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Geo-Composite Drain for Capillary Cut-Off and Horizontal Sub-Surface Drainage in High Altitude Roads in Uttarakhand – A Case Study

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Abstract. Geosynthetic material are increasingly finding their way into the design and construction of road infrastructure in recent years. In this domain, drainage of backfills of retaining walls, subsurface drainage, railway track-beds, etc. are some areas where higher drainage capacity of geocomposites are better suited. This case study deals with a project location where drainage geocomposite has been used below the flexible pavement structure in a high altitude road in cutting formation in order to provide capillary cut-off as well as drain out the subsurface water which flows from the hill side on to the road pavement. Water saturates the road shoulder and subgrade during monsoons, severely compromising the modulus of resilience of the composite pavement structure. Mud-pumping is also seen in flexible pavements due to traffic load, causing much distress to the pavement wearing course, like loss of tensile strength in bituminous layers, stripping of bitumen from aggregate and eventually ruts and potholes. The provided geo-composite was found to provide sufficient factor of safety against the expected flow quantities. Post installation of the Geocomposite drain, no distress or water accumulation on pavement surface has been observed, even after 2 seasons.

Keywords: Geocomposite, Flexible pavements, Hill roads, Horizontal Drainage

1 General

Geosynthetics have found their way into the design and construction of road infrastructure in a big way in the recent years. These materials come in different forms, such as geotextiles, geogrids, geonets, geomembranes, and geocomposites, each serving a specific function. Geotextiles, also known as filter fabrics, find wide and distinct uses in geotechnical engineering applications in -

i) Separation of dissimilar materials placed contiguously to avoid intermixing
ii) Reinforcement of weak soils (or other load bearing materials like flyash, slag, etc.)
iii) Filtration, where the water flows across the textile and works to retain the fines
iv) Drainage, where the water flows within the geotextile (in-plane) or in cross plane direction

In most cases, the geotextile performs more than one function. Only the textile is to be designed for each application separately considering the engineering requirements.

2 Introduction

Geocomposites are manufactured as a combination of any two or more synthetic materials like geotextiles, geogrids, geonets, geomembranes, etc. in laminated or composite form, to achieve desired engineering properties. One of the more popular and extensively used geocomposite is a drainage geocomposite, which is formed by combining a geotextile with a drainage core in the form of extruded geonet, or cuspated sheets and yield much higher flow properties than even very thick geotextiles.

In the present context, we are essentially looking at the capillary break and drainage function of the geocomposite material. The drainage function can be achieved by using plain geotextiles for low volumes of flow water. For higher water flow conditions, different types of drainage geocomposites are better suited. The drainage core provides large in-plane flow capacity whereas the geotextile provides separation, filtration, some drainage and capillary break actions. The capillary break is provided by draining out the capillary water through the drainage core. The selection of geocomposites depends on site specific soil and moisture conditions, availability and cost considerations.

Flow performance of geo-composites are found to deteriorate over time due to –

i) Elastic deformation of the adjacent geotextile intruding into the drainage core space
ii) Creep deformation of the drainage core itself and / or creep deformation of the adjacent geotextile intruding into the drainage core space
iii) Chemical clogging of the geotextile and / or drainage core
iv) Biological clogging of the geotextile and / or drainage core

Usually manufacturers provide reduction factors for different range of products and different application areas so as to provide allowable flow rate to be used in design. The short term flow rate is determined from short term tests as per relevant codes.

3 Sub-surface Drainage Requirement in Flexible Pavements

It is well known that ingress of water into the pavement crust is one of the major causes of distress in flexible pavements. Water in the asphalt surface leads to loss of tensile strength, stripping of bitumen from aggregate and reduction of stiffness modulus of the order of 30%. Moisture in the unbounded base and sub-base layers lead to loss of stiffness of around 50%, thereby causing large deformation under load in flexible pavements. It causes erosion of fine aggregates/soil, erosion of shoulders, and eventually ruts and pot-holes [9].

In hill roads in cutting, the source of water can be from rainfall, snow melt, seepage of water from hill side, waterfalls, capillary rise of water from the soil subgrade, etc. Water enters the crust through cracked / rutted surface, joints and edges, pervious shoulders, pervious/damaged side-drains, etc. Surface drainage as well as sub-surface drainage are required for keeping the structural elements of the pavement in well drained conditions – the latter having been mostly neglected in practice. Sub-surface drainage requirement is both vertical (behind retaining and breast walls) as well as horizontal (open graded granular sub-base). However, with the advent of geotextiles and geo-composites, good quality vertical as well as horizontal subsurface drainage options are available.

