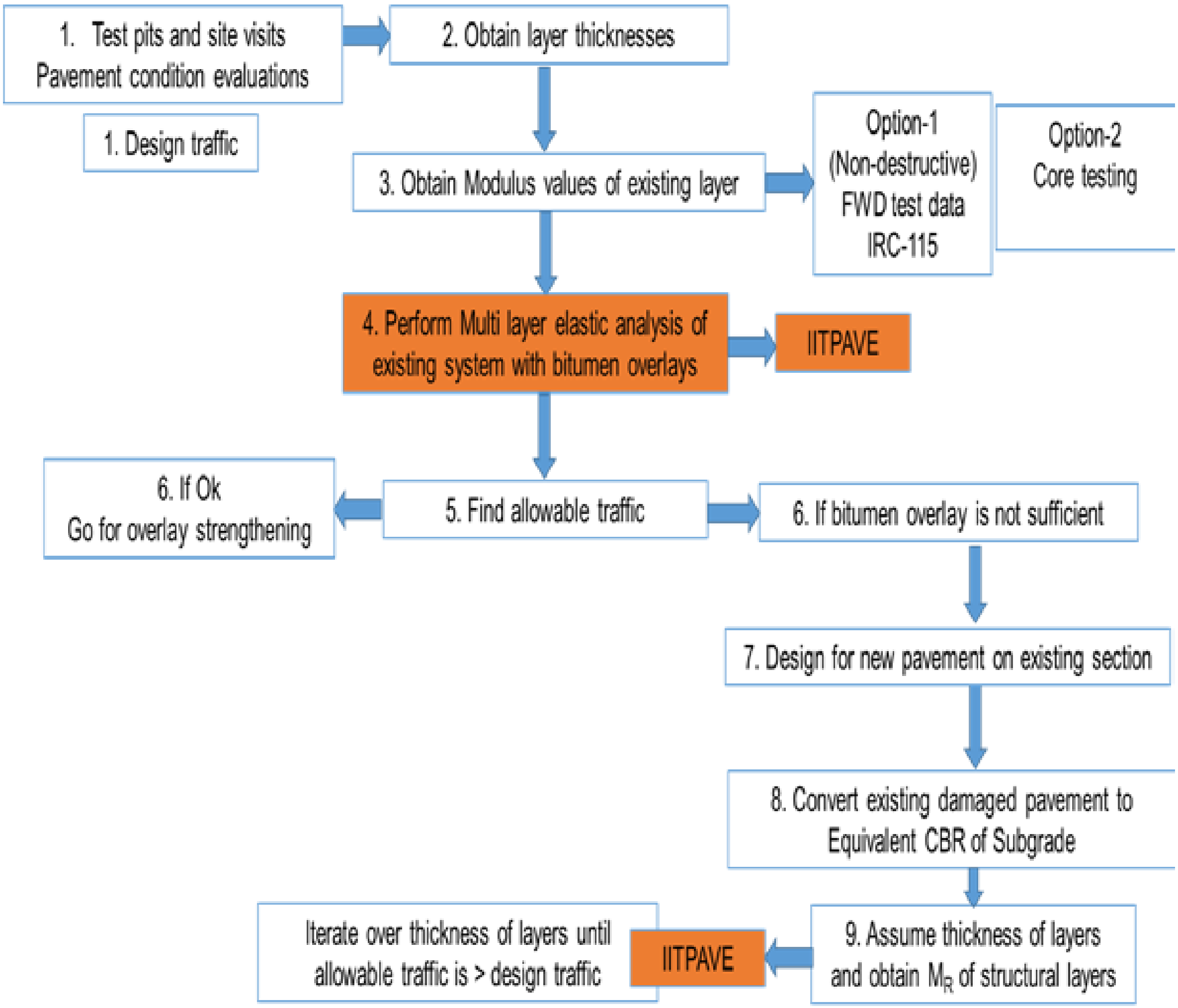


**Fig. 30** : Flow chart for the design of the rehabilitation of distressed flexible pavement using IRC:SP:59-2019

Section 3.4 gives detailed design steps for the design of geocomposite for drainage. Besides, a design check for filtration has to be carried out for complete design for hydraulic functions. Additionally, BIS guidelines are available. IS 16391:2015 provides specifications for geotextiles to be used in subgrade separation, and IS 16393:2015 provides specifications of geotextile to be used in subsurface drainage applications.

**Table 7** : Geotextile Separation Requirements (Table 700-4 of MoRTH (2013))

| S. No. | Geotextile Property | Requirement (Subgrade Soaked CBR ≥ 3) |
|---|---|---|
| 1 | Permitivity as per ASTM D 4491 | 0.02 per sec |
| 2 | Maximum Apparent Opening Size as per ASTM D 4751 | 0.60 mm |

**Table 8** : Geotextile Requirements for Separation (Table 700-5 of MoRTH (2013))

| S. No. | Geotextile Property | Requirement (Subgrade Soaked CBR ≤ 3) |
|---|---|---|
| 1 | Permitivity as per ASTM D 4491 | 0.05 per sec |
| 2 | Maximum Apparent Opening Size as per ASTM D 4751 | 0.43 mm |

**Table 9** : Minimum Geotextile Strength Property Requirements (Table 700-1 of MoRTH (2013))

| Installation Condition | Type | Strength Property Requirement (MARV) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Grab Strength (N) ASTM D 4632/ IS:13162 Part-5 | | Tensile Strength (N) ASTM D 4533/ IS:14293 | | Puncture Strength (N) IS:13162 Part-4 | | Burst Strength (N) ASTM D 3786/ IS:1966 | |
| | | Elongation at Failure | | | | | | | |
| | | <50% | >50% | <50% | >50% | <50% | >50% | <50% | >50% |
| Harsh Installation Condition | Type 1 | 1400 | 900 | 500 | 350 | 500 | 350 | 3500 | 1700 |
| Moderate Installation Condition | Type 2 | 1100 | 700 | 400 | 250 | 400 | 250 | 2700 | 1300 |
| Less Severe Installation Condition | Type 3 | 800 | 500 | 300 | 180 | 300 | 180 | 2100 | 950 |

**Table 10** : Geotextile Requirements for Subsurface Drainage (Table 700-3 of MoRTH (2013))

| In-situ Soil Passing 0.075 mm sieve (%) | Permittivity, per sec ASTM D 4491/ IS:14324-1995 | Maximum Apparent Opening Size, mm ASTM D 4751/ IS:14294-1995 |
|---|---|---|
| <15 | 0.5 | 0.43 |
| 15 to 50 | 0.2 | 0.25 |
| >50 | 0.1 | 0.22 |

**Table 11** : Requirements for Geotextile used in drainage composite (Table 700-9 of MoRTH (2013))

| In-situ Soil Passing 0.075 mm Sieve (%) | Permittivity, per sec ASTM D 4491/ IS:14324-1995 | Maximum Apparent Opening Size, mm as per ASTM D 4751/IS:14294-1995 |
|---|---|---|
| <15 | 0.5 | 0.43 |
| 15 to 50 | 0.2 | 0.25 |
| >50 | 0.1 | 0.22 |

**Table 12** : Requirements for core material used in drainage composite (Table 700-10 of MoRTH (2013))

| Property | Test Method | MARV |
|---|---|---|
| Tensile Strength | EN ISO-10319 | 16 kN/m |
| CBR Puncture Resistance | EN ISO-12236 | 3 kN |
| Mass per unit area | EN ISO-9864 | 710 g/m$^2$ |
| Thickness of composite | EN ISO-9863 | 4.5 mm |
| In-plane permeability | | |
| Hydraulic Gradient, i=1 at 100 kPa pressure | EN ISO-12958 | 0.55 l/m |
| Hydraulic Gradient, i=1 at 200 kPa pressure | | 0.45 l/m |

## 9. CONSTRUCTION GUIDELINES

IRC:SP:59-2019 (Chapters - 5 and 6) provides construction guidelines and handling guidelines for the use of geosynthetics in reference to MoRTH (2013). In addition, BIS guidelines are also available for the installation of various geosynthetics in flexible pavements. Designers must provide best practice methods along with the designs. IS 16343:2015 provides the guidelines for installation of geotextile in bitumen layers of pavement. IS 16349:2015 provides the guidelines for installation of geogrids in base and sub-base Layers. IS 16363:2015 provides guidelines for installation of geotextile used in subsurface drainage applications. IS 16345:2020 is meant for installation guidelines for geotextiles to be used in subgrade separation for different subgrade conditions. It provides guidelines such as minimum overlap requirements and maximum allowable drop of aggregates on textile.

## 10. LIMITATIONS AND SCOPE FOR FUTURE RESEARCH

The very nature of the pavement design process is Mechanistic/Empirical. Hence, several assumptions are made in developing a theory as well as in regression type of analysis. These have been mentioned wherever such assumptions are made. For successful pavement performance, these have to be noted, and while carrying forward, these need to be supplemented by both analytical/numerical analysis, laboratory studies for parametric choice, and finally by field studies. Knowing the geographic and climatic variations in the country, these need to be kept in mind as there is no shoe that fits all.

The empirical relations between resilient modulus and CBR of subgrade must be validated for different Indian subgrade conditions.

The empirical nature of finding the modulus of the granular layers as a function of thickness and support modulus is questionable. There is little study available to show its reliability. Reliable empirical correlations need to be developed.

The MIF values should be obtained for each Geosynthetic product for given subgrade conditions and Granular materials. The product manufacturer must develop MIF values for each product and place them in the public domain. The MIF values are presently considered as the same for both base and sub-base layers. There is a dire need to study the variability of MIF values for different granular materials.

IRC:SP:59-2019 suggests an alternate method of finding improved modulus of resilience of granular layers from LCR approach of AASHTO. The structural numbers and LCR values have to be evaluated for Indian conditions.

Design method for the use of asphalt reinforcements in bitumen layers needs to be established. Presently the choice of asphalt reinforcement is heuristic.

Damage models of the M-E method should be updated to incorporate the various climatic factors interacting with pavement functioning over time, like AASHTO (2008).

The mechanistic component of the M-E method of IRC uses multi-layered homogeneous elastic layers under uniform circular loading. The analysis can be updated to non-linear with pressure dependency of modulus and modulus degradation with strain using non-linear material models.

Adopting the present design methodology for stabilizing subgrade for low CBR (<3%) especially for temporary unpaved roads or as the foundation for highways needs to be examined because the advantage of using geosynthetics is maximum for lower CBR values even up to 1.

Given that India is already developing into a hub of manufacture of quality geosynthetic products, the above limitations should be taken into cognizance, and relevant research is to be undertaken.

## 11. CONCLUSIONS

This paper presented a review of design methods for flexible pavements with Geosynthetic stabilization. The Guidelines of Indian Roads Congress IRC:37-2018 and IRC:SP:59-2019 are discussed in detail. Parametric analysis is carried out for different values of subgrade CBR and traffic conditions and discussed the insights.

The analysis revealed that both geogrid and geocell stabilization yielded about 25 to 125% reduction in granular base layer thickness requirements for the considered subgrade and traffic conditions. The reduction in pavement thickness due to two-layer stabilization is two times more than one-layer stabilization for all CBR values and design traffic conditions. The greater MIF values of geocell yielded a more significant reduction in granular layer thickness requirements than geogrid stabilization. The selection of MIF values needs to be done carefully in the absence of certified data.

The minimum CBR of subgrade required for National Expressways and Highways is 5%. This study shows the potential advantages of geogrid/geocell stabilization at lower values of subgrade CBR. Even at subgrade CBR of 3%, the reduction is about 10% and 20% for one-layer geogrid stabilization and two-layer geogrid stabilization, respectively. The percentage reduction is similar at 5% subgrade CBR, but it is to be remembered that the total thickness required at low CBR values is high and hence saving in thickness is more for subgrades of lower CBR values. Similar results are observed for geocell stabilization as well.

Hence, stabilization by the use of a geogrid and/or geocell has greater potential at lower values of subgrade CBR which will reduce the high costs of making prepared subgrade or lime/cement stabilized subgrades to meet the high subgrade strength requirements of 5% CBR. It is also pertinent to note the Geotextiles, Geogrids, and Geocells specified are being manufactured in India. This should give a fillip to a confident and economic use of geosynthetic stabilized systems on Indian Roads.

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# APPLICATION OF GEOSYNTHETICS IN RESTORATION OF DIVIDE BUND OF UKAI DAM: A CASE STUDY OF GUJARAT, INDIA

**Vivek P. Kapadia**

*Secretary to Government of Gujarat and Director, Sardar Sarovar Narmada Nigam Limited, Gandhinagar, India*

**ABSTRACT**

*Dams have several components which are vulnerable in different situations at different points of time. No component can be ignored ever. Several dams were constructed in India were constructed soon after independence and hence have become old and therefore require repairs. Divide bund in the downstream of a dam separating tail race channel of the hydropower station and main gorge of the river that carries flood water from the spillover section is a very important component as it ensures a proper hydraulics not only within the river gorge but also in the tail race channel for the turbines of the hydropower station. Any kind of disruption in hydraulics may cause a large damage to the hydro power station. Therefore, besides stability of the divide bund, maintenance of its profile is very much important. As Ukai dam on Tapi river has been over 50 years old, its divide bund was found in distress and was restored using geosynthetics in the year 2019. Fast execution of the solution of a very complex problem was possible using geosythetics. The solution has been found not only working well but also cost effective.*

## AN OVERVIEW OF UKAI DAM

River Tapi is the second largest west flowing river of India. Its total length of 724 km of which 214 km lies in Gujarat. There is a dam by name Ukai - a multipurpose and major terminal project on it located at Ukai village, Taluka - Songadh, District – Tapi. It harnesses nearly half of the river yield for benefits of irrigation, hydro power and other benefits.

