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USE OF POLYMERIC-FABRIC WASTE IN ROAD CONSTRUCTION

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Abstract: *Rural and urban road development programmes for connecting towns and villages have been consuming huge amount of funds over last few decades; however, there is a dire necessity to connect the rural population to the urban centres. To provide connectivity to all rural habitations, it is essential to adopt cost effective and durable roads in our country. The prohibitive cost of commercially available geotextiles in India can be overcome by the extensive use of discarded and used polymeric bag fabrics. In addition, the exponential growth in construction activity has increased the volume of discarded polymeric cement bags, which are not bio-degradable and disposed off indiscriminately creating an imbalance in eco-system. These polymeric bags can be joined together by several methods such as epoxy bonding, thermal bonding, seaming and stitching etc., and the same can be used as an alternative component instead of commercially available geotextiles. If this program is effectively implemented, then it'll provide several jobs for the rural poor and will also significantly bring down the degree of pollution caused by the indiscriminate discarding of plastic wastes. This research paper focuses on the productive utilization of discarded and used High Density Poly-Ethylene (HDPE) bag fabrics as a geotextile material in the construction of rural roads. The properties of HDPE bag fabrics for their efficient use have been explored. Suitability can be tested by finding the tensile strength properties of the HDPE bag fabrics using CBR Plunger Push through Test (ASTM D4833). The desired equipment for testing the same can be found in any undergraduate level technical institutions.*

I. INTRODUCTION:

In order to achieve higher growth rates of economic development in India, the quality of level of service provided by the roads should improve. A well connected road network is one of the basic infrastructure requirements which play a vital role for the fast and comfortable movement of inter-regional traffic in our country. The above objectives are being met with a missionary zeal by our national planners under the direction of Ministry of Road Transport and Highways, Government of India. This paper briefly reviews the theoretical model and design procedure for predicting the thickness of base course layer for geotextile reinforced road system as reported by Krishnaswamy and Sudhakar (2005). The design method developed takes into consideration the worst type of natural subgrade soil, usually in the form of soft, saturated clays exhibiting low values of cohesion under undrained conditions. The analytical procedure indicates the tensile strength characteristics of the HDPE bag fabric used and its effect on the performance of the roads. As there are no readily available design catalogues developed by Indian Road Congress for Indian conditions with weak soil subgrades whose CBR < 2%, the present paper hopes to fill this void. The design thicknesses obtained for very weak subgrade soils (CBR<2%) have also been compared with those from Giroud and Noiray (1981). In order to examine the HDPE bag fabrics to be used for reinforcement purposes in road construction, the tensile strength properties of the HDPE bag fabrics have been tested in the laboratory by conducting CBR Plunger Push through test as recommended by Koerner (1999).

II. THEORETICAL BACKGROUND:

Giroud and Noiray (1981) have developed a semi-empirical method for designing the reinforced roads. The study in this paper addresses the lack of design procedures for reinforced roads by developing a method which enables to calculate the required thickness of base course layer and make a proper selection of the geotextile. The model considers rut-depth as the key design criteria.

Giroud and Noiray use the geometric model shown in the figure below, for a tire wheel load of pressure p_{ec} on a B by L area, which dissipates through h_0 thickness of stone base without a geotextile and h thickness of stone base with geotextile. The geometry indicated results in a stress on soil subgrade of p_0 (without geotextile) and p (with geotextile) as follows.

$$P_o = \frac{P}{2} \quad B + 2h_o \tan\alpha_o \quad L + 2h_o \tan\alpha_o \quad + \Delta h_o \qquad 1$$

$$P = \frac{P}{2} \quad B + 2h \tan\alpha \quad L + 2h \tan\alpha \quad + \Delta h \qquad 2$$

P in Eqs (1) and (2) is the axle load, and Δ is the unit weight of the stone aggregate.