In case of hill roads in the Himalayan region, many situations are seen where the phreatic line comes out of the cut slope surface, leading to seeping surfaces. This situation is more prolific in the summer seasons when the snow melts in the upper reaches and otherwise dry hillsides start seeping water. Perforated pipe drains in the hillsides [7] may not be feasible due to presence of boulders, or fractured rocks with irregular drainage paths.

4 Conventional Subsurface Drainage Systems

A typical flexible pavement consists of an asphaltic layer, a base layer of Wet Mix Macadam or Crusher Run Macadam, a granular sub-base (GSB) layer for drainage and the available or compacted subgrade. In case of hill roads in cutting, the subgrade available is part of a hill slope and has to be checked for stability. In case of high altitude roads, a capillary barrier is also provided in the form of a sand layer, to ameliorate the effects of freeze-thaw action in frost susceptible soils [10]. The GSB layer is provided in two parts – one upper sub-base (drainage layer) and a lower sub-base (separation layer). The drainage layer (Grading 2 of IRC 37) has a typical permeability of 15 to 45 m/day [9].

One of the major problems faced by field engineers in conventional GSB drainage layers, especially in hill roads are poor quality control of GSB material and its placement, blockage of longitudinal drains and cross drainage facilities by debris leading to pooling of water over the pavement, large variations in discharge from streams leading to design failure, etc. Furthermore, high altitude hill roads also suffer from additional factors like –

- Steep slopes in catchment area leading to sudden floods,
- Snowfall accumulating on pavement surface and its clearing operations leading to severe damage to top bituminous layers,
- Diurnal freeze-thaw on road surface creates cracks on road surface,
- Seasonal waterfalls damaging the pavement structure as well as spraying the shoulders and road surface continuously during monsoons

5 Geocomposite Sheet Drains for Subsurface Drainage

A geocomposite sheet drain having sufficient in plane flow capacity is an excellent drainage alternative, as being a manufactured item, variations in quality and engineering properties are minimal. Sheet drains do not suffer from any day lighting problems (Less UV stability may result is loss of material at the exposed edge over time, which is inconsequential). It works as a separation and filtration material as well as a capillary break. The placement of GCD is usually over the soil subgrade [4].

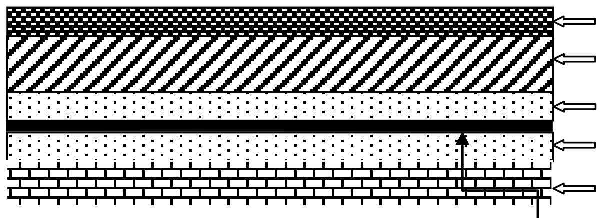

Fig. 1. A Typical section showing placement of Geocomposite Drain

The requirements of a good horizontal geocomposite drain (GCD) are :

i) Sufficient stiffness to support traffic without significant deformation under dynamic loading, ii) Inflow capacity greater than infiltration from adjacent layers, iii) Sufficient transmissivity to rapidly drain the pavement section and prevent saturation of the base, iv) Sufficient air voids within the geocomposite to provide a capillary break, v) Prevent fines from the subgrade or subbase to enter the drainage core.

For the GCD to act as a capillary barrier, it is important that it has a capacity for drainage that leaves an air gap at the top of the drainage core even with traffic load [2]. In hill road sections where peak flow is much higher than the average flow, it is not always possible to provide such high capacity subsurface drains. In such cases, the sand layer provided below the GCD also helps as a capillary break.

5.1. Design Methodology

The design of a GCD is done to evaluate the flow requirement of the drainage system and deciding on a suitable GCD whose allowable rate is such that a suitable FOS is achieved with reference to the required flow rate to provide effective drainage. The Geosynthetic Research Institute (GRI) Standard GC8 methodology has been followed to arrive at the factor of safety [4]. The design process consists of :

Determination of the required drainage capacity of the system (q_{reqd}) – The longitudinal and cross drainage provided in hill roads take away most of the storm water flow. Only a fraction of the total discharge is required to be carried by the subsurface drainage system, and that too, at specific vulnerable locations [9,10]. In a hill road the water entering the subgrade may come from adjacent hill faces, rainfall in the catchment area, percolation of water through the wearing surface, capillary rise from the water table, or from snow melt. It is only possible to identify locations and estimate the flow from site observations.