Ukai project was cleared by the Planning Commission in the year 1961, but due to the Chinese hostility in 1962 and the Pakistani aggression in 1965, the actual construction started in 1966 and was completed in 1972 and commissioned. The dam construction works mainly comprise a composite dam with main earth dam in the river gorge, Non- Overflow section, Spillway and Power block on the left bank of river Tapi. Ukai reservoir has live storage of 6,730 MCM at FRL 345 ft. (105.156 m). It spreads nearly in 600 sq. km with a maximum length of 112 km. Ukai dam is a composite dam with maximum height of 80.7 m above its deepest foundation. The total length of the dam is 4,926 m of which 4,058 m is an earth dam of zoned fill type. Masonry gravity dam, including 868 m long spillway and power dam occupies the remaining length. The spillway is located on the left bank with 22 radial gates of 51 ft x 48.5 ft (15.54 m x 14.78 m). The maximum discharge capacity of the spillway at FRL is 13.37 lakh cusecs (37, 865 cumecs).

Ukai dam has two power houses; one located on the left side of spillway having four units of 75 MW each and generally operates as peaking station while the second power house is downstream of the dam at the canal head having two units of 2.5 MW each. The water released from the dam toe power house is picked up at Kakrapar weir for firming up the irrigation in Kakrapar canal system. The storage of water in Ukai is utilized for irrigation to 3, 31,577 ha under the Ukai Kakrapar command area along with generation of 300 MW of hydro power (maximum) from the dam hydropower house and 5 MW hydropower from the Ukai left bank canal. The Ukai reservoir project also provides flood control benefits to the downstream areas and Surat city.

Operations of the dam and the hydropower turbines are independent and therefore in order to maintain a proper hydraulic condition in the downstream of the turbines i.e. in the tail race channel, a divide bund has been provided. The divide bund also facilitates appropriate hydraulic conditions in the river gorge in the downstream of the spill over section. Its shape and length has been decided based on a 3D model study.

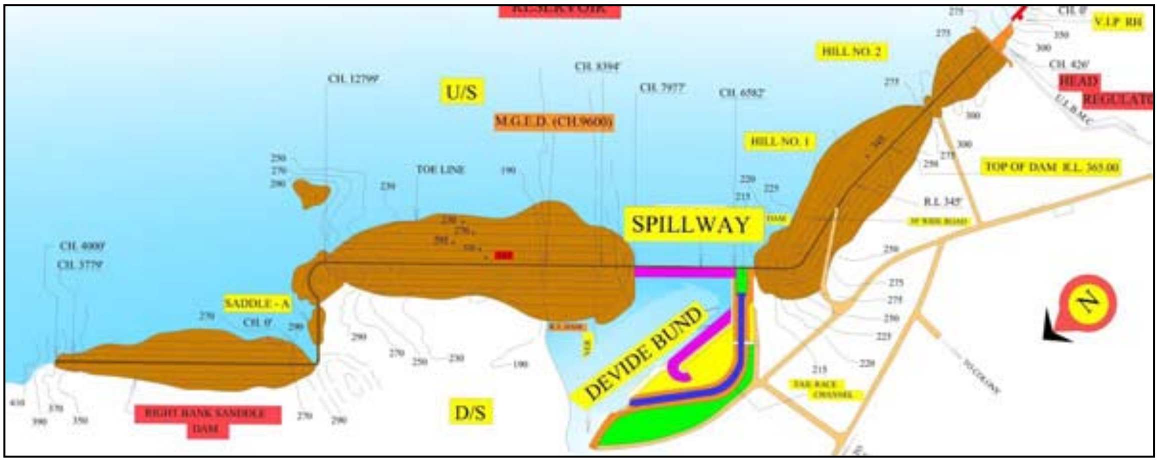


**Fig. 1** : Layout of Ukai Dam

**Fig. 2** : View of Ukai Dam

## SIGNS OF DISTRESS IN THE DIVIDE BUND

The divide bund is generally subjected to sudden variations in the pore pressure and external buffeting forces i.e. impacts on any of the two sides and sometime even on both the sides and therefore its stability and the condition of the outer surface are under a different type of challenges as compared to any conventional earthen bund. Because of the said forces fatigue is also enormous in case of such divide bunds.

**Fig. 3** : Distressed Divide Bund

In the year 2019, it was observed that the overall stability of the divide bund of the Ukai dam was not an issue but its outer slope was in serious distress. Not only the original stone pitching was almost lost but even the earthen slopes had caved in. Such phenomenon is generally due to the possible high magnitude of local shear stress transferred on the soil mass during buffeting of the water. This kind of damage was not unexpected after a long service period of 50 years. However, one phenomenon was a matter of concern which was the erosion of the river bed up to 5 m depth and 8 to 10 m in width in a significant length at the toe of the divide bund, though the natural river bed is of basalt. An important role of the divide bund is to channelize the spilled flow which causes eddy formation throughout the length which could be observed during past inspections. It was learnt from a study of the eddies that the velocity concentration along the entire length of the toe was very high which had resulted in to such an erosion. In the slopes with stone pitching, it is important to note that the initial impacts due to water waves result in to displacements of the stones and thereafter the soil behind is subjected to impacts. Depth of pits in the soil depends on the magnitude of incessant impacts during periods of heavy monsoon. Repetitive impacts may also lead embankment collapse. In this case, the restoration was taken up before the state of collapse.

## ESSENTIALS OF RESTORATION STRATEGY FOR BETTER PERFORMANCE

Fillip up of the trench near the toe of the divide bund and provision of a long lasting encasing was envisaged as the primary requirement in order to maintain stability of the divide bund and to re-establish proper hydraulic flow pattern in the downstream of the spill over section of the dam. The function of the encasing material was considered not only as a protective layer on the trench filling but also as a launching apron to take the forces of eddies along the toe.

Stability of the fresh material added to the existing damaged bund was also to be considered. Impact resisting mechanism of the outer surface and load dispersion mechanism such that avoiding failure of the soil in the bund due to high magnitude local shear stresses were also to be ensured as a part of the restoration plan. Another aspect was to control the variations of the pore pressure inside the bund. Sudden pore pressure variations are inimical for the long term stability of any earthen embankment. Actually, in this application, the pore pressure variations follow the instances of local shear stress induced by impact and therefore are far more critical than conventional applications.

## RESTORATION MEASURES – INSTALLATION AND DESIGN PHILOSOPHY

Restoration was to be made between April and June of any year considering the condition of the downstream gorge of the river. Accordingly, the design and tendering was taken up. The restoration was carried out during the year 2019.

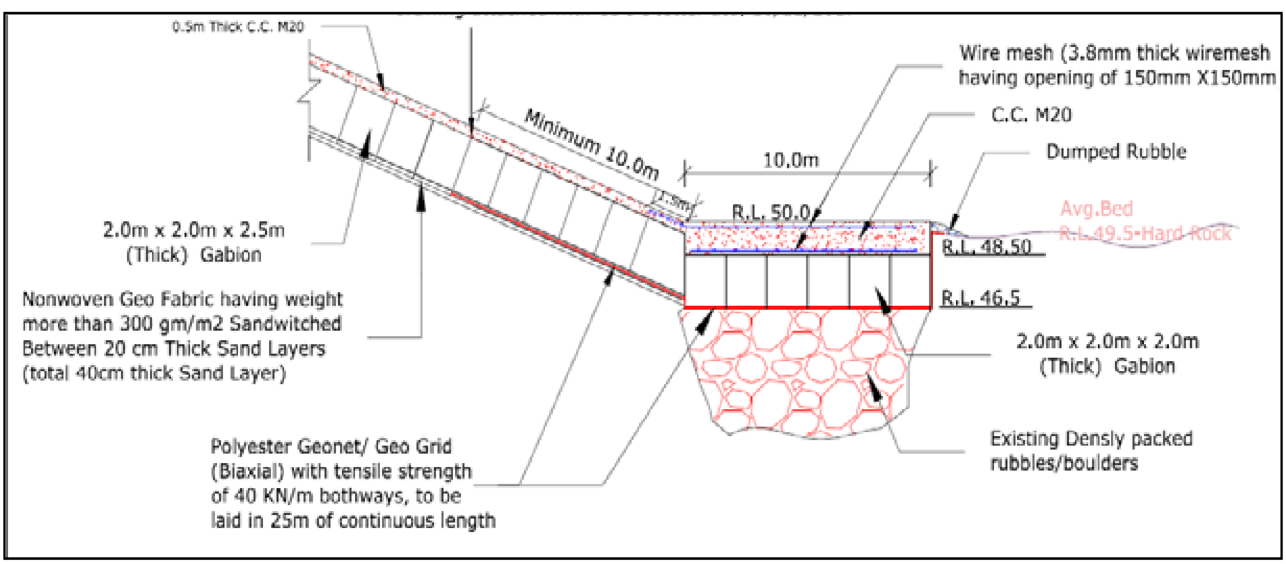


**Fig. 4** : Design of Restoration of Divide Bund (Cross Section)

First activity to be taken up was filling up of the trench at the toe of the Divide Bund. Locally available large rubbles and boulders were used for this purpose. In order to provide protection to the rubbles and boulders, gabions of 2m x 2m x 2m were used.

**Fig. 5** : Restoration in Progress

From the inclined surface of the bund, all loose material was removed and proper surface dressing was done by adding cohesive soil which was compacted in slope as per original design. Intermediate berms were also provided to the bund in order to enhance the stability. Such newly prepared surface was covered with a 20 cm thick sand layer on which was spread a non-woven thermally bonded Polypropylene geotextile with good filter properties and reasonable tensile strength (Properties detailed in Table 1) up to the full height i.e. from toe level to the top of the free board. On the top of the non-woven sheet was provided a biaxial polyester geogrid (Properties included in Table 2) with a tensile strength 40 kN minimum in each direction in the bottom 25 m inclined height. Then again a 20 cm thick sand layer was provided. Thus, on top and bottom, both the sides of the non-woven geotextile and geogrid there was a sand layer. On the sand layer was provided a layer of gabions 2m x 2m x 2.5 m. All the gabions were made up of PVC coated and galvanized wire mesh confirming to IS 16014 and MoRTH (Fifth Revision) 2013.

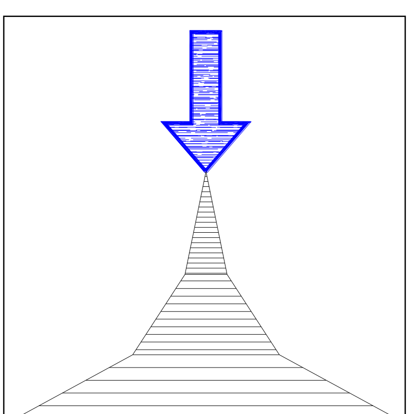

**Fig. 6** : Dispersion of Force using Different Materials and Mechanisms

**Table 1** : Properties of Non-woven polypropylene Geotextile

| Mechanical Properties | Value | Tolerance |
|---|---|---|
| Mean Peak Strength | 8.0 kN/m | - 2 kN/m |
| Elongation | 24 % | ± 15% |
| Mass Per Unit Area | 120 gsm | |
| Tensile Strength @ 5% Elongation | 3.4 kN/m | NA |
| CBR Puncture Resistance | 1500 N | -270 N |
| Dynamic Cone Puncture | 38 mm | NA |
| Opening Size O90 | 150 µ.m | ≤ 110 µm |
| Permeability (H50) | 100 l/m2s | - 10% |
| Minimum Roll width | 4.5 m | |
| Minimum Roll Length | 100 m | |

**Table 2** : Mechanical Properties of Polyester Geogrid

| Ultimate Tensile Strength (kN/m) | | Elongation at Nominal Strength (+/- 2%) | | Tensile Strength (kN/m) at 2% Strain | | Tensile Strength (kN/m)at 5% Strain | |
|---|---|---|---|---|---|---|---|
| MD | CMD | MD | CMD | MD | CMD | MD | CMD |
| 40 | 40 | 10 | 10 | 9 | 7 | 20 | 13 |

Atop the gabion surface on the inclined surface of the bund and on the horizontal one was placed a concrete apron. On the inclined surface it was plain concrete 50 cm thick apron whereas on the horizontal surface down the toe was an R.C.C. apron of 1.5 m thickness. Grade of concrete used was M20. Top surface of the horizontal R.C.C. apron was adjusted to be in level with the natural river bed.

Impact is generally dispersed within a medium as per its properties but hard surface resists the impact effectively and transfers the less magnitude in to the medium and hence composite materials are preferred in some applications. Impact of water waves can be transferred to the soil base by different mechanisms. There could be a thick rigid medium or there could be a sandwiched composite material or there could be a multilayer composite mechanism that would use different materials' properties and behavioral configuration for this purpose. Multilayer composite mechanism is used in design of the slope protection work in such a way that the impact is transferred to the soil of the bund in the form of a gradual and well dispersed force. This is illustrated in Figure 6.

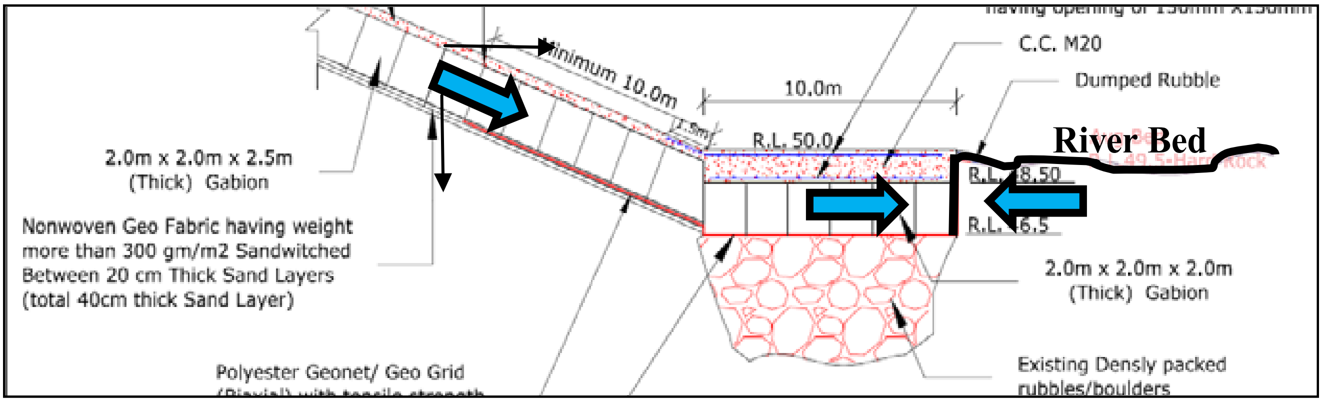


**Figure 7** : Force Resolution and Stability Aspects

Concrete apron was provided to act as a rigid surface against impact of the water waves. Gabions below the rigid concrete apron being semi-rigid were provided to transfer downward the force in a little dispersed manner. Beneath the gabions was provided a sand layer which would have three functions – to act as a cushion beneath the gabions, to provide proper roughness to the non-woven geotextile and the biaxial geogrid and to act as a filter material to provide exit to the pore pressure. The non-woven geotextile was also selected to have adequate filter properties. Gabions by nature have good filter quality. Geogrid from toe upward on the inclined slope would take high magnitude of tension during eddy generation and hence would significantly reduce the effect of impact and would disperse the force effectively. Eddies were found up to 10 m height from the toe and hence the biaxial geo-grid was provided up to 25 m inclined slope height for better dispersion of the force. To facilitate the filter mechanism to work well, concrete apron was also cast in the form of blocks with gaps. This graded filtration had an objective of gradual pore pressure variations which was not there in earlier design. Moreover, the restoration design incorporated a check against particle migration from the bund.