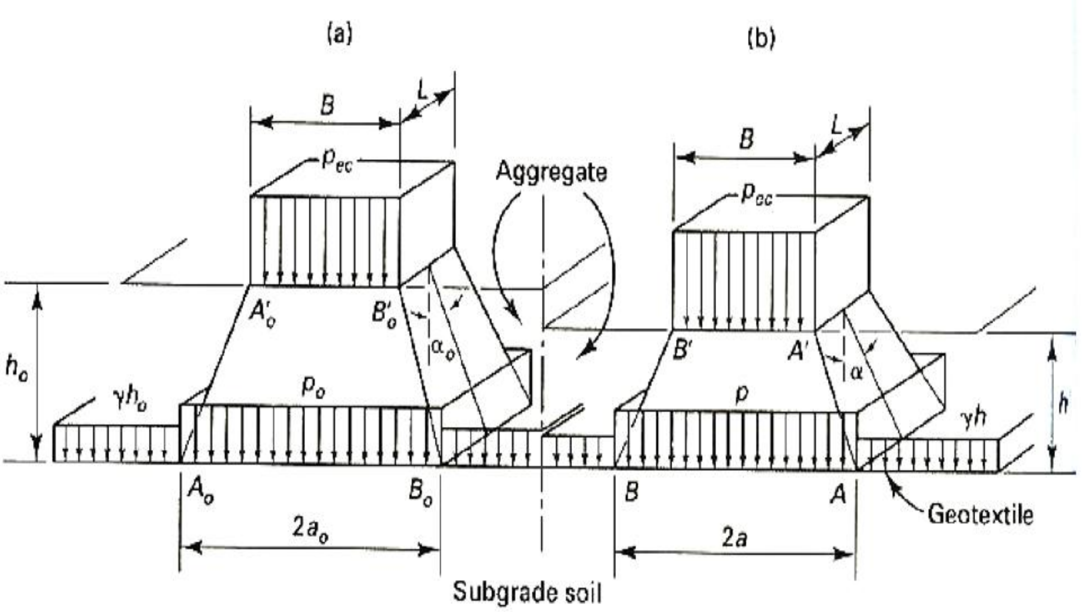
Knowing the pressure exerted by the axle load through the aggregate and into the soil subgrade, the shallow foundation theory of geotechnical engineering can now utilize. Assumed throughout in the analysis is that the soil is functioning in its undrained condition and thus its shear strength is represented completely by the cohesion (i.e., τ = c). Thus the tacit assumption is that the soil subgrade consists of saturated fine-grained silt and clay soils. Critical in this design method are the assumptions that without geotextile the maximum pressure that can be maintained corresponds to the elastic limit of the soil, that is,

$$P = \pi C + \Delta h_o \qquad 3$$

And that with geotextile the limiting pressure can be increased to the ultimate bearing capacity of the soil, that is,

$$P* = \pi + 2\ C + \Delta h \qquad 4$$

Fig 1-Load distribution by aggregate layer (after Giroud and Noiray)



Case (a): without geotextile, case (b): with geotextile.

Thus assumptions agree reasonably with the earlier findings of Barenberg and Bender using small-scale laboratory tests.

Thus for the case of no geotextile reinforcement, equations (a) and (c) can be solved resulting in equation (e), which can result in the desired aggregate thickness response curve without the use of a geotextile.

$$c = \frac{P}{2}\left[2\pi\left(\sqrt{\frac{P}{p_c}}\right) + 2h_o \tan\alpha_o\right]\left[\left(\sqrt{\frac{P}{2p_c}}\right) + 2h_o \tan\alpha_o\right] \qquad 5$$

Where c = the soil cohesion,

P = the axle load,

p_c = the tire inflation pressure,

h_o = the aggregate thickness, and

α_o = the angle of load distribution (≈26 deg)

For the case where geotextile reinforcement is used, p^* in equation (d) is replaced by $p - p_g$, where p_g is a function of the tension in the geotextile; hence its elongation is significant. On the basis of the probable deflected shape of the geotextile-soil system,

$$P_g = \frac{K\varepsilon}{a\sqrt{\left[1 + \left(\frac{a}{2S}\right)^2\right]}} \qquad 6$$

Where K = the secant modulus of geotextile,

ε = the elongation (strain),

a = the geometry property

S = the settlement under the wheel (rut depth).

By combining the equations (b),(d), and (f) using $p^* = p$ □ $p_{g,}$ Equation (g) results in which h is the unknown aggregate thickness. It can be plotted for various rut-depth thickness and various moduli of fabrics.

$$\pi+2\ \ c=\frac{P}{2}\ \ B+2h\tan\alpha\ \ \ L+2h\tan\alpha\ \ -\frac{K\varepsilon}{a\sqrt{\left[1+\left(\frac{a}{2S}\right)^{2}\right]}} \qquad 7$$

With these two sets of equations, the design method is essentially complete, since both h_0 (thickness without geotextile) and h (thickness with geotextile) can be calculated. From these two values $\Delta h = h_0 - h$ can be obtained, which represents the savings in aggregate due to the presence of fabric.