Short term or basic flow capacity (100 hours testing condition is required by GRI GC 8) of the GCD(q_{basic}) - It depends on the type of GCD core chosen (e.g. biplanar/triplanar geonet, geomat, cuspated core, etc.), hydraulic gradient, normal stress on the GCD, testing boundary conditions (soft/soft contact, rigid/soft contact), test seating time, etc. The short term or basic flow rates of the GCD can be determined in accordance with ISO 12958 – 2010 (or ASTM D4716). However, most of the time design is done as per technical data sheets provided by the reputed manufacturers. The GCD used in this pilot project is realized by thermo-bonding an extruded mono-filament drainage core, with two similar non-woven geotextiles on both sides, to act as filtering / separation layers. The 3-D draining core has longitudinal parallel channels. The technical details and calculations are given in subsequent sections.

Estimation of Normal Stress on the GCD :

The normal stress on the GCD is essentially due to tyre pressure of traffic. IRC 37 : 2012 recommends that for stress analysis, a surface pressure of 0.56 MPa with with point load of 40kN be adopted for pavement design [7].

P = 40,000 N q = 0.56 N/mm^2

But $q = P/\pi a^2$ Hence $a = \sqrt{(P/\pi q)}$ We get a = 151 mm say 150 mm

The stress levels at the top of subgrade level is worked out based on Burmister's two layer theory [6]. Here each layer is assumed to be homogeneous, isotropic and linearly elastic with an Elastic Modulus (E) and Poisson Ratio (ν). The top layer has a finite thickness and the bottom layer has infinite depth. The stresses in a two layer system depend on the Elastic Modulus Ratio (E_1/E_2) and the thickness to radius ratio (h_1/a); where

h_1 = thickness of top layer a = radius of surface pressure,
q = surface pressure and σ_c = interface stress at centre line below loaded area of radius 'a'

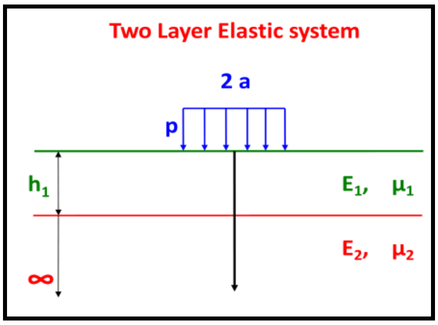

Fig. 2. The Two Layer Pavement System

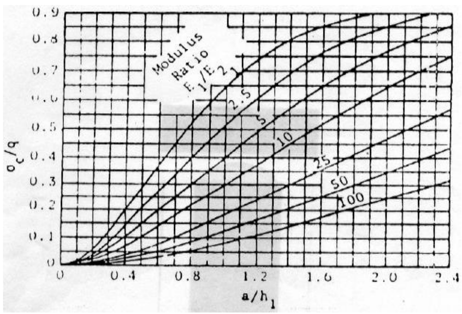

Fig. 3. Variation of Interface stress with E_1/E_2 The curves assume $\nu = 0.5$ (After Huang 1969)

It can be seen that higher E_1/E_2 ratio for a given a/h_1 leads to a lower σ_c/q meaning less load transfer to the subgrade and hence on to the GCD.

It is revealed in various literature that the typical E values for Asphalt, Aggregate Base Courses and Subgrade of silty sand are 3500 MPa, 450 MPA and 20 MPa respectively [1]. Although the pavement crust is made of three layers, i.e. GSB, CRM and DBM/BC layers, considering a composite top layer hardly makes a difference. In fact by neglecting the impact of higher E value of the bituminous layer, we err on the side of caution. We can take the E value for the Aggregate base courses as the governing E value and find the vertical stress at the top of the subgrade level below the loaded area. At best, an equivalent E value considering all layers above the subgrade may be calculated using the relation [3] :

$$E_{eq} = \Sigma H_i E_i / \Sigma H_i$$

Now E_1 / E_2 is calculated by taking a suitable value of E for the soil subgrade. This method, however neglects the impact of lower E-value of the subgrade on the E-value of the pavement crust.

Alternatively, we can use the design method given in IRC 37 – 2012 to arrive at the ratio E_1 / E_2 [8]. When both sub-base and the base layers are made up of unbound granular layers, the composite resilient modulus of the granular sub-base and the base is given as:

$$M_{R\_granular\ overlay} = 0.2 * h_1^{0.45} * M_{R\_subgrade}$$

Where h_1 = total thickness of granular sub-base and base (in mm)
M_R = Modulus of Resilience of respective layer (in MPa)
Poisson's ratio for granular bases and sub-bases is recommended as 0.35.