Resolution of forces was also taken care of in the restoration design in such a way that stability of the cladding materials which form the slope protection work is ensured without any external mechanism. Trench filling and the encasing were designed to perform as a launching apron for the eddies and the basaltic river bed itself would act as a key for the composite launching apron. This intrinsic stability mechanism was envisaged to regain the original river bed profile for better hydraulic behavior of the river channel.

By the onset of the monsoon of the year 2019 only top panel remained incomplete, all otherwise the work was completed and the outflow was sufficient to test the restoration work. Subsequently the balance work was also completed. Monsoon of 2020 was quite good and a good opportunity for testing was there and the functional performance was found satisfactory. Post monsoon inspection revealed no sign of distress anywhere.

**Fig. 8** : Actual Performance of Divide Bund during monsoon of 2019

## CONCLUSION

Technological upgradation is required in the field of maintenance and repairs especially in hydraulic structures. Actual utilization of large investment in construction of big dams requires maintenance and repair. With advancement in technologies the situation has changed in a sense that better solutions and alternatives have become available which are also cost effective and long lasting. The designer has to select the right proposition amongst them that could serve various purposes and still is workable in the given situation, particularly the limited time available for execution.

All the components of any dam are functionally very special and hence their restoration requires special considerations along with site specific aspects. As dams are meant for flood control, some of their components have to be subjected to extra ordinary forces and combination of forces which necessitate careful periodical inspections and repairs. Due assessment of the damages and their probable causes along with thorough understanding of behavior of respective element of the dam during different exposures is very important for the solution provider.

In several requirements for repair of different elements of a dam, there could a very important role of Geosynthetics as a part of the solution. Geosynthetics can help design promising solutions with better performance due to feasibility of complex and desirable mechanisms they can offer to address various issues. How the designers make them to work depend the level of success and effectiveness. The case study of restoration of divide bund of Ukai dam has evinced that in a very limited execution period available, a much better solution as compared to what could have been derived with conventional techniques has been executed with more convincing design philosophy and with much satisfactory performance during immediate flood modulation and control exercise.

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# CASE STUDY ON THE RESERVOIR SEEPAGE AT CONCENTRATED SOLAR THERMAL POWER PLANT, RAJASTHAN, INDIA

**R.K. Anjana, D.N. Arnepalli, S. Jain, P. Cherishma and S.R. Gandhi**
*Department of Civil Engineering, Indian Institute of Technology Madras*

**K. Divakara Rao**
*Areva Renewable Energies India Pvt. Ltd.*

**ABSTRACT**

*Rajasthan Sun Technique Energy Pvt. Ltd. has implemented a 125 MW large-scale grid connected concentrated solar thermal power project in Jaisalmer district, Rajasthan, India. This manuscript is a critical evaluation of the design and construction of raw water reservoir liner system at the concentrated solar thermal power plant. The initial liner consisted (from bottom to top) of compacted earth, sand layer, HDPE liner, cement plaster and a PCC layer. The initial liner failed and caused the intrusion of saline ground water into the raw water reservoir and seepage loss of fresh water into the surroundings, prior to commencement of its intended function. To mitigate the above problems, the designer proposed a rectification scheme, which was also found to be ineffective. The present study elaborates on reasons that caused the malfunctioning of the above liner system. Finally, remedial measures that were proposed to rectify the problems have been discussed, in detail.*

## 1. INTRODUCTION

Many power plants today use fossil fuels as a heat source to boil water for generating steam. The steam from the boiling water spins a large turbine, which drives a generator to produce electricity. However, a new generation of power plants with concentrating solar power systems uses the sun as a source of heat. Concentrated solar power (CSP) systems concentrate a huge amount of solar thermal energy onto a small area with lenses or mirrors to generate solar power. This solar power is converted into thermal energy, which in turn is used to drive a heat engine (usually a steam turbine). This turbine is connected to an electrical power generator (Boerema et al. 2013). Concentrating technologies exist in five common forms, namely parabolic trough, enclosed trough, dish stirlings, concentrating linear Fresnel reflector, and solar power tower (Letcher 2008). Due to the differences in the way that the solar concentrators track the sun's irradiance and focus light, different types of concentrators produce different peak temperatures and correspondingly varying thermodynamic efficiencies. New innovations in CSP technology are leading systems to become more energy-efficient and cost-effective. Giovanni Francia (1911–1980) designed and built the first concentrated-solar plant in Sant'Ilario, Italy in 1968. This plant served as the basis of architecture for today's concentrated-solar plants in the world. The plant was built with a solar receiver in the centre of a field of solar collectors. The plant was able to produce 1 MW with superheated steam at 100 bar and 500 °C.

Rajasthan Sun Technique Energy Private Limited, a wholly owned subsidiary of Reliance Power, India, was awarded the CSP project in December 2010, based on international competitive bidding conducted by NTPC Vidyut Vyapar Nigam Limited, which is a subsidiary of NTPC Ltd., India. The project is located at Dhirubhai Ambani solar park at Pokaran in Jaisalmer district of Rajasthan, India. This is also the largest plant in the world in terms of compact linear Fresnel reflective (CLFR) technology usage. The CSP plant is expected to generate about 250 million kilowatt hours of clean and green energy annually, equivalent to consumption of a quarter million households, contributing to India's energy security goal. The project will reduce $CO_2$ emissions by about 2,40,000 tonnes per year which is equivalent to $CO_2$ sequestered by 6 million tree seedlings grown for 10 years or taking 80,000 cars off the road. The CFLR technology for the project is provided by AREVA Solar (the US subsidiary of the AREVA SA of France), which is proved to have minimal environmental spill, lesser land requirement and is more efficient than other solar thermal technologies available. The reflectors focus the solar radiation to an overhead pipe that contains an efficient heat-absorbing fluid. This fluid transfers heat to water, producing steam to drive a steam turbine which in turn is connected to a generator.

Water is a crucial resource required for the successful operation of solar thermal plants. It is required mainly for the regular cleaning of solar receptors and production of steam to run the turbine. Raw water is stored in huge reservoirs at the CSP plant. In order to minimise seepage losses, a liner system (consisting of compacted earth, sand layer, HDPE liner, cement plaster and a PCC layer) was initially designed. However, this liner system was faulty and it failed to serve its purpose. Rectification schemes were proposed further, which also proved to be ineffective to perform the intended function. The paper discusses the possible flaws in the previous designs, proposes new measures to mitigate losses as well as contamination of reservoir water and elaborates on the importance of proper usage of geosynthetics in liner applications.

## 2. STATE OF CSP IN INDIA

CSP technology concentrates solar radiation to produce heat and convert water into steam. Therefore, the technology requires direct solar radiation to fall on reflective mirrors to concentrate at a particular point. The direct normal irradiance (DNI) map of India depicts that several states in India are suitable for solar thermal projects, namely Gujarat, Rajasthan and Maharashtra in the west, Jammu and Kashmir, Himachal Pradesh and Uttarakhand in the north, and Karnataka, Andhra Pradesh and Tamil Nadu in the south of India (Indian Solar Resource Maps 2010). Of these nine states, the entire land masses of Gujarat and Rajasthan receive good DNI on yearly average. According to the trans-mediterranean renewable energy cooperation (TREC), each square kilometre of hot desert receives solar energy equivalent to energy produced from 1.5 million barrels of oil (Wolff et al. 2008). The Thar desert, in Rajasthan, receives more than 2,000 kWh of DNI per square metre per annum, estimated to be sufficient to generate 700-2100 GW of energy (Bhushan et al. 2015). Therefore, theoretically, India has a good potential for CSP technology. From an environmental impact perspective, it was found that a typical CSP plant produced 7 MWh by utilising 20,000 litres of water per day, which means 2.85 cubic metres of water per MWh. According to the central electricity authority (CEA), a typical 2 x 500 MW coal-based power plant uses 4,000 cubic metres of water per hour, mainly for fly ash disposal and cooling, which translates into 3.5-4.0 cubic metres of water per MWh (International Energy Agency Report 2010). This means that water consumption of a CSP plant is 20 to 40 % less than that of coal-based thermal power plants. Hence, the energy industry can be immensely benefitted by adopting newer technology of CSP over conventional methods.

In India, capital cost for thermal power is INR 50 million/MW against INR 150 million/MW for solar thermal power. In terms of cost of generation, thermal power stands at INR 3/kWh whereas solar thermal power is at INR 15/kWh (Central Planning Authority 2004). A comparison of thermal power generation with CSP generation options for India shows that thermal power is the cost-effective option—both in terms of the capital cost and the final cost of generation. The prices may come down on account of an indigenous manufacturing base and cheaper finances made available to developers. CSP is still in the initial stage of the technology maturity curve. Though there have been significant R&D activities on CSP for several decades now, the technology needs governmental support through subsidies to develop demonstration projects and build an environment that promotes investment. On the other hand, thermal power plants have the highest $CO_2$ emission factors and are also responsible for local air pollution ($SO_x$, $NO_x$, particulates). Thermal power plants emits nearly 1000 tonnes of green house gases into the atmosphere for every one GWh of power generated, where as the emissions from CSP are considered to be insignificant. In view of natural resource requirement and green house gas emissions, solar power plants are considered to be favourable as compared to their counter parts. Further, solar power plants depend on reliable environmental friendly energy sources.

## 3. ROLE OF LINER SYSTEMS IN WATER RESERVOIRS

The field of barrier systems was restricted to canal linings initially. In later stages, it expanded to landfill linings. A detailed account of the chronological developments in the area of landfill engineering; limitations with conventional liners, invention of the modern geosynthetic materials and their application in landfill engineering and their long term performance has been presented by the authors in a companion study (Anjana and Arnepalli 2015). While thermoset liners may have been used prior to the 1930s, the use of polyvinyl chloride sheeting for liners began in the 1940s. Uncovered PVC geomembranes had a tendency to undergo progressive brittleness and cracking. Other thermoplastic liner materials, less susceptible to this problem, followed in rapid succession. Giroud was instrumental in the development of the double liner concept, which he presented in a paper in 1973 (Giroud 1986). Giroud employed a double liner system in a liquid impoundment in 1972 and a second time in 1974. This author is also credited for the first use of a geonet associated with two geomembranes to form an entirely geosynthetic double liner system in 1980.

Atmospheric exposure and possible degradation of polymeric geomembrane is a complex subject (Arnepalli and Rejoice 2013a; 2013b). To shield the liner from UV radiation, temperature extremes, ice damage, wind stresses, accidental damage, and vandalism, a cover is usually required. For potable water storage, service lifetimes of approximately 20 years must be considered (Koerner 2005). This is similar to general water storage for agricultural use. PVC has been widely used, due in large part to its ease of installation compared with that of other materials. As noted earlier, it must be covered to prevent excessive degradation, and this tends to offset its lower installation cost when compared with other liner materials that are not soil covered. Indeed, there are other types of geomembranes that can be used for potable or storage water containment, due to the relative inertness of water. Also, geomembranes are used as covers above the surface of storage reservoirs for liquids, to minimise evaporation losses.

Raw water, which is used to produce steam in the solar thermal power plants, is stored in huge reservoirs at the CSP plants. These reservoirs need to have efficient lining systems in place for the purpose of minimizing seepage losses as well as restricting the contamination from the surroundings. High density polyethylene (HDPE), linear low density polyethylene (LLDPE) and poly vinyl chloride (PVC) are the most widely used polymers for manufacturing geomembranes. In the early 1980s, HDPE essentially replaced PVC as the geomembrane of choice because of its broad chemical resistance, its high strength, its relative inherent flexibility achieved without addition of plasticizers and additives, its weathering resistance that allows it to be left uncovered, and its ability to be integrally fusion-welded by thermal methods rather than by using solvents and adhesives. Today, various types of polyethylene are being commonly used for the containment of liquids.

## 4. INITIAL LINER SYSTEM AT CSP PLANT

The designer had proposed a initial liner consists (from bottom to top) of compacted earth, 50 mm thick sand, 250 µm HDPE sheet, 10 mm cement plaster and 75 mm thick PCC layer, as depicted in Fig. 1.

It has been reported that, the above liner was ineffective and caused the intrusion of ground water into the raw water reservoir as well as loss of fresh water into the surrounding via seepage, prior to the commencement of its intended function. The possible reasons behind the malfunction of the above liner system are discussed in detail in the following sections.

### 4.1 Role of Perched Ground Water and its Impact on the Performance of the Liner

During the initial design of the liner, the designer underestimated the existence of perched (or local) aquifer below the footprint of the raw water reservoir(s) and its impact on overall performance of the initial liner system with 250 µm HDPE sheet. In addition to this, the recharge capacity of this perched aquifer was proved to be significant. Investigations showed that the pumping of water from tube wells that were installed in the near vicinity of raw water reservoir at a rate of 9900 liters/hr resulted in decrease of water level in the tube wells to 8.4 m below the ground level from its original level in a short period of time (about three minutes). This indicates the storativity (storage capacity) of the perched aquifer is quite low. To demonstrate the rate of ground water recharge in this perched aquifer, the observed recuperation rates in the tube wells 1 and 2 are plotted in the form of Fig. 2.