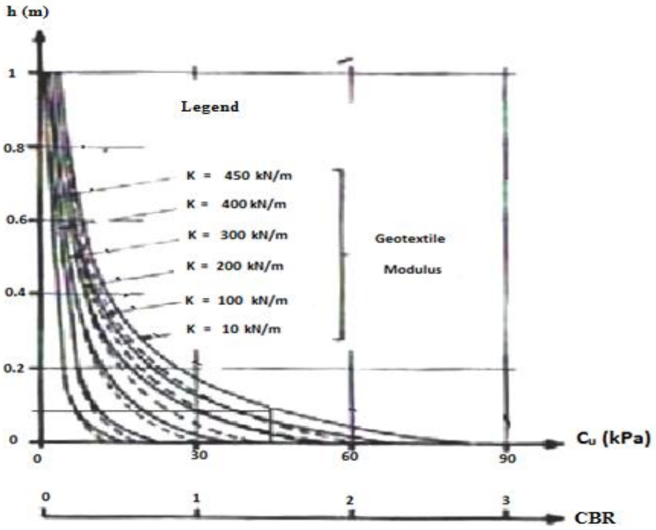


Fig 2 : Aggregate Thickness ‘h’ Versus Subgrade Soil Cohesion (Quassi-Static Analysis for the case with Geotextile) after Giroud&Noiray (1981)

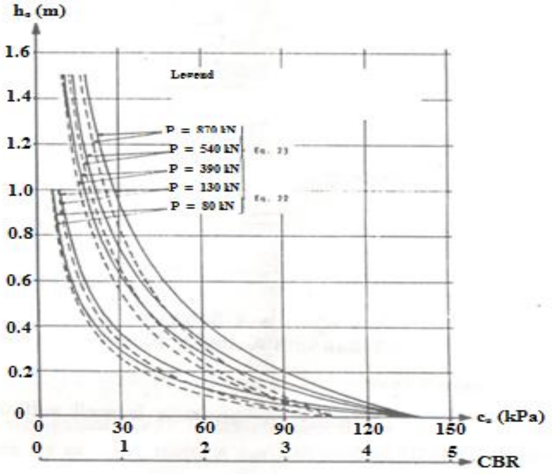


Fig 3 : Aggregate thickness h_o versus Subgrade Soil cohesion (Quasi-Static analysis for case without Geotextile) after Giroud and Noiray (1981)

According to Giroud&Noirey (1981), Δh can be calculated precisely as

$$h_o - h = \Delta h \qquad 8$$

where h_o = base course thickness without Geotextile,

h = base course thickness with Geotextile and

Δh = Reduction in base course thickness

When traffic is taken into account, according to Giroud&Noirey (1981),

$$h_o' - h' = \Delta h \qquad 9$$

where h_o' = base course thickness without Geotextile under traffic

h' = base course thickness with Geotextile under traffic

Δh = Reduction in base course thickness under traffic

This procedure assumes that the value of Δh does not depend on the traffic.

According to Giroud and Noirey (1981), by providing reinforcement, Geotextiles improve the performance of roads: for a given thickness of base course, the traffic can be increased or in other words, for the same traffic, the thickness of the base course can be reduced. The above mentioned concepts are utilized in the case of analysis reported by Krishnaswamy and Sudhakar (2005).

The following assumptions are made use of in the development of the theoretical model.