Modulus of resilience is the elasticity modulus of a material under repeated loads. The pavement layers are normally not elastic and will show plastic deformations in every load cycle. But if the traffic load is less than the strength of the material, after a certain number of load repetitions (approximately 100 – 200 cycles), the strain is almost completely recoverable and can be considered elastic [14]. In such case, the Elastic Modulus can be taken as the Moment of Resilience. In a triaxial test, Moment of Resilience is defined as the ratio of deviator stress to elastic strain of the soil.

As such, if we assume that $M_R = E$, then

$$E_1 / E_2 = M_{R\_granular\ overlay} / M_{R\_subgrade} = 0.2 * h_1^{0.45}$$

It can be seen that the modulus ratio in this case, does not depend on the individual M_R values, but is empirically related to the thickness of the pavement layer. For typical values of E, h_1, etc. the IRC method yields higher load transfer at the subgrade level, and leads to a conservative design for the GCD.
Having arrived at the E_1 / E_2, and a/h_1 values, σ_c / q can be read off the graph in Fig 3.

It is also seen that even an increase of surface pressure to 0.80 MPa has little effect on the absolute normal stress levels on the GCD.

Assessment of allowable flow rate (q_{allow}) -
The allowable flow rate is achieved by reducing the basic flow rate for various factors detailed below :

(a) Reduction factor for creep to account for long term behavior (RF_{CR})
(b) Reduction factor for chemical clogging (RF_{CC})
(c) Reduction factor for biological clogging (RF_{BC})

It is pertinent to mention here that ASTM D7931 2018 also envisages another reduction factor for geotextile intrusion into the core for continued stress exposure (RF_{GI}). This is beyond what is expected during the 100 hour testing of the product, and will also depend, in case of sub-surface drainage application in roads, on the type and intensity of traffic, structure and material properties of the GCD core, material and properties of the geotextile, wetting conditions of the geotextile, etc.

$$q_{allow} = q_{basic} \left[\frac{1}{RF_{CR} \times RF_{CC} \times RF_{BC} \times RF_{GI}} \right]$$

And

$$FOS = q_{allow} / q_{reqd}$$

The FOS depends on reliability of allowable flow rate (product dependent) as well as required flow rate (site dependent). The Compilation of Codes, Rules and Regulations of the State of New York Department of Environmental Conservation Part 363 Sub-part 6 (6 CRR-NY 363-6.12 Geosynthetic Drainage Layers) specifies that for hydraulic flow capacity calculations in landfill leachate collection or drainage systems, the designer must use a factor of safety of at least **three**, in addition to reduction in flow rate due to creep, biological and chemical clogging [14]. Any higher FOS would result in requirement of very large flow capacity GCDs and consequently cost as well as availability may be restrictive.

5.2 Selection of Geocomposite, Placement, and Causes of Failure :

The performance of geocomposites depend on the performance of the component geotextile filters and the performance of the drainage core. [12,17]. As seen from the typical section adopted, the sand layer is kept adjacent to the geocomposite for preventing installation damage to the GCD as well as to ensure that it is compatible for filtration / separation function with the veneer geotextile provided. For the latter objective, the formulation of Luettich, et. al. [12,13] may be used. Alternately, Carrols simplified formulation $AOS_{geotextile} < 2.5 * D_{85}$ may be used, where D_{85} is that size of soil particles in mm, of which 85% of provided sand is finer. AOS is the Aperture Opening Size (O_{95}) of the veneer geotextile. Sandwiching the geocomposite with at least 100mm of sand on both sides gives us the freedom to tweak the sand properties as well as the geotextile properties, considering availability, cost, lead time, etc. Another important aspect of the textile is that it spans over the openings of the drainage core. As such it should be strong and stiff enough not to intrude into the core under load and thereby increase the flow reduction factor for core intrusion (RF_{GI}).

In so far as the selection of drainage core is concerned, it should have adequate flow capacity. It should not yield under traffic loads, including impact. In case of hill road applications requiring large flows, cuspated core material with lower pitch may be desirable provided they are available satisfying other properties. In case of large volumes, it is preferable to have samples tested in GAILAP accredited laboratories (*IRC:113:2018*). In case the GCD is expected to function as a capillary barrier, the drainage core should have air gap at the top, i.e. the top geotextile should not saturate from capillary rise of water.