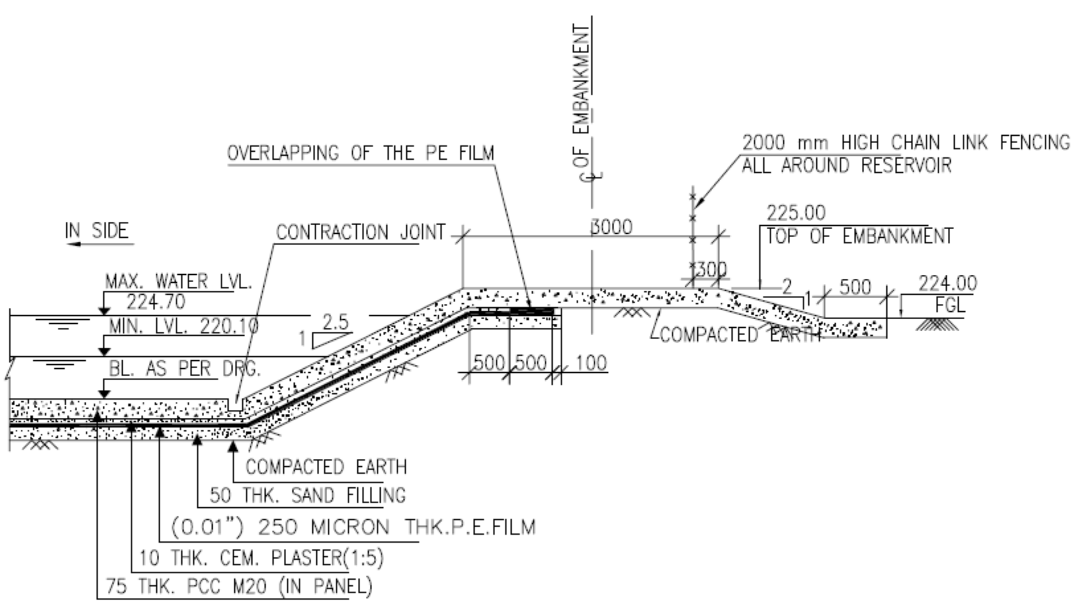


**Fig. 1:** Schematic view of initial liner with 250 µm HDPE sheet
(Drawing supplied by Areva Renewable Energies India Pvt. Ltd.)

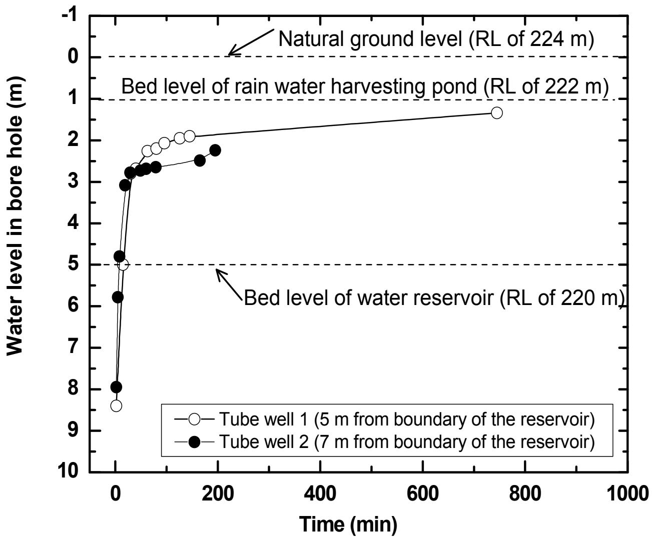


**Fig. 2:** The observed recuperation rates in tube wells (Data adapted from report submitted by Geo-Appraisal Pvt. Ltd.)

It can be observed from the Fig. 2 that, the recuperation rates are very dramatic and water level in these tube wells have reached their levels prior to the pumping (i.e., 1.5 m to 2 m below the ground level) within a period of 12 hours. This indicates that the recharge capacity of this perched aquifer is quite high. This may be due to its near vicinity to the rain water harvesting pond, whose average bed level is at RL 222 m (2 m below the ground level and 2 m above the bed level of the raw water reservoir). Further it can be noted from the Fig. 2, that, the higher recuperation rates caused the rise of water level in these tube wells to bed level of the raw water reservoir (i.e., RL 220 m) within first 10 minutes of recuperation. This indicates the existence of persistent local ground water above the bed level of the raw water reservoir (to the maximum extent of 2.5 m above the bed level). Though the unanticipated high ground water level below the raw water reservoir may be due to existence of perched aquifer, however its impact in terms of upward hydraulic gradient that may exert at bed level of reservoir has been conveniently ignored by the designer.

The elevation of ground water in the perched aquifer is highly dependent on climatic conditions of the site and water level in the rain water harvesting pond, which in turn alters the magnitude of upward hydraulic gradient (i.e., 2.5 m to 0.4 m) exerting at the base of the raw water reservoir. This upward hydraulic gradient at the base of raw water reservoir might have caused uplift of the entire liner including the 75 mm thick PCC layer and might have led to cracking of the concrete layer, in addition to the opening of construction and expansion joints in it. It can also be noted from investigations that, majority of chemical constituents in ground water are substantially higher than the prescribed values for construction and potable purposes. As a result the salty ground water is unsuitable for drinking and construction purposes.

## 4.2 Failure of HDPE Geomembrane

Observations showed that the 250 μm thick HDPE sheet has been punctured invariably during the installation, as depicted in Fig. 3. It can also be observed from the field notes that, at least one row of 75 mm thick PCC panels has been constructed without cement mortar between the HDPE sheet and concrete panels. This might have caused further puncturing of 250 μm HDPE sheet due to gravel particles present in the concrete. As reported in the field note, the HDPE liner is found to be damaged in many locations, prior to its installation. Further it is reported that, the seaming of joints between the adjacent sheets of HDPE liner is not executed as per the design drawing, particularly in terms of maintaining required overlap width.

**Fig. 3:** Photographic view of punctured 250 micron HDPE Liner (Photograph supplied by Areva Renewable Energies India Pvt. Ltd.)

As a result, the initial liner system was ineffective in terms of its performance as an advective and diffusive barrier. Further, the above scenarios might have transformed the entire raw water reservoir with its initial liner system as a hydraulic trap or hydraulic containment, as depicted in Fig. 4.

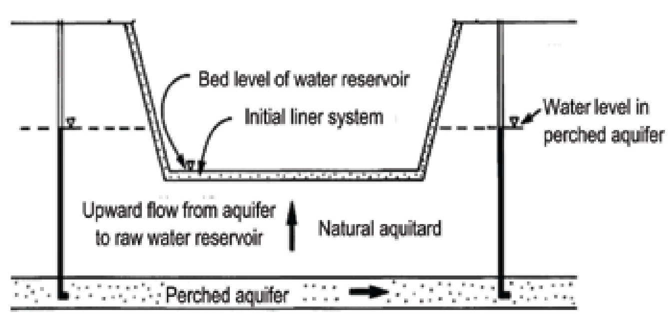


**Fig. 4:** Schematic representation of hydraulic trap concept (Adapted from Rowe et al., 2004)

To understand the synergetic effect of existence of upward hydraulic gradient at the base of the reservoir due to the perched aquifer, adverse chemical composition of ground water and ineffective initial liner system on the quality of water to be stored in raw water reservoir, the variation of observed chemical properties such as pH, EC and chloride contents of water during initial leak testing of reservoir-1 is presented in the form of Figs. 5 and 6. It can be observed from the above Fig. 6 that, both concentration of chloride and electrical conductivity value of the water in the reservoir increases gradually over a period of 140 days. This is mainly due to ingress of contaminants by advection phenomena owing to upward hydraulic gradient and by diffusion mechanism because of upward concentration gradient at the base of the reservoir. The relative contribution of these mechanisms (i.e., advection and diffusion) towards contamination of water in the raw water by the salty ground water primarily depends on net magnitude & direction of hydraulic gradient acting on the liner system.

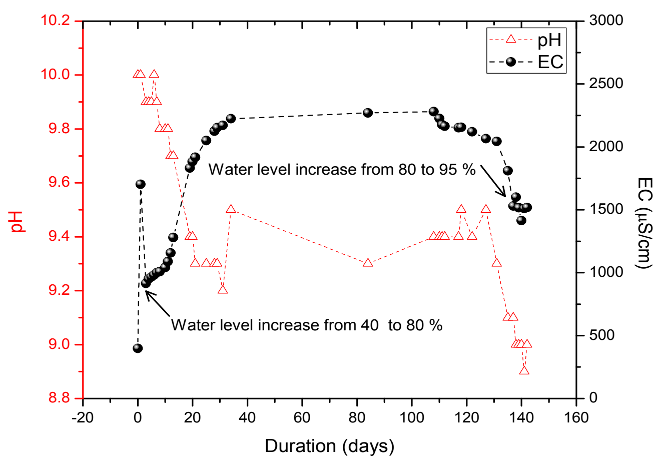


**Fig. 5:** Variation of pH and electrical conductivity of water in reservoir-1 during initial leak testing
(Data supplied by Areva Renewable Energies India Pvt. Ltd.)

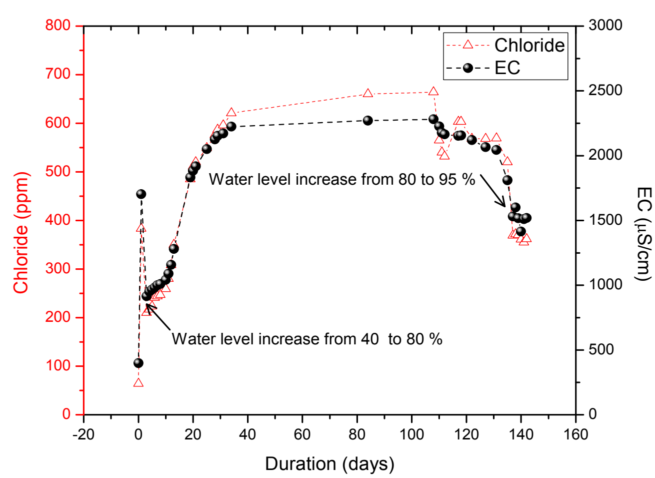


**Fig. 6:** Variation of chloride and electrical conductivity (EC) of water in reservoir-1 during initial leak testing
(Data supplied by Areva Renewable Energies India Pvt. Ltd.)

If the water level in the raw reservoir is lower than the water level in perched ground water (as depicted in Fig. 4); this will induce advective flow of salty ground water into the raw water reservoir. The severity of contamination of reservoir water depends on the magnitude of the damage that occurred to the liner system during construction, which in turn decides the impervious nature of the liner in terms of its permeability and the net upward gradient acting at the base of the raw water reservoir. If the water level in the reservoir is higher than the water level in perched ground water, as illustrated in Fig.7; this will induce diffusive transport of contaminants from salty ground water into the raw water reservoir, even though the net hydraulic gradient is downward. In this scenario the fresh water from raw water reservoir will also leaks into the ground water. As a result loss and contamination of fresh water will takes place, simultaneously.

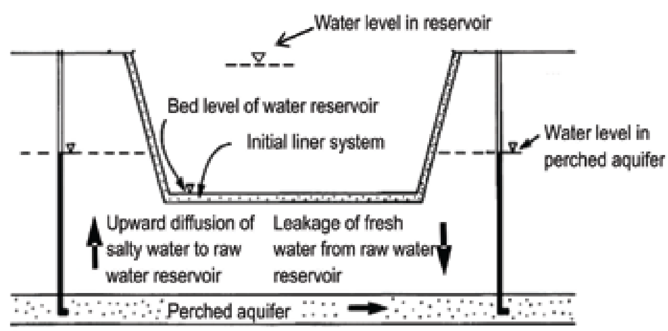


**Fig. 7:** Schematic representation of hydraulic trap concept (Adapted from Rowe et al., 2004)

It is worth mentioning here that, intact HDPE liners have demonstrated their ability as an effective advective and diffusive barrier towards many ionic inorganic contaminants. For all practical purposes these liners can be treated impervious, if they are constructed properly. This indicates that, the initial liner system failed to perform its intended function due to the above mentioned technical reasons. It was observed that the peak chloride concentrations in raw water reservoir-2 is substantially higher than that of reservoir-1, however their residual concentrations are comparable. This indicates that advection is predominant contaminant migration mechanism in case of reservoir-2, whereas diffusion controls the level of contamination of water in reservoir-1. Further, it was noted that the concentration of chloride, electrical conductivity and other ions (salts) in both the reservoirs are higher than the prescribed values for its use in plant. This demonstrates the unsatisfactory performance of initial liners with 250 µm HDPE sheets of reservoirs 1 and 2, as an advective and diffusive barrier.

## 5. INITIAL RECTIFICATION SCHEME

In order to minimize the seepage losses, to mitigate the contamination of fresh water by the salty ground water and to enhance the performance of the liner, the designer proposed the rectification scheme as shown in Fig. 8.

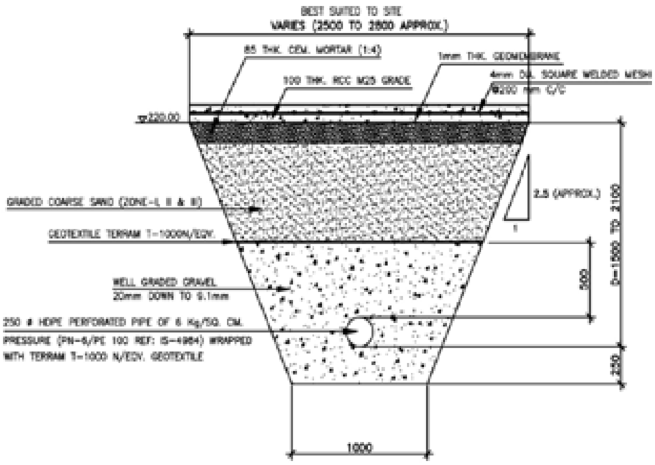


**Fig. 8:** Schematic view of proposed rectification scheme (Drawing supplied by Areva Renewable Energies India Pvt. Ltd.)