1. The friction coefficient of the base course layer is large enough to ensure the mechanical stability of the layer.
2. The friction angle of the geosynthetic layer in contact with the base course layer under the wheels is large enough to prevent sliding of the base course layer on the geosynthetic layer. Basically, this study evaluates the risk of failure of the subgrade soil and of the geosynthetic layer.
3. Since the friction coefficient of the base course layer is large and sliding of the base course on the geosynthetic layer is prevented, the base course layer does not fail in shear.
4. Therefore, the bearing capacity of the subgrade soil with and without geosynthetic reinforcement layer governs the solution.
5. The geosynthetic reinforcement layer is placed along the interface of the base course and the subgrade soil in order to get the maximum benefit from the associated functions like separation, filtration and drainage. The case of geosynthetic layer placed within the base course is less effective and hence precluded from the present investigation.
6. The placement of the geosynthetic layer on the soft subgrade soil appears to have the effect of forcing a general shear failure. However, in the absence of geosynthetic reinforcement layer, a punching type of shear failure of the subgrade soil would occur which is referred to as elastic bearing capacity failure of the subgrade soil by Giroud and Noiray (1981). The above mentioned effect results in the increase of the Bearing Capacity Factor, N_c from π to $(\pi + 2)$ for the case of road system with geosynthetic reinforcement layer at the interface.
7. Allowing sufficient time for the rutting to take place in the unpaved road system, the ruts are backfilled and the geosynthetic reinforcement would have mobilized necessary tension. At this stage, the unpaved road can be converted into a paved road by providing a permanent asphalt or concrete pavement as a wearing surface.
8. Under loading, the base course behaves like a beam in bending. Thus the bottom layer experiences the tension tending to move apart, the individual lumps of base course material allowing the intrusion of soft subgrade soil into the base course layer resulting in mud-pumping. This movement is eliminated if needle punched non-woven geotextiles are used. So, in this case, the geosynthetic reinforcement serves as a filtration medium. According to a review paper by Little (1992), there is an observable improvement in the performance of the road systems with the inclusion of even low stiffness geotextiles due to the separation and filtration functions performed by the geotextile rather than its reinforcing effect. These beneficial effects are not taken into consideration in the development of the analytical model.
9. The subsidence associated with the wheel path rutting develops tension in the geotextile, the upward resultant of which neutralizes the stress on the subgrade. This type of reinforcing effect is known as membrane support.
10. The present investigation considers the effect of geo-synthetic reinforcement under static loading conditions as a first step. So, at this stage the analysis can be considered as Quasi-static. However, the analysis presented can be extended to consider the effect of traffic passes in the same manner as recommended by Indian Road Congress (IRC).
11. The wheels are assumed to travel always along the road in the same track rendering the problem bi-dimensional.
12. The elongation is uniform along the entire length of the geo-synthetic material used.
13. The axle load transmitted through the dual tyres and its contact area is assumed to be circular in the same manner as reported by Jaya Ganesh (2002).
14. This study applies only to purely cohesive subgrade soils under fully saturated, undrained condition, representing the worst case.

Practically, this means:

$$\Phi = 0 \qquad 10$$

And soil possesses only apparent cohesion, C_u.

This paper presents a more rational design procedure for predicting the thickness of base course layer for geosynthetic reinforced road systems. By providing reinforcement in the form of geotextiles or geogrids, the thickness of the base course can be decreased for a given number of traffic passes or in other words the number of traffic passes can be increased for a given thickness of the base course layer. The effects of membrane support and traffic passes have been included in the design procedure in the same manner as recommended by Giroud and Noiray (1981). Based on the results of the newly developed present theoretical model, pavement design catalogues have been developed in conjunction with those of Indian Roads Congress, IRC: 37-2001. The experimental study is aimed at providing an effective alternative design procedure based on simple laboratory evaluation of Equivalent California Bearing Ratio (CBR) of the composite layered system namely, the geotextile sandwiched between the base course material and the soft subgrade soil. Modified CBR tests have been carried out on a layered system consisting of crushed stone aggregate as base course layer and soft silty -clay as subgrade soil. The influence of the height of subgrade soil on the CBR value is studied. Four different kinds of geotextiles have been used and the influence of the secant modulus of the geotextile on the CBR of the composite system is examined. This experimental study shows that there is an increase in the CBR value of the composite layered road system with the introduction of the geotextile. The results of the experimental study have paved the way for an effective alternative design procedure based on simple laboratory evaluation of equivalent California Bearing Ratio (CBR) of the composite layered system namely, the geotextile sandwiched between the base course material and the soft subgrade soil.