5.3 Care during construction

The following steps during work execution are necessary to maintain integrity and effectiveness of the GCD :

1. The GCD has exposed geotextile and should always be stored away from sunlight.
2. While laying the GCD, the main drainage direction should be in the flow direction and should always be placed with an outward gradient for easy drainage.
3. One edge of the GCD roll is generally provided with 150mm extra geotextile. The contiguous GCD on that side is placed inside the overlap, butting the core of its neighbor. This ensures lateral continuity of the drainage core while ensuring proper separation. While placing the GCD in cold windy conditions, it is preferable to use wide packing tape to hold down the GCD panels to each other.
4. It is imperative that while laying the sand cover on the GCD, care should be taken that the construction equipment does not move over the GCD directly. No tracked vehicle like dozer should be allowed on the material either.

In a study in the US where geocomposites used for drainage have been exhumed after 1 to 15 years of use [17]. It was found that though age did not seem to affect the results, failure was seen in filter function of geotextile, as a result of which soil finer than AOS of the textile had clogged the drainage core entirely. Installation related damage and excessive core deformation were also seen in some cases. A control layer of sand would therefore go a long way in keeping good contact with the GCD and also work better for retention.

6 Case Study – A Pilot Project in High Altitude Region of Himalayas (Uttarakhand)

The instant case is a road built by CPWD in Uttarakhand region which is at around 9000 ft. Two small patches of approximately 20m. road length with a properly designed horizontal geocomposite drain (GCD) were at locations where subsurface water was seen rising to the top of base course. Road is through cutting in hard rock. The crust consists of 200mm Crusher Run Macadam, 60mm Dense Bituminous Macadam and 40mm Bituminous Concrete. The Geo-Composite Drain (GCD) has been placed over a sand bed of 100mm overlaid on rocky granular subgrade.

The base course was removed and the subgrade exposed for this stretch. The GCD has been laid in 3% cross gradient. It was decided to provide GCD sandwiched between 100mm sand layers for this stretch before laying the CRM and compacting. The sand layers are provided to avoid construction damage. . The work was executed in the month of October 2017 under very cold and windy conditions. After considering the available options in the market and very small working window available, a geo-composite consisting extruded monofilament UV stabilized PP core laid in longitudinal channels in the drainage direction, with two needle punched thermally bonded non-woven PP geotextiles on both sides, was chosen for the particular site. It is a first of its kind application in hill roads in India.

6.1. Design of GCD

Determination of the required drainage capacity of the system (q_{reqd}) – In the instant case, two locations were identified in cut-sections where water was flowing in from the cut-face and also by capillary rise (as evident from wet side slopes of the hill on valley side). The water was seen to flow in small channels at two or three locations in the approximately 20m stretches. Only the water flowing in the main surface channel was measured. Measurements were done for 5min periods three times during the day, at around three hours interval. The maximum discharge collected was 8 litres during a 5 minute period. The water was found to affect a road length of 2 – 4 m. at critical locations or less. Therefore the flow per metre width per sec works out to 0.009 litres. This discharge can be increased to account for seasonal variations, site specific sub-surface flow, extent of run-off management provided in the stretch, level of maintenance anticipated, etc. In this case a factor of 3 is applied to account for above effects. Thus design / required discharge capacity ***(q_{reqd})*** works out to **0.03 litres / (m.s)**

Short term or basic flow capacity (100 hours testing condition) of the GCD (q_{basic}) –
*Normal Stress on the GCD :*The stress ratio (stress on GCD / stress on road surface) on the top of lower sand layer using the formulation above works out to 0.14. Hence the stress on GCD resting on lower sand layer (100 mm above subgrade) is
Equal to 0.14 * 560 kPa = 78 kPa (say 100 kPa for design)
*Hydraulic gradient = 0.*03
Basic flow rate from manufacturer's technical data sheet : 0.20 litres/(m.s)
Assessment of allowable flow rate *(q_{allow})* - The allowable flow rate is achieved by reducing the basic flow rate for various factors detailed below :
(a) Reduction factor for creep deformation of drainage core (RF_{CR}) = 1.3†
(b) Reduction factor for chemical clogging (RF_{CC}) = 1.1@
(c) Reduction factor for biological clogging (RF_{BC}) = 1.1@
(d) Reduction factor for geotextile intrusion into the core (RF_{GI}) = 1.4†
†This factor has been adopted from Koerner [12]
@These reduction factors have been taken from GRI-GC8 and ISO 12228-4 as reported by Blond [2]