It can be noted from Fig. 8 that, the proposed rectification scheme consists of infiltration gallery along the periphery of reservoir bottom to control the head in perched aquifer, so that the upward gradient exerted at the base of the reservoir can be minimized. In addition, the proposed scheme envisaged the construction of new reservoir lining with 1 mm thick HDPE geomembrane, to minimize the seepage loss from the reservoir.

## 5.1 Failure of the Rectification Scheme

It can be noted from the Fig. 8 that the longitudinal and transverse infiltration trench consists of 250 mm diameter HDPE perforated pipe wrapped with non-woven geotextile, encapsulated in well graded gravel. This arrangement may be ineffective in controlling the ground water level, as the influence zone of the infiltration trench is limited to few meters away from its boundary. As a result mound of water table may form between the adjacent infiltration trenches, as shown in Fig. 9.

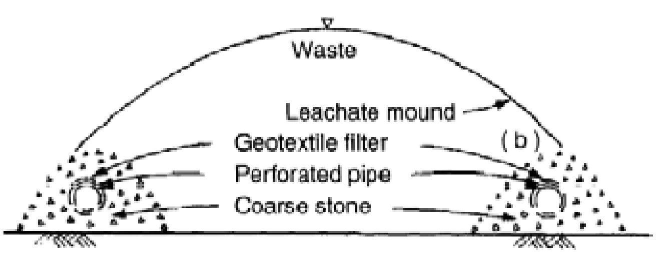


**Fig. 9:** Schematic representation of anticipated ground water mound between infiltration trenches (Adapted from Rowe et al, 2004)

It can be observed from the Fig.9 that, the water head at the center distance between infiltration trenches is maximum and is low at the edge of the infiltration trench. This scenario may reduce the head that caused the upward gradient at the edge of the trench, however it will have insignificant role in reducing the head at the center distance between the trenches. As a result the upward gradient exerted on the liner, particularly at the middle of the reservoir base, is more or less same as earlier. This will cause of uplift and cracking of the concrete panels and liner almost at the middle of the reservoir base, as depicted in Fig. 10.

**Fig. 10:** Photographic view longitudinal crack at middle of reservoir base (Photograph supplied by Areva Renewable Energies India Pvt. Ltd.)

Further the above scenario is responsible for formation of random crack pattern throughout the reservoir base, as shown in Fig. 11.

**Fig. 11:** Photographic view random alligator cracks at reservoir base (Photograph supplied by Areva Renewable Energies India Pvt. Ltd.)

As shown in Fig. 8, the 250 mm diameter HDPE pipe perforated with 8 mm diameter hole is wrapped with non-woven geotextile in view of protecting the pipe (particularly perforated holes) from physical clogging owing to the presence of grit or fines in the ground water. This arrangement may be effective in protecting the pipe from the physical clogging during its early service life. However, this may enhance the chemical clogging of the geotextile wrapped around the pipe, as confluence of flow of salt water near the pipe gives rise to high mass loading per unit time, and hence, increases the rate of clogging of geotextile and possibly drainage gravel. As a result, the long term performance of infiltration trench may not be assured.

As shown in Fig. 8, the 1 mm thick HDPE geomembrane is firmly sandwiched between 20 mm thick cement paste. This might have caused shearing of intact geomembrane as well as welded seams due to the uplift of entire liner system, as illustrated in Fig. 11, even though the break strain of HDPE geomembrane is 800 percent. The geomembrane only need maximum of 8 mm uplift perpendicular to its plane to reach its break strain. This is mainly due to the fact that, the movement of geomembrane in lateral direction is completely restricted in planar direction. The uplift of the entire liner by 8 mm is very much possible, as the width of the surface crack on concrete panel is almost 30 mm (refer Fig. 12).

**Fig. 12:** Photographic view random alligator cracks at reservoir base (Photograph supplied by Areva Renewable Energies India Pvt. Ltd.)

## 6. PROPOSED FINAL REMEDIAL MEASURES

In view of the entire history of the project, the following remedial measures can be adapted to mitigate the seepage loss as well as contamination of ground water.

As depicted in Fig. 13, the remedial measure-1 involves (from bottom to top) placement of approximately 150 to 250 mm thick drainage layer using 50 mm size uniform gravel on top of the existing reservoir base and a suitable geonet on slopes, followed by laying of 250 gsm non-woven geotextile with prescribed percent open area and pore size distribution, as separator layer. On top of this geotextile, a 50 mm thick protection layer using fine sand is envisaged to safeguard the liner from indentation due to the gravel in drainage layer. A 1.5 mm thick high quality HDPE geomembrane is placed on top of the protection layer, which is expected to perform as an efficient advective-diffusive barrier. The HDPE geomembrane is covered with a suitable concrete panel or fly ash bricks without pointing their joints with cement mortar. Further a 250 gsm nonwoven geotextile is essential in between HDPE geomembrane and concrete panel or fly ash bricks to protect the geomembrane from puncturing.

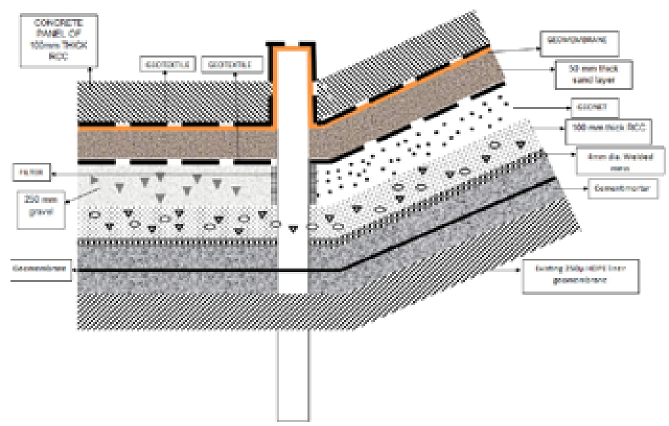


**Fig. 13:** Schematic view of Remedial Measure-1 (Figure not to scale)

The remedial measure-2 involves filling of the entire reservoir with sand up to RL of 224 m and construction of new liner system above the ground level, as shown in Fig. 14.

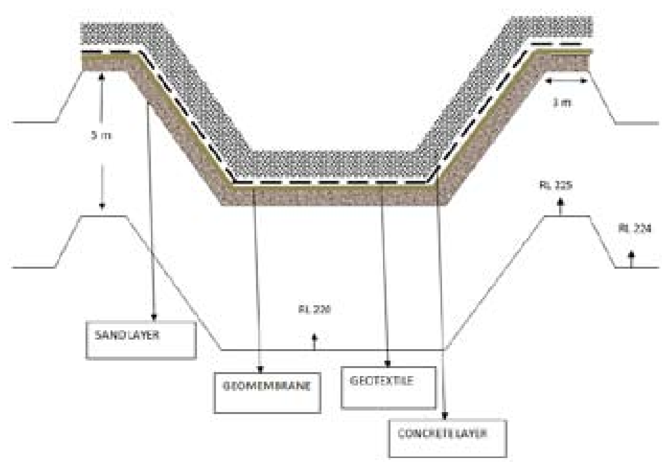


**Fig. 14:** Schematic view of remedial measure-2 (Figure not to scale)

## 7. CONCLUDING REMARKS

The attributes and challenges of CSP have set the ground for a possible way forward. Globally, CSP has a bright future. Countries such as USA, Spain and Israel are shaping the future. India too is optimistic about CSP and has set very aggressive targets in the near future. However, to set the ground right in the first place, every stage of the plant should be designed with extreme care and caution by considering all possible critical scenarios. Since, CSP is water-intensive, suitable design of the liner systems for the raw water reservoir is highly essential. This study is the best example to show how inconsideration of critical design parameters leads to the failure of the system. All the subsurface features need to be carefully considered before designing the liner system, as demonstrated by the study. Also, proper usage of geosynthetics should be carried out, having the material properties and geometrical considerations of the material in mind.

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# DESIGN AND DEVELOPMENT OF INCREASED STORAGE CAPACITY OF A LINED POND AT HINDUSTAN ZINC LTD.

**Ranjit Dash**
*Garware Wall Ropes Ltd., India*
**K. Rajagopal and D.N. Arnepalli**
*Indian Institute of Technology Madras*

**ABSTRACT**

*Construction of embankments on soft soil or sludge is a challenging task due to the inferior strength of the foundation soil and excessively large total as well as differential settlements. If the embankment is constructed as part of an engineered landfill project, it becomes even more challenging because of the requirement of leak-proof lining system, risk of failure and associated environmental disasters. The stability of the structure as well as the integrity of lining system design and engineering needs are to be critically analyzed before impalementing the project. The present study highlights the insights of expansion of a slurry pond dyke height from existing average height of 10 m to 12 m. The perimeter of the slurry dyke is approximately 1600 running meters. Out of this, space for filling soil and increasing the dyke height was available for 1200 m whereas for 400 m stretch, there was no space or access for construction. This posed a unique challenge in terms of both the design and planning for the construction activities including soil transport.*

*As the sludge surface is very soft and has very low shear strength to withstand the pressure from the fill material and liner, special construction techniques were deployed to enhance the strength of the underlying sludge. In parallel to the construction of dyke, vinyl sheet piles were driven 1 m away from the toe of the inner dyke to a depth of 4.5 m below the sludge surface all along the 400 m stretch to reduce the seepage. The inner dyke was constructed on reinforced subgrade which was achieved by laying slag, geogrid and finally geocell filled with aggregate intermittently. This allowed the construction of dyke of 2 m above the slurry surface. The inner dyke was lined with GCL and HDPE geomembrane which were connected with respective liners at the intersections of the outer dyke and thus ensuring the continuity of the lining system. The body of the dyke itself was also further strengthened by introducing geogrid reinforcement layers to ensure the strength and long-term performance of the dyke.*

*This manuscript discusses the details of the engineering requirements, the particular site conditions, proposed construction methodology, design and construction aspects. Particular difficulties encountered during the construction are also discussed in the paper.*

## BACKGROUND

The first stage expansion of the pond was carried out in 2010-11 with 1:1.5 slope of the dyke with reinforcement geosynthetics and a lining system comprising of HDPE geomembrane and geotextile. The site was operated as per the original design. However, as the capacity was about to be exhausted by 2016, management took a decision to check the feasibility of expanding it by another 2.0 m.

The technical feasibility of expanding the height and to ensure the sustainability and stability of the structure, the following techniques were adopted.

1. Reinforcement of the structure by using reinforcement geosynthetics across the height of the structure to enhance the stability.
2. Turfing on the outer slope for preventing erosion of the soil from the dyke section.
3. Extending the geosynthetic lining consisting of GCL, HDPE geomembrane on the inner embankment to the top of the proposed structure.
4. This pond is being used for disposal of Jarosite slurry. The leachate water is collected through the infiltration well and perforated pipelines, finally into a lined leachate pit and transferred to ETP for further treatment and reuse.

The maximum height of the existing embankment is 14 m and minimum height is 6 m. It was decided to increase the height of these embankments to 16.0 m and 8.0 m, respectively. the side slope is 1V:2H on the inner side of the slurry disposal pond and 1V;1.5H on the outside slope.

## DESIGN FUNDAMENTALS OF JAROSITE POND-III EXPANSION

The main component of designing the expansion of the jarosite pond-III by 2 m from the existing height is to carry out a slope stability analysis of expanded section throughout the periphery. In its first expansion of dyke from 558.4 m to 561.4 m, the height was increased by 3.0 m. The other important aspect was to join the existing lining system comprising of HDPE geomembrane to the new HDPE geomembrane. However, there were a few problems which made the project extremely challenging to design and implement.

The jarosite pond was in operation and slurry is being continuously discharged, at a flow rate of 80 $m^3$/hr, into the pond from the North dyke towards the South dyke. Also, as the ground slope is from West to East side, the slurry while flowing from North towards South direction slurry also was flowing towards the wall of the Eastern dyke, as shown in Fig. 1.

As there was no space on a 400 m stretch on the outer slope on part of Northern and Eastern dykes, the only way to increase the height was to make a dyke of 400 m on the inner side of the slurry pond while the pond is in operation.

Third challenge was to design a lining system which can connect the final lining system which will be inside the slurry pond to the existing lining system which will be outside of the inner dyke.

## A MEASURE TO MITIGATE SPACE NON-AVAILABILITY FOR EXPANSION OF JAROSITE POND

As sufficient space was not available on the outer side of embankment, a slightly steeper slope of 1:1.5 was erected with geosynthetic reinforcement layers. This geosynthetic was placed across the slope width at various depth intervals to increase its stability. This was successfully executed and in the year 2010. Over the past four to five years, there was no distress in the embankment, probably due to the introduction of geosynthetic reinforcement layers and relatively large factor of safety. As the maximum height for which it was designed was 14 m on the Eastern side, it is convincing that, we can adopt similar technology for expanding on North, South and West sides where the maximum height that will be attained is less than 14 m. However, as the overall structure's height is increasing by 2 m, additional reinforcement with uniaxial geogrid in combination with high strength geotextile is introduced in the new construction.

It is also seen that, as the site does not have enough space which will enable us to start the filling up of the soil at North-East corner and going towards South-East corner and raising the height of the dyke, it is decided to construct the dyke for 400 m length from North-East end towards South-East end on inner side the Jarosite pond instead of outer side. This embankment which will be constructed on the inside of the present dyke will be 2 m in height with 1:2 slope on either side and a top width of 4 m. As soon as the length of 400 reaches which is exactly half way of the length of the Eastern dyke, the mouth of the embankment will curve towards the existing dyke. From there onwards till the end of the South-East end, the dyke will be expanded on the outer side.

The steps in the increase of dyke height by 2 m on inside of the North-East corner and towards South-East side are described in the following.