The studies to facilitate the prediction of the thickness of base course layer required when a geosynthetic planar reinforcement layer is provided between the base course layer and a soft subgrade soil, a typical situation occurring in highway and airport pavement construction industry. With the help of CBR tests, an appropriate laboratory design procedure has been developed to predict the saving in thickness of the base course layer when geosynthetic reinforcement is deployed over weak subgrade soils. This paper also discusses a rational analytical method for predicting the thickness of the base course layer to be laid over the subgrade material when geotextile is used as a planar reinforcement layer. The results predicted by the present analytical method have been compared with those from an existing design method for geotextile reinforced road.

Comparison of the Results predicted from the theory of Krishnaswamy and Sudhakar (2005) with those of Giroud and Noiray (1981)

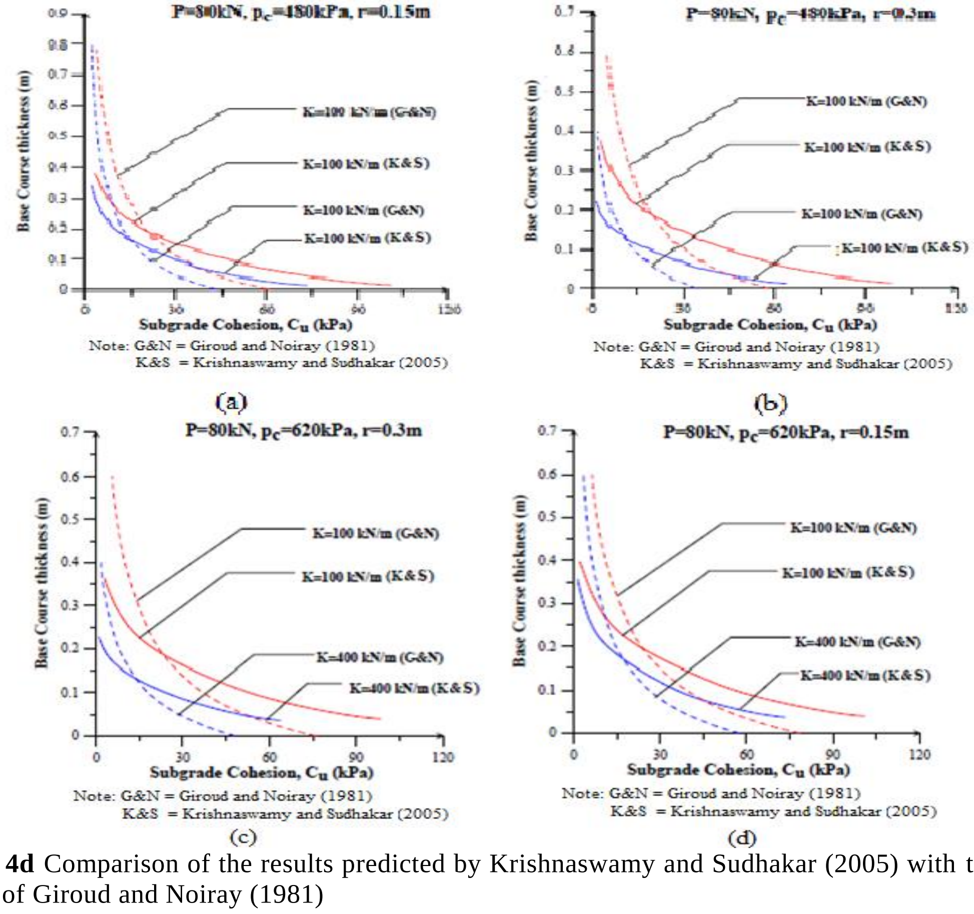


Fig. 4a to 4d Comparison of the results predicted by Krishnaswamy and Sudhakar (2005) with those from the theory of Giroud and Noiray (1981)

The results predicted by the present theoretical model have been compared with those obtained from those of Giroud and Noiray (1981). The Figs 4a to 4d show the comparison between the two for specified values of a secant modulus of the geotextile. The comparison was made for several cases and only typical graphs are presented herein. The variation of base course thickness with subgrade soil cohesion is shown in Figs. 4a to 4d. The constant parameters considered in Figs. 4a to 4d, are: equivalent single axle load, P=80 kN, tyre pressure, pc=620 kPa and 480 kPa, CBR of the base course material is 80 % and rut depths, r=0.15 m and 0.3 m. The results obtained are compared for two different secant moduli of the geotextile fabric namely, K=100 kN/m and 200 kN/m.