Total Reduction Factor = 1.3*1.1*1.1*1.4 = 2.2
(q_{allow}) = 0.20 / 2.2 = 0.091 litres/(m.s)
Hence FOS = ***(q_{allow}) / (q_{reqd})*** = 0.09 / 0.03 = 3

Table 1. Important Properties of The Geocomposite Drainage Material [7,11,16]

S.No.	Material	Standard	Unit	Value	Tolerance	IRC : 34-2011 (Para 4.6.2)
1.	Tensile strength (MD)	EN ISO 10319	kN/m	18	-	≥ 16
2.(a)	In plane flow capacity (MD)	EN ISO 12958	l/(m.s)	For i = 0.03 @ 100 kPa = 0.20 l/(m.s) @ 200 kPa = 0.10 l/(m.s)	± 30%	For i = 0.03 Not provided
2.(b)	In plane flow capacity (MD)	EN ISO 12958	l/(m.s)	For i = 1.0 @ 100 kPa = 1.40	± 30%	For i = 1.0 @ 100 kPa ≥ 0.55 l/(m.s)

				l/(m.s) @ 200 kPa = 0.80 l/(m.s)		@ 200 kPa ≥ 0.45 l/(m.s)
B.	GEOTEXTILE (UV stabilized polypropylene)					
1.	Static puncture resistance	EN ISO 12236	N	1400	± 20%	≥ 3000
2.	Permittivity	EN ISO 11058	l/(m^2.s)	100	(-) 30%	≥ 100
3.	Apparent opening size (AOS)	EN ISO 12956	micron	110	± 50	≤ 150

Note : In case of provision of conventional drainage system, the GCD and the 100 mm sand layers on both sides would be replaced by 200mm (t = 0.2 m) granular sub-base (GSB). The permeability (k) of granu base of Grading 2 of IRC:37 is around 30 m/day or 0.35x10^{-3} m/s. Discharge per metre width for hydraulic gradient of 1.0 (i = 1.0) works out as under :

$Q_{\text{per m width}}$ (m^3/sec) = k*i*(W*t) = 0.35x10^{-3} * 1.0 * (1.0 * 0.2) = 0.07x10^{-3} m^3/s = 0.07 litres/sec.

This compares well with the GCD capacity of 0.8 litres/sec even at 200 kPa normal stress on GCD at hydraulic gradient of 1.0 as per manufacturer's data sheet.

Fig.4. Geocomposite MacDrain™ W-1071

Fig.5. Seepage water visible on CRM surface before installation

Fig. 6. Geocomposite Drain being rolled out for cutting

Fig.7. GCD laid in slope and being covered by sand layer

The installation stretches are being monitored during the working season when the roads are in operation, to gauge the effectiveness of the horizontal sub-surface drainage system. In the snow melting season of 2018 and 2019, no distress or water accumulation on pavement surface has been reported.

6.2. Drawbacks of the study

This pilot project was done when surface water was observed on the pavement surface before black topping. A more detailed survey of other vulnerable locations, at various points of time during the working season, including more number of measurements, would have given more insight into the quantity and variation of water seepage as well as capillary rise.

Similarly, a better market survey of available GCD options could have been done, which was obviated by the impending close of working season.

It is difficult to assess the subsurface flow during the most critical monsoon period, as precipitation saturates all catchment area, obliterating the difference between surface flows and subsurface flows.

The simplistic methodology adopted for estimating E_1/E_2 of the composite layer needs validation by instrumented studies to assess the stresses on the GCD due to traffic.

Also after few years of use, especially with monsoon wetting, the pavement crust deteriorates leading to reduction of Moment of Resilience of the top layers and therefore increased vehicular loads on the GCD. This may cause crushing of the drainage core, intrusion of textile into the drainage core, loss of integrity of the textile, etc. – leading to functional failure of the GCD.

7 Conclusions

In this case we could provide a FOS of 3 which is quite sufficient to provide drainage of subsurface water as well as act as a capillary barrier.

Large variety of GCDs are available in the market for which selection guidelines and design codes are required for different applications. More testing of GCDs, especially independent third party testing by accredited laboratories, are required for higher volumes of application. For this testing facilities are required to be developed.

The various reduction factors being used in design calculations are generic values taken from literature. These may require to be revisited for specific applications for different climatic zones and environmental conditions, especially in a hot and humid country like India.

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