Dewatering was to be done in the beginning which will reduce the level of the sludge surface and consolidate the mass underneath. This will be followed by placing of slag and soil. A separator geotextile is introduced followed by geocell of 150 mm height filled with 20 mm down size aggregates. The geocell layer is further overlain by a 100 mm thick layer of native soil. The embankment will now be constructed on the strengthened surface. The difficulty

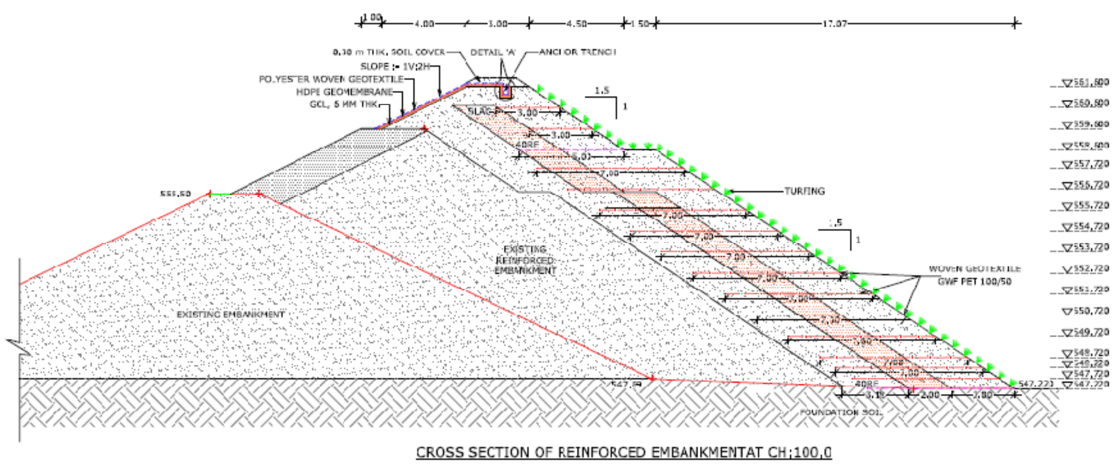
**Fig. 1:** Pictorial view of the Jarosite pond-III

envisaged was the continuity of the lining which will be now behind the outer embankment of newly constructed embankment. To compensate this difficulty, it is assumed that, HDPE liner on the existing anchor trench will be jointed with a new section of liner having length to cover the runout of the existing embankment, length of the proposed embankment bed and slope and anchor section of the expanded embankment, as shown in Fig. 2.

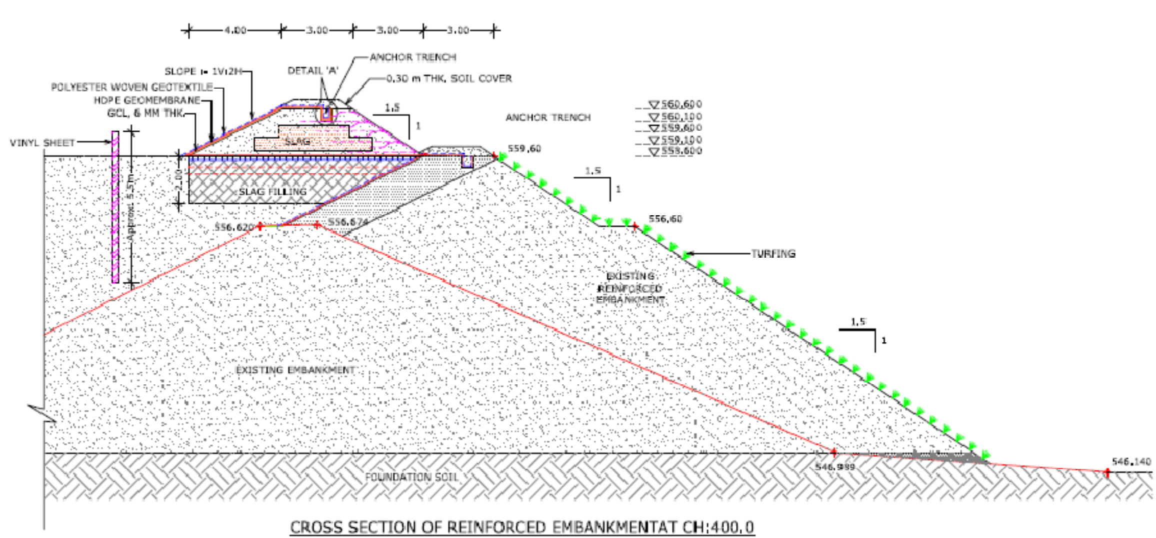
It is expected that when the consolidation and strengthening will happen on inside of the pond, water/ slush may come inside the proposed embankment footprint. Hence to avoid it permanently, a vinyl sheet piling is proposed at a distance of 2 m away from the toe of the inner embankment, as depicted in Fig. 3. It will be inserted up to a depth of 5.5 m which will be less than the height at which the sheet piling will touch the liner. It is also designed that the vinyl sheet piling will be 4.5 m below the soil and 1.0 m above the soil.

## OUTER SLOPE STABILITY ANALYSIS AND CONSTRUCTION

As the height of the dyke is expanded from 8-16m with slope of 1:1.5, it was estimated through engineering calculations that the slope will be unstable unless reinforced. For this reason, stability analysis performed in 2010 was taken as baseline information. Based on this, woven polyester geotextile and uniaxial geogrids were proposed as reinforcement material for constructing the embankment. This eliminated the formation of slip circle failure. The reinforced embankment was designed using the GEO5 and RESSA computer programs to achieve a factor of safety 1.5. For global slope stability check, Bishop's slip circle method was used to find the factor of safety. The designs are carried out for both static and seismic conditions.




a. Cross-section at Chainage 100




b. Cross-section at Chainage 400

**Fig. 2:** Schematic view of embankment height rising with HDPE liner extension

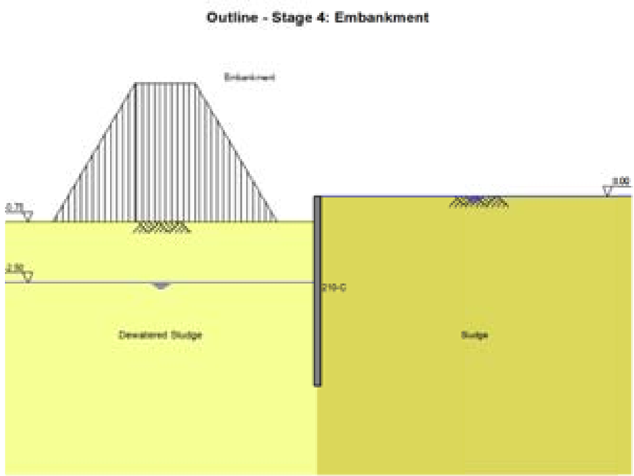



**Fig. 3:** Schematic view of embankment height rising with vinyl sheet piling

Following are the design parameters:

***Soil Properties:*** Based on the soil investigation report, the following soil properties are considered for design.

| Embankment Soil | | | |
|---|---|---|---|
| Unit weight | : γ | = | 21 kN/m³ |
| Angle of internal friction : | φ′ | = | 22° |
| Cohesion of soil : | c′ | = | 25 kPa |
| Saturated unit weight : | $\gamma_{sat}$ | = | 21 kN/m³ |

| ***Foundation Soil*** | | | |
|---|---|---|---|
| Unit weight : | γ | = | 20 kN/m³ |
| Angle of internal friction : | φ′ | = | a19° |
| Cohesion of soil : | c′ | = | 30 kPa |
| Saturated unit weight : | | = | 20 kN/m³. |

Uniaxial geogrids were proposed at bed level and intermediate berm level and woven geotextiles was proposed at various vertical spacings throughout the height of the slope based on the design requirement, as shown in Fig. 4.

**Fig. 4:** Pictorial view of geogrid reinforced embankment

## INNER BASE & SLOPE STABILITY ANALYSIS AND CONSTRUCTION

The biggest challenge was the stability analysis of the base and slope of the inner dyke. There were many questions going in mind while designing as well as constructing. Designing and construction of the inner dyke on the slurry surface while the flow was in progession was a big challenge. Hence, few design ideas were incorporated from arresting settlement to building a slurry cut off wall.

Hence, two layers of biaxial geogrids with 30 kN/m tensile strength were proposed with a vertical spacing of 300 mm within the 2 m thick slag fill and a 150 mm thick geocell layer filled with aggregates is proposed over the geogrid reinforced foundation, as illustrated in Fig. 5.

(a) (b)

**Fig. 5:** Application of geocells for strengthening of inner base

However, while the dilemma as whether to construct the slurry cut off wall through sheet pile followed by building the dyke or strengthening the underlying slurry surface followed by construction of slurry cut off wall posed a big obstacle. Finally, it was decided to strengthen the slurry surface by construction of hard standing which would allow the machine to operate.

Initially, the slag which was dumped posed a severe obstacle for the machines as well as the transport vehicles (as shown in Fig. 5a) and at one point of time, this looked impossible to construct. Hence, again design and drawing was checked to validate the original design concept would work eventually. The construction was slowed deliberately to allow the slag to settle and strengthen the underlying strata slowly and once it was felt that the bearing capacity has been mobilized, geogrid, separation geotextile and geocell was laid (as shown in Fig. 5b). After the geocell was filled up, it was observed that, heavy earth moving machines and transport vehicles could move and confirmed that the necessary strength has been achieved. After this, the dyke construction began, as illustrated in Fig. 6.

## INSTALLATION OF LINER SYSTEM

As per the design, a clay liner, geomembrane and woven geotextile layer was proposed as liner system on inner slopes of the expanded embankment. As difficulties were experienced in compaction of clay on the inner slopes of the embankment, it is proposed to lay geosynthetic clay liner with equivalent permeability criteria of < $10^{-9}$ m/sec.

The liner system on the outer dyke was fairly straight forward as the existing lining system was to be joined with the new liners, as shown in Fig. 7. To do that, the soil fill on the old liner was removed, the old liner was cleaned up and the new liner was joined and tested.

The difficulty came on the junction of inner dyke with outer dyke as the location of the inner liner of the outer dyke, outer liner of the inner dyke and the existing liner had to be joined in such a way so that, no open surface remains and the junction was welded properly. Extrusion welding was done at these points and further tested with water to cross check.

**Fig. 7:** HDPE lining on outside raised portion of the dyke

Another difficulty was to connect the old liner which was outside of the inner dyke slope toe line. As this liner must be welded and continually moved on the bed of the dyke and laid over the slope and the anchor trench.

As per original scheme, the HDPE geomembrane was to be protected against the UV rays and hence, a geotextile was laid over it, as shown in Fig. 8.

## CONCLUSIONS

It can be broadly concluded that, with proper knowledge and understanding of various geosynthetic materials, its properties and it applications, space as well as

**Fig. 6:** Construction of embankment on geocell strengthened inner base & sheet piling


**Fig. 8:** HDPE liner covered with geotextile protection layer

engineering limitations can be overcome. The described case study is a worthwhile demonstrated project wherein, space, materials, operating parameters still allowed us to expand the dyke while the dyke was in operating condition. The authors are keen on demonstrating the application of modern geosynthetic materials in large landfill projects with engineering, space and operating limitations.

## REFERENCE

Feasibility Report & Design and Drawings of the project "Expansion of Jarosite Pond-III height by 2.0 m from existing level 561.4m" for Hindustan Zinc Ltd-Debari-Udaipur, M/s Garware-Wall Ropes Ltd., Geosynthetics Division, Pune, February 2014.

# CALENDAR OF UPCOMING EVENTS

| Sl. No. | Event Name | Place | Date |
|---|---|---|---|
| 1 | 4th ICTG | Chicago, Illinois, USA | May 24-27, 2021 |
| 2 | EuroGeo7 | Warsaw, Poland | September 19-22, 2021 |
| 3 | 3rd EUROENGEO2020 | Athens, Greece | October 7-10, 2021 |
| 4 | 10th International Conference on Scour and Erosion (ICSE-10) | Arlington, Virginia | October 17-20, 2021 |
| 5 | Geo Asia 2021 | Taipei, Taiwan | November 22-26, 2021 |
| 6 | Geo Africa 2022 | Cairo, Egypt | February 21-24, 2022 |
| 7 | 12th International Conference on Geosynthetics: 12 ICG | Rome, Italy | September 18 - 22, 2022 |

# 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
- 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.
- **advertisement in the *IGS Member Directory* and on the IGS Website**
- **IGS Corporate Membership Plaque**
- **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
g.mannsbart@tencate.com

**Belgium**
Belgian Chapter 2001
Noel Huybrechts
jan.maertens.bvba@skynet.be
info@bgsvzw.be

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

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

**China**
Chinese Chapter 1990
Prof. Chao Xu
c_axu@tongji.edu.cn

**Chinese Taipei**
Chinese Taipei Chapter of the IGS
Dr. Jason Wu
Cga18241543@gmail.com

**Colombia**
Colombian Chapter 2013
Prof. Bernardo CaicedoHormaza
bcaicedo@uniandes.edu.co

**Czech Republic**
Czech Chapter 2003
ZikmundRakowski
president@igs.cz

**Egypt**
Egyptian Chapter (2018)
Prof. FatmaElzahraaAlyBaligh
baligh.fatma@gmail.com

**Finland**
Finish Chapter 2011
MinnaLeppänen
igsfin.secretary@gmail.com
minna.leppanen@tut.fi

**France**
French Chapter 1993
Nathalie Touze
nathalie.touze@irstea.fr

**Germany**
German Chapter 1993
Dr.-Ing. Martin Ziegler
service@dggt.de
ziegler@geotechnik.rwth-aachen.de

**Ghana**
Ghana Chapter 2012
Prof. Samuel I.K. Ampadu
skampadu.coe@knust.edu.gh
jkkemeh@hotmail.com

**Greece**
HGS, Greek Chapter 2005
Anastasios KOLLIOS
akollios@edafomichaniki.gr

**Honduras**
Honduran Chapter – Hon-duran Society of Geosynthetics 2013
MSc. Ing.Danilo Sierra D.
sierradiscua@yahoo.com

**India**
Indian Chapter 1988
M. Venkataraman
venkataramanm2000@gmail.com / uday@cbip.org

**Indonesia**
INA-IGS, the Indonesian Chapter 1992
GouwTjieLiong
amelia.ina.igs@gmail.com
ameliamakmur@gmail.com

**Iran**
Iranian Chapter 2013
Dr. Seyed Naser Moghaddas Tafreshi
Iran_geosynthetics@yahoo.com

**Italy**
AGI-IGS, the Italian Chapter 1992
Dr. Ing. Daniele Cazzuffi
agi@associazionegeotecnica.it

**Japan**
Japanese Chapter 1985
Dr. Hiroshi Miki
miki-egri@nifty.com

**Kazakhstan**
Kazakhstanian Chapter 2012
ZhusupbekovAskarZhagparovich
astana-geostroi@mail.ru

**Korea**
KC-IGS, The Korean Chapter 1993
Prof. ChungsikYoo
csyoo@skku.edu

**Malaysia**
Malaysian Chapter – 2013
Dr. Fauziah Ahmad
cefahmad@yahoo.com

**Mexico**
Mexican Chapter 2006
Dr. Rosember Reyes Ramirez
contacto@igsmexico.org

**Morocco**
Morocco Chapter 2014
HoussineEjjaaouani
ejjaaouani@ipee.ma

**Netherlands**
Netherlands Chapter 1992
E.A. Kwast
mail@ngo.nl

**North America**
North American Geosynthetics Society (NAGS)
(Canada, USA) 1986
Dr. Richard Brachman
richard.brachman@queesu.ca