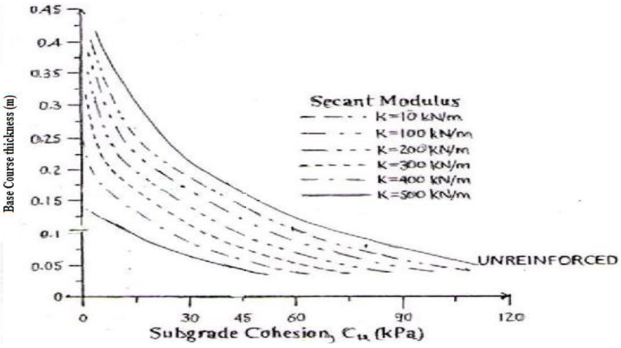
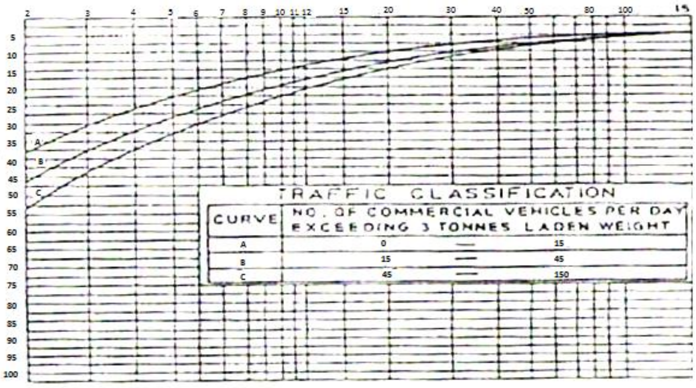


Fig 5 : Effect of Secant Modulus of Geotextile, K, on base course thickness.

Sikdar P.K (2001): The roads constructed under this programme will be owned and maintained by the concerned panchayat raj institutions (PRI) (District panchayat or panchayatsamithi). At present the PRI does not have technical manpower and in many states the rural roads are owned by PWD of the state. The present and past experience of rural road maintenance is very sad and it is largely due to non-availability of funds. But the institutional short coming was also responsible. For sustaining the road infrastructures in ten rural areas, PRI should be trained involving local technical institutions the supervisory role. If the funds are made available by the state government as per the standard norms, the suggested model should be able to maintain the roads at required standard. The institutional arrangement with back up of technical manpower only will be able to sustain the assets created under Pradhan Manthri Gram SadakYojana (PMGSY). The assists created created under this programme and maintained at required level of service are likely to transform the rural India to a huge resource base.

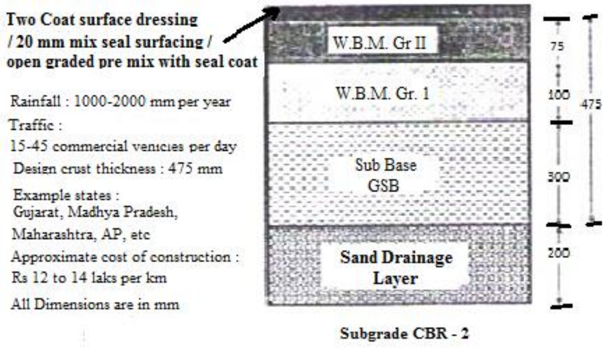
The following figures show Sikdar's charts which been produced below for the use of concerned engineers in charge of rural construction projects.



TRAFFIC CLASSIFICATION

CURVE	NO. OF COMMERCIAL VEHICLES PER DAY EXCEEDING 3 TONNES LADEN WEIGHT
A	0 — 15
B	15 — 45
C	45 — 150

Fig 6 : CBR curve for flexible pavement design after Sikdar (2001)



Rainfall : 1000-2000 mm per year
Traffic :
15-45 commercial venicies per day
Design crust thickness : 475 mm
Example states :
Gujarat, Madhya Pradesh, Maharashtra, AP, etc
Approximate cost of construction :
Rs 12 to 14 laks per km
All Dimensions are in mm

Fig 7 : Pavement Cross Section for Black Cotton Soil Area after Sikdar (2001)

III. EXPERIMENTAL STUDIES:

In addition to determining the wide-width tensile strength indirectly using equation (1) given below, there is a need for an assessment of geotextile resistance to objects such as rocks or pieces of wood under quasi-static conditions. Such a test is described under ASTM D4833. This test calls for a penetrating steel rod to be 0.31 in.(8.0mm) in diameter. The geotextile is clamped in an empty cylinder of 1.75inch (45mm) inside diameter, and the rod is pushed through it via a compression testing machine. Resistance to puncture is measured in force units.