**Norway**
Norwegian Chapter of IGS 2008
AinaAnthi
aina.anthi@vegvesen.no
tse-day.damtew@vegvesen.no

**Pakistan**
Pakistanian Chapter of IGS 2011
Mr. Hasan S. Akhtar
Secretary.igspk@gmail.com

**Panama**
Panama Chapter 2014
Amador Hassell
amador.hassell@utp.ac.pa

**Peru**
Peruvian Chapter 2001
Mr. Jorge Zegaree Pellanne
administracion@igsperu.org
aalza@tdm.com.pe

**Philippines**
Philippine Chapter 2007
Mr. Mark Morales
mark.k.morales@gmail.com
paul_navarro_javier@yahoo.com

**Poland**
Polish Chapter 2008
Mr. Jakub Bryk
sekretarz@psg-igs.pl

**Portugal**
Portuguese Chapter 2003
Jose Luis Machado do Vale
jose.vale@carpitech.com

**Romania**
Romanian Chapter 1996
Laurentiu Marculescu
adiol@utcb.ro

**Russia**
Russian Chapter of IGS (RCIGS) 2008
Dr. Andrei Petriaev
info@reigs.ru

**Slovakia**
Slovakian Chapter of IGS 2011
Dr. Radovan Baslik
radobaslik@gmail.com

**South Africa**
South African Chapter 1995
Mr. Johann Le Roux
secretary@gigsa.org

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

**Switzerland**
Swiss Chapter (2018)
ImadLifa
svg@geotex.ch

**Thailand**
Thai Chapter 2002
Prof. SuksunHorpibulsuk
suksun@g.sut.ac.th

**Turkey**
Turkish Chapter 2001
Dr. Ayse Edincliler Baykal
aedinc@boun.edu.tr

**United Kingdom**
U.K. Chapter 1987
Mr. Andrew Belton
committee@igs-uk.org

**Vietnam**
Vietnam Chapter (VCIGS) 2013
Dr. Nguyen Hoang Giang
giangnh@nuce.edu.vn

# 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 Kapadia,** *Secretary to Government of Gujarat and Director*, SSNNL

***Vice-Presidents***

- **Dr. R. Chitra,** *Scientist E,* 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***

- **Dr. G.P. Patel**, *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 Kapadia, Secretary to Government of Gujarat/Director, SSNNL

## IGS Student Award Winners from India

The IGS has established Student Paper Award to disseminate knowledge and to improve communication andunderstanding of geotextiles, geomembranes and associated technologies among young geotechnical andgeoenvironmental student engineers around the world. The IGS student award consists of US$1,000 to be used tocover 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, NationalInstitute 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 TechnologyJalandhar

## 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 ofgeosynthetics 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 ofGeosynthetics 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

## *Webinars on*

# CHALLENGES IN DEVELOPING CODES OF PRACTICE FOR GEOSYNTHETICS FOR DURABLE INFRASTRUCTURE DEVELOPMENT

**14 September 2020**

***and***

# CHALLENGES IN GEOSYNTHETIC AND GEOTECHNICAL TESTING

**15 September 2020**

**BRIEF REPORT**

With increasing emphasis being laid by the Government of India on fast development of Infrastructure, more particularly road infrastructure which gives better road connectivity to revitalize the economy, the role of Geosynthetics is becoming increasingly evident. India now produces a large variety of Geosynthetics of world standards. Bureau of Indian Standards and the Indian Road Congress have issued some guidelines/manuals/standards in this regards and are still working towards developing more documents of International Standards, to ensure their effective use through Codes of Practice and Manuals. In this context, to introduce our experiences together with the product range available in drafting the documents commensurate with International documentation, together with the enthusiasm of introducing newer applications, is a challenge.

Rational use of geosynthetics relies heavily on conformance to the Specifications of Geosynthetics in terms of engineering properties, installation damage and durability. Also, the properties where testing is 'under confined conditions' like pullout resistance and interface friction, are also dependent the correct evaluation of the geotechnical properties of soil.

Keeping the above in view, Central Board of Irrigation and Power (CBIP), Indian Chapter of IGS in association with Geosynthetics Technology Advisory Services LLP and Landmark Material Testing and Research Laboratory Pvt Ltd, Jaipur, organised Webinars on “Challenges in Developing Codes of Practice for Geosynthetics for Durable Infrastructure Development” on 14 September 2020 and “Challenges in Geosynthetic and Geotechnical Testing” on 15 September 2020, to share the experiences of the different experts, the challenges being faced in drafting such documents and the pressing needs of the country, for more documentation, and focus attention on relevant testing and evaluation of geosynthetics wherein the views of BIS and NABL are also shared along with other experts.

More than 200 participants took part in the discussions.

The Webinar on “Challenges in Developing Codes of Practice for Geosynthetics for Durable Infrastructure Development”, started with Welcome Address by Dr. G.V. Rao, Chairman, Geosynthetics Technology Advisory Services LLP, Jaipur followed by Introduction of the activities of Indian Chapter of IGS by Mr. M. Venkataraman, President, Indian Chapter of IGS.

The Webinar was then inaugurated by Mr. Vivek Kapadia, Secretary to Government of Gujarat and Director, Sardar Sarovar Narmada Nigam Ltd.

The keynote lectures, delivered by following professionals, were discussed:

- Mr. Saurabh Vyas, Techfab (India) Industries Ltd.
- Mr. Atanu Adhikari, Reinforced Earth India Pvt. Ltd.
- Dr. Ratnakar Mahajan, Maccaferri Environmental Solutions Pvt. Ltd.
- Mr. Sharokh Bagli, Strata Geosystems (India) Pvt. Ltd. -
- Prof. M. Venkataraman, President, Indian Chapter of IGS and Guest Professor, IIT Gandhinagar

The discussions session was coordinated by Dr. G.V. Rao, Former Professor & Head, Department of Civil Engineering and Dean, IIT Delhi & Visiting Professor, IIT Gandhinagar and Dr. Jimmy Thomas, Geotechnical Consultant.

Webinar on “Challenges in Geosynthetic and Geotechnical Testing” started with Welcome Address by Dr. Anil Dixit, COO, Geosynthetics Technology Advisory Services LLP, Jaipur followed by Introduction of the activities of Indian Chapter of IGS by Dr. G.P. Patel, Member Secretary & Treasurer, Indian Chapter of IGS and Secretary, Central Board of Irrigation and Power.

The Webinar was then inaugurated by Dr. I.K. Pateriya, Director (Technical), National Rural Roads Development Agency, Ministry of Rural Development, Government of India.

The keynote lectures, delivered by following professionals, were discussed:

- Mr. J.K. Gupta, Bureau of Indian Standards
- Mr. C. Venugopal, NABL
- Prof G.L. Sivakumar Babu, IISc. Bangalore
- Ms. Dola Roy Choudhury, Gcube Consulting Engineers LLP
- Col. Mahesh Narayan, RITES Ltd.
- Dr. Jimmy Thomas, Geotechnical Consultant
- Dr. Anil Dixit, Landmark Material Testing and Research Laboratory Pvt Ltd

The discussions session was coordinated by Prof Amit Prashant, Department of Civil Engineering, IIT Gandhinagar and Dr. Anil Dixit, Landmark Material Testing and Research Laboratory Pvt Ltd

# IGS NEWS

## IGS AMBASSADORS PROGRAM

The main task of the Ambassadors Program is to help increase awareness of the geosynthetics industry among members of the scientific community. Ambassadors achieve this objective through active dissemination of information on geosynthetics at various events worldwide.

Ambassadors offer support and assistance, when needed, to all chapters of the IGS. Ambassadors also help foster relationships between local and global geosynthetics groups with the objective of expanding and developing the local IGS Chapter. One way Ambassadors reach out to the scientific and engineering communities is by acting as official representatives of the IGS while attending or actively participating in conferences, lectures, and other educational events.

IGS Ambassadors may work with a local IGS Chapter, or potential new IGS Chapter, to help plan and organize events and activities. The Ambassadors can contribute to a specific program of an existing chapter or help organize an event with the goal of forming a new IGS chapter.

When no local chapter exists, Ambassadors coordinate a meeting with a local geosynthetics group to discuss the benefits of forming an IGS Chapter. The Ambassadors also assist in the formation of a new chapter by instructing the group on how to set up their membership roster and bylaws.

## IN 2015, THE IGS FUNDED AMBASSADORS TO EVENTS IN PERU, TUNISIA, ALGERIA, CHINA, COLOMBIA AND INDIA.

IGS Ambassadors Prof. Chiwan Hsieh (Chinese Taipei) and Prof. Fumio Tatsuoka (Japan) attended the 5th Chinese Geosynthetic Reinforcement Conference, which was held 22 May 2015 in Sichuan, China. The conference took place at Southwest Jiaotong University in Chengdu.

A meeting, hosted by Prof. Chao Xu, Vice President of the Chinese Chapter of the International Geosynthetics Society (CCIGS), was held with representatives of the Chinese Chapter. The meeting included discussions on the history and operations of the society along with updates on the activities of the CCIGS and IGS chapters throughout the world.

The Ambassadors Initiative helps foster improved communications between the society, regional council committees, and IGS chapters. This program allows for the sharing of future development plans and discussing ways to engage members of the geosynthetics community with the IGS on the regional, national, and international level.

Ambassadors may work with an IGS chapter to plan and organize activities including securing the venue, providing on-site support, and promoting and marketing an event. IGS members interested in the Ambassador program should contact their Regional Activities Committee to request sponsorship to help cover travel expenses.

## IGS EDUCATE THE EDUCATORS PROGRAM

Graduating engineering students often have had little or no exposure to the appropriate use of geosynthetics in engineering practices. The International Geosynthetics Society (IGS) Educate the Educators (ETE) program shows professors how the core principles of geosynthetics can be incorporated into their existing curricula.

The main goal of this program is to make sure that every student graduating from an undergraduate engineering program receives some basic exposure to geosynthetics. One way to carry out this action is to supply educators with the necessary knowledge and tools to help them integrate geosynthetic topics into their engineering curricula. ETE workshops provide attending professors with a host of resources to support this mission.

ETE programs are hosted through a partnership between an IGS Chapter and the IGS itself. In each program the IGS Education Committee helps organize the educational portion, including the sponsorship of the speakers, while the host Chapter is responsible for event management, attendee selection, fund raising, and logistics.

ETE events are open for registration to invited professors and academic staff. The expected attendance at each event is about 40 participants, with applications vetted and seats awarded based on an applicant's credentials and ability to influence curricula at their institution. The IGS and the sponsoring IGS Chapter provide all funding resources and logistic support for these events. ETE attendees are responsible for the cost of their travel to and from the host city. Accommodation, meals, and educational materials are provided free of charge by the event.

The IGS encourages all chapters to consider leading an ETE workshop in their country. Incorporation of geosynthetics in undergraduate education will positively influence the growth of these technologies and the expansion of the appropriate use of geosynthetics. Any geosynthetics group, IGS Chapter, and Professors, with the support of an IGS Chapter, are invited to submit a request for an ETE Workshop.

The benefits of hosting an EtE Workshop include:

- No cost to participating faculty for the duration of the workshop (though transportation to and from the workshop is the responsibility of the attendee)

- Educational materials are ready for immediate incorporation into existing curricula
- Focus on undergraduate education with the ability to expand to graduate courses
- Emphasizes the one, mandatory geosynthetics class that faculty should teach
- Generates interest in advanced level EtE events
- Significant impact on IGS Chapter activity and membership

## EDUCATE THE EDUCATORS (ETE) PROGRAM CONTACTS

IGS Chapters should contact the Chairs of their respected Regional Activities Committees to request support for an ETE event. For questions regarding the ETE curriculum, contact the IGS Education Committee Chair, Prof. Takeshi Katsumi at katsumi.takeshi.6v@kyoto-u.ac.jp.

## OVERVIEW OF THE ETE PROGRAM

In the 1980s, geosynthetic material development, polymeric research, and wide-scale manufacturing advances helped the field of geosynthetics mature quickly. Regulatory support, such as the RCRA Subtitle D rule from the US EPA, contributed significantly to growth and encouraged outside investment. However, a knowledge gap existed because few people in influential positions, such as lead regulators, policymakers, facility owners, and professors, were aware of geosynthetics.

A non-commercial Educate the Educators program was created in the 1990s to help overcome this gap. ETE events and workshops were scheduled and the results were substantial. Geosynthetic engineering provided a major growth area for geotechnical careers and the market grew substantially. As testament to this educational program, all major engineering firms now have designated geosynthetic experts on staff.

However, in the years since those first ETE events, the responsibility for passing on the latest information on geosynthetics has fallen to college and university engineering programs, just as it has for other materials sectors. This has presented a new challenge to the geosynthetics industry, as the market has developed faster than the education required to pass on the knowledge. In North America, for example, only 45 university engineering programs include geosynthetics education in their curricula.

The International Geosynthetics Society has revived the Educate the Educators initiative with the creation of a new non-commercial program, which multiple organizations have signed on to support (e.g., IFAI, Geosynthetic Institute).

## HISTORY OF THE IGS ETE INITIATIVE

A major goal that the IGS Council adopted during the 2010 strategy meeting in Guarujá, Brazil, was *"That geosynthetics become indispensable to the point that they are regularly included in engineering curricula and relevant design standards."*

With this long-term goal in mind, a specific objective was established for the IGS four year-plan to *"Begin our efforts to increase geosynthetic education at the undergraduate level."*

These efforts started with a pilot program that addressed the educational needs in the country of one of the youngest IGS Chapters: Argentina. Specifically, Educate the Educators ("Educando al Educador") took place in Villa Carlos Paz, Argentina, 26 – 28 May 2013. This is a good example of a joint effort between an IGS Chapter (IGS Argentina) and the IGS (through its Pan-American Activities and Education Committees).

The focus of the program was on undergraduate education with the larger objective that every student graduating from a civil engineering program in Argentina will have received a basic exposure to geosynthetics. The goal was perhaps a simple one, a basic one-hour class, offered to every civil engineering undergraduate in the country. Thirty civil engineering professors received a fellowship that covered their expenses to attend this premier training program on geosynthetics.

The program benefited from the involvement of the Argentinean Council on Civil Engineering Curriculum (CODIC), an agency that has encouraged development of this educational program.

The revival of ETE built upon the terrific precedent of teaching civil engineering professors about geosynthetics. That earlier iteration was established in North America more than 20 years ago, with Prof. David Elton leading the program from 1994 to 1998. Each year, 25 professors were competitively selected to take part in the courses, which were conducted at Auburn University (Alabama, USA). Attendees had only to arrange their travel to and from Auburn. Meals, housing, and workshop materials were all provided free of charge to the participants.

The format for what was at the time called the *"Professor Training Course for Geosynthetics"* included lectures by well-known professors, who reviewed extensive class notes prepared as handouts for the course. The lectures covered polymers, manufacturing, erosion control, steep slopes, landfills, mechanically stabilized backfill, pavement applications, embankments over soft ground, and filtration and drainage. The concept of "modular notes" was used, with the notes broken down into many stand-alone parts. In this way, different components of the training session could easily integrate geosynthetics material into existing courses.

Over 15 years after this initial experience in North America, education on geosynthetics at the undergraduate level remains a current, worldwide need. The IGS is not alone in recognizing this important need. Undergraduate students in every civil engineering program deserve to receive a basic exposure to the types, functions, and applications of geosynthetics.

## GEOTEXTILES AND GEOMEMBRANES: BEST PAPERS 2019

Following the Editorial Board meeting held in Yokohama in September 2006, it was decided that it would be desirable to recognise some of the best papers published in Geotextiles and Geomembranes, one of the IGS Journals. We started with Volume 23 and have selected the Best Paper in each subsequent year. This year, the Associate Editors and Editorial Board were charged with selecting what they considered to be the "Best Paper" published in Geotextiles and Geomembranes in 2019. Papers were considered for their contribution to the discipline in terms of providing significant new insights and/or of being of high potential impact on the discipline. All Technical Articles, except those where the Editor is corresponding author, were eligible. The selection of winning papers was decided based on a vote of the Editorial Board members.

Following a rigorous review of the papers, we are pleased announce that the winner of the Best Paper Award for 2019 is:

- A new generation of soil-geosynthetic interaction experimentation published in Geotextiles and Geomembranes 47(4):459-476 by A.M. Morsy, J.G. Zornberg, J. Han, D. Leshchinsky

Two papers also tied for Honourable Mention:

- Performance of geosynthetic-reinforced flexible pavements in full-scale field trials published in Geotextiles and Geomembranes, 47(2):217-229 by Thanongsak Imjai, Kypros Pilakoutas, Maurizio Guadagnini
- Investigating the mechanism of downslope bentonite erosion in GCL liners using X-Ray published in Geotextiles and Geomembranes 47(1):75-86 by T. Mukunoki, K. Sato, J. Fukushima, K. Shida, W.A. Take

The Honourable Mention papers are considered runners-up and, hence, have been judged to be amongst the four best papers published in Geotextiles and Geomembranes in 2019. Congratulations to all of the authors for their very significant contribution to the geosynthetics discipline.

## BEST GEOSYNTHETICS INTERNATIONAL PAPER FOR 2019

Geosynthetics International is an official journal of the International Geosynthetics Society (IGS) and serves the mandate of the society to disseminate important technical developments to its members.

We are delighted to announce results of the competition for best paper in Volume 26 (2019) based on votes cast by the Editorial Board Members. In this annual competition, the Editor and Editorial Board Chairman are not eligible for this award and do not vote.

The *"Best Geosynthetics International Paper for 2019"* award goes to two papers:

Abdelaal, F. B. and Rowe, R. K. (2019). Degradation of an HDPE geomembrane without HALS in chlorinated water. Geosynthetics International, 26, No. 4, 354–370.

AbdelRazek, A. Y. and Rowe, R. K. (2019). Performance of GCLs in high salinity impoundment applications. Geosynthetics International, 26, No. 6, 611–628.

The following two papers were selected as runner-up and thus receive honourable mention as "one of the best papers published in Geosynthetics International in 2019":

Yang, K.-H., Thuo, J. N., Chen, J.-W. and Liu, C.-N. (2019). Failure investigation of a geosynthetic-reinforced soil slope subjected to rainfall. Geosynthetics International, 26, No. 1, 42–65.

e Silva, R. A., Negri, R. G. and de Mattos Vidal, D. (2019). A new image-based technique for measuring pore size distribution of nonwoven geotextiles. Geosynthetics International, 26, No. 3, 261–272.

All IGS members have free access to these papers, as they have free access to all papers published in the Journal.

Geosynthetics International is published by ICE Publishing a division of Thomas Telford Ltd.

## THE GIROUD LECTURE – A SPEAKER'S PERSPECTIVE

The renowned Giroud Lecture has been a pioneering platform for geosynthetics education for nearly 30 years. Named in honor of J.P. Giroud, it has seen some of the most experienced members of the geosynthetics community sharing their ideas on an international stage.

Given every four years during the International Conference on Geosynthetics, the lecture has until recently been solely delivered by men. This changed in 2018 when Dr. Nathalie Touze, Vice President of the

IGS, became the first woman to give the Giroud Lecture, at the 11th ICG in Seoul, Korea.

As the IGS Council considers nominations for the next speaker at the 12th ICG in Rome in 2022,

## IGS SETS PLANS FOR 2021

IGS Officers and Council Committee members met online recently to confirm developments and set priorities for the year ahead.

Highlights during the virtual meetings included official confirmation of the IGS's new charitable body, the IGS Foundation. The organization aims to improve the learning and adoption of geosynthetics worldwide. It will build on more than $100,000 USD of donations already received.

The popular IGS Educate the Educators (EtE) programme was also strengthened with the ratification of EtE Minimum Guidelines, outlining the basic requirements expected at any activity. This will help members deliver an event with impact.

The Chairs of committees were formally confirmed, as well as the creation of the Sustainability Committee, which was previously a Task Force. Chaired by IGS Vice President Nathalie Touze, it is committed to proactively furthering the understanding of the positive role geosynthetics can play in a sustainable future. Other committee chairs were confirmed as Pietro Rimoldi (TC-R), Eric Blond (TC-H) and Jonathan Shamrock (TC-B).

A new Task Force was also created to develop an IGS University Online Lecture Series.

- Discussions also centered on how each committee could plan activities that incorporated the aims of IGS President Chungsik Yoo's strategic plan, which are to:
- Enhance and optimize Technical Committee activities
- Improve education and knowledge sharing through up-to-date communication tools
- Enhance awareness of geosynthetics for sustainable development and global challenges
- Get connected with members
- Get more young members involved

## THE IGS FOUNDATION

The IGS Foundation was formed in late 2019 and aims to boost efforts to increase the understanding of geosynthetics worldwide through education programs, adding to existing IGS initiatives such as Educate the Educators.

The organization has already secured sponsorship from industry stars including geosynthetics pioneer J.P. Giroud, as well as businesses such as TRI Environmental, Solmax, SKAPS, and others, so far raising more than $100,000 in donations.

The Foundation recently supported 19 engineering students by providing scholarships for them to attend the virtual GeoAmericas 2020, giving these young people a unique opportunity they might not have otherwise had.

## THE GEOAMERICAS 2020 CORPORATE CASE STUDY COMPETITION WINNERS

During GeoAmericas 2020 Online (26 – 31 October 2020), the International Geosynthetics Society (IGS) held its first Corporate Case Study competition open exclusively to IGS Corporate Members. A shortlist of seven entries were presented during the conference, all of which focused on geosynthetic projects in the Americas.

The winning entry from GeoAmericas now goes forward to the International Final Corporate Case Study Competition in September 2022 at the 12th International Conference on Geosynthetics (12ICG) in Rome, Italy. Winning case studies will also be promoted on the IGS website and in IGS social media feeds.

Additional corporate case study competitions will be held at other IGS regional conferences (EuroGeo, GeoAsia, GeoAfrica).

## GEOAMERICAS 2020 CORPORATE CASE STUDY WINNERS

### Geo Americas Winner

- Application of Geosynthetics Solutions in the Construction of 'El Salitre' Artificial Beach – Chile by Fernando Ruiz & Markus Wilke of Huesker Synthetic GmbH

Photos by HUESKER

### GeoAmericas 2020 Runner Up

- 25m3 Geotextile Bags and Geotextile Tubes Used to Protect a 42" Pipeline against Scouring, 30m Deep on the Sea Bed – Colombia by Nicolas Ruiz of TenCate

Geosynthetics Americas & Mauricio Rendón G. of Geomembranas SAS

Photo by TenCate Geosynthetics and Geomembranas SAS

Additional Shortlisted Presentations

- Reinforced soil slopes for mine remediation – Peru
- Geotextile bags to reconstruct causeway/road – Peru
- Soil nailed slopes with erosion protection adjacent to dam – Brasil
- Erosion protection for key infrastructure – Costa Rica
- Channel Lining with G-CCM to reduce irrigation water leakage – Chile

## FREE ACCESS TO GIROUD LECTURES

Thirty years of Giroud Lectures are now available to download for free.

The Institution of Civil Engineers is now allowing free access to all the lecture papers via the website of Geosynthetics International, the official journal of the IGS.

The Giroud Lecture was established by the IGS in 1994 in recognition of the invaluable contributions of Dr. J.P. Giroud to the technical advancement of the geosynthetics discipline and his central role in the development of the IGS.

Included in the Giroud Lectures, and in recognition of Dr. Giroud, is the inaugural 'first Giroud lecture' which was presented at the opening session of the 5th International Conference on Geosynthetics in 1994 before the Giroud Lecture was officially established. Giroud Lectures have followed every four years during the opening of the International Conference on Geosynthetics ever since.

There have been six speakers since the inaugural lecture; Professor Robert Koerner (1998), Prof. Kerry Rowe (2002), Chris Lawson (2006), Prof. Heinz Brandl (2010), Prof. Richard Bathurst (2014) and IGS Vice President Dr. Nathalie Touze (2018).

Their fascinating lectures are now available in full – a unique resource for practitioners at all stages of work, research and interest in the industry.


The IGS Giroud Lecturers. Top Left to Right: Professor Robert Koerner (1998), Prof. Kerry Rowe (2002), and Chris Lawson (2006). Bottom Left to Right: Prof. Heinz Brandl (2010), Prof. Richard Bathurst (2014) and IGS Vice President Dr. Nathalie Touze (2018)

# INDIAN CHAPTER OF INTERNATIONAL GEOSYNTHETICS SOCIETY

## EXECUTIVE BOARD 2020-2022

# 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 <u>must.</u>**

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 **uday@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**: **uday@cbip.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 Membership for 01 Calendar year | : | Rs. 2,500.00 |
| • Individual Membership for 10 Calendar years | : | Rs. 12,500.00 |
| • Individual Membership for 20 Calendar years | : | Rs. 25,000.00 |
| • Institutional Membership for 01 Calendar years | : | Rs. 25,000.00 |
| • Institutional Membership for 02 Calendar years | : | Rs. 45,000.00 |
| • Institutional Membership for 03 Calendar years | : | Rs. 60,000.00 |

**For membership and other details, please contact**

**A.K. Dinkar**
*Member Secretary*
International Geosynthetics Society (India)
C/o Central Board of Irrigation and Power
Plot No. 4, Institutional Area
Malcha Marg, Chanakyapuri
New Delhi 110 021

Tel. : 011 2611 5984/2611 1294
Fax : 011 2611 6347
E-mail : uday@cbip.org, cbip@cbip.org

# Innovative Technologies Building Trust










**Garware Technical Fibres Ltd.**, Geosynthetics Division offer products and services in the field of civil engineering & infrastructure development. The division has a team of highly qualified and fully competent civil, geotechnical, transportation and environmental engineers to undertake design and detailed engineering for a wide range of applications. We have a full fledged R & D centre recognized by the Government of India. A number of world class products have been developed at our plant and we have 6 patents to our credit as on date.

We use internationally accepted softwares like Geo5, Talren, MSEW, ReSSA, Reslope, GeoCoPS, FoSSA, etc. to design solutions in areas like roads, railways, environmental and waste management, coastal and water front structures, etc. Our team of qualified and experienced project managers, engineers, technicians and supervisors has been successfully implementing turnkey projects involving geosynthetic / geoenvironmental solutions with utmost efficiency and quality.

## Services delivered include

- Problem analysis
- Propose appropriate solutions
- Design & consultancy services
- Product supply
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- Turnkey implementation

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- Polymer rope gabion
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- Nonwoven geotextile
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**Garware Technical Fibres Ltd.**
**Geosynthetics Division**

**Head Office:**
Polt No. 11. Block D-1, MIDC, Chinchwad,
Pune - 411 019, India. Tel.: +91-20-3078 0000 | 3078 0187
Fax: +91-20-3078 0350.
**Email :** geo@garwaregibres.com
**Website :** www.garwarefibres.com