This test is popular due to its simplicity and ability to be automated. It is reported by all manufactures and is listed in most specifications. A considerably large database exists using this test method. The exact shape of the end of the metal rod is important to note. Three types are in current use; hemispherical, flat, and beveled flat. The interrelationships and differences between these types have not been identified. The latter type, with a 1/32-in. (0.80mm), 45-deg. Bevel around its circumference is the test (i.e., D4833). According to Koerner (1999), the small size of the aforementioned device is also of concern. For example, a lightweight nonwoven geotextile can selectively be chosen in a low-density fiber region or in a high-density fiber region. The differences in puncture resistance will be large.

With such a concern in mind, Koerner(1999) has recommended a larger size puncture test. It uses a geotechnical engineering CBR plunger and mould. The penetrating steel rod is 2.0 inch (50mm) in diameter, and the geotextile is firmly clamped in an empty mould of 6.0 inch (150mm) inside diameter. The circumference of the plunger should be beveled 1/32 inch (0.80mm) on a 45-deg. Angle so as not to cut the yarns at the edge of the rod. Table 1 shows data from this type of test on both woven and non-woven geotextiles. There is a direct relationship between this type of puncture resistance value and the tensile wide-width strength of the geotextile. This is because the geotextile between the inner edge of the specimen holder and the outer edge of the puncturing rod is indeed in a state of pure axi-symmetric tension.

Cazzuffiand Venesia (1986) propose the following empirical equation as a correlation between the breaking force of the CBR test and the wide-width tensile strength for isotropic, nonwoven geotextiles;

$$T_f = \frac{F_p}{2\pi r} \qquad 11$$

Where T_f = the tensile force per unit width of fabric, kN/m, and

F_p = the puncture breaking force, kN.

According to Koerner (1999), the tensile elongation at failure (€$_f$) is calculated as follows;

$$\varepsilon_f = \frac{x-a}{a}\times 100 \qquad 12$$

Where *x* = the diagonal elongation of the geosynthetic at failure, and

a = the horizontal distance between the outer edge of the plunger and the inner edge of the mould.

According to Koerner (1999) the strength predications are reasonable and the variation in predicted elongation at failure seems to have a bit more scatter. The CBR test for puncture strength or as a form of axi-symmetric tensile strength has considerable merit.

Extensive tests were carried out in the geotechnical laboratory of V.V.I.E.T, Mysore on 60 specimens of HDPE bag fabrics collected from various sources at Mysore. The experimental results are tabulated as furnished in Table 1.

Photo: CBR Plunger Push through Test (ASTM D4833). Before and after rupture of the specimen.

Properties of fabrics used in the test program

Polymer composition = HDPE-High Density Polyethylene

Type & Structure = Woven (slit film) fabrics

Purpose of Manufacture = For making bags to store cement/granular materials

Table. 1 Specimens of HDPE bag fabrics collected from various sources at Mysore & experimental results

Specimen no.	Used to store	Source	Mass/unit area g/m^2	Secant modulus(K), kN/m at ε = 10%
1	Cement	Construction site	120	23.6
2	Cement	Construction site	90	15.8
3	Cement	Construction site	90	15.5
4	Cement	Construction site	100	21.3
5	Cement	Construction	90	19.4
6	Cement	Construction site	120	19.7
7	Cement	Construction site	100	19.6
8	Cement	Construction site	80	16.5
9	Cement	Construction site	90	21.3
10	Cement	Construction site	80	17.4
11	Cement	Construction site	100	18.2
12	Cement	Construction site	80	21.5
13	Cement	Construction site	90	19.4
14	Cement	Construction site	120	19.7
15	Cement	Construction site	100	19.6
16	Ferilizer	Agro shop	150	28.4
17	Fertilizer	Agro shop	180	41.0
18	Fertilizer	Agro shop	170	37.8
19	Fertilizer	RMC	90	17.5
20	Fertilizer	Agro shop	170	37.8
21	Fertilizers	Agro shop	150	34.0
22	Fertilizers	RMC	130	27.5
23	Maize	RMC	180	38.6
24	Maize	Big bazar	110	20.0
25	Maize	RMC	180	38.6
26	Paddy	Agro shop	150	23.1
27	Paddy	Agro shop	150	23.1
28	Poultry	Poultry	110	36.6
29	Ragi	RMC	90	17.5
30	Ragi	Local store	130	31.0
31	Ragi	Super market	120	19.8
32	Ragi	Local store	130	31.0
33	Rice	Royal world	100	31.8
34	Rice	More store	100	19.8
35	Rice	Local store	100	19.7
36	Rice	Local store	100	20.1
37	Rice	RMC	120	21.0
38	Rice	Local store	110	19.4
39	Rice	Supermarket	80	14.8
40	Rice	A-z super market	100	17.5
41	Salt	Local store	100	20.0
42	Sugar	Big bazzar	90	18.7
43	Sugar	Local store	130	22.0
44	Sugar	Local store	90	17.6
45	Sugar	Local store	110	21.0
46	Sugar	Akshayabandara	90	18.5
47	Sugar	Local store	100	21.0
48	Sugar	Local store	90	15.2
49	Sugar	RMC	160	32.4
50	Sugar	Local store	110	21.0
51	Vegetable	Mg market	160	37.0
52	Vegetable	Mg road	140	24.0
53	Vegetable	Mg market	140	32.0
54	Vegetable	Mg road	140	24.0
55	Wheat	RMC	140	35.0
56	Wheat	RMC	160	29.8
57	Wheat	A-z super marker	100	26.5
58	Wheat	More	140	24.6
59	Wheat	RMC	160	29.8
60	White	Construction site	170	34.3

Note: The variation in the secant modulus for the similar type of Polymer bags is due to the different levels of degradation due to the age, storage, exposure to sunlight etc.

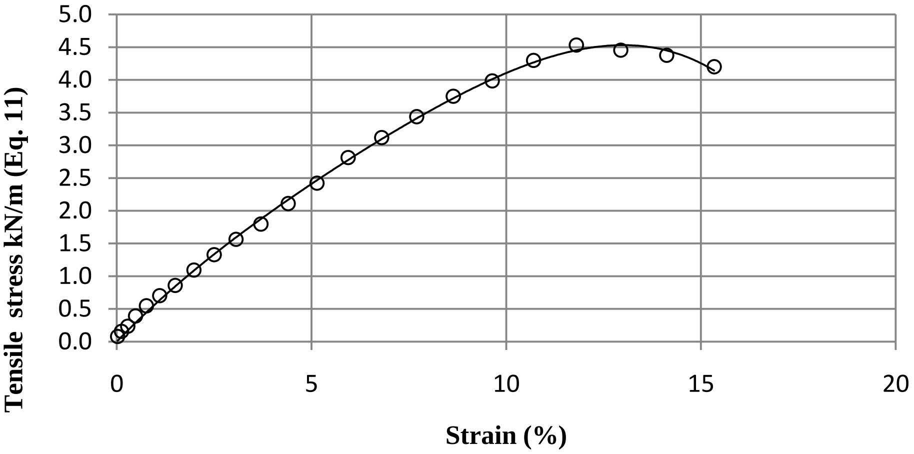


Fig 8 : Typical Stress – Strain Graphs from the experimental data obtained for specimens 16

Analysis for Black Cotton Soil Area

Black cotton soil deposits are found in India in the states of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra etc. Majority along a band above the A-Line, in the plasticity chart of IS Soil Classification System. Typical values of liquid limit and plasticity index for these soils are abs of CBR for some of these soils can be below 2%, necessitating special ground improvement techniques. In this context, use of discarded and used polymeric bag fabrics offers an economical solution to road construction problems. This is illustrated by the example shown below.

According to Sikdar (2001), the pavement cross- section for black cotton soil area without the use of Geotextile is as shown in Fig 7

Table 2. shows the comparison of the calculated thickness of the sub base course as per Giroud and Noiray (1981) and Krishnaswamy and Sudhakar (Fig. 2, 3 and 5) & without geotextiles as per Sikdhar

Table 2: Table showing comparison of the calculated thickness of the sub base course

Subgrade Base Course Type	Base course thickness without Geotextile h_o (mm)		Base course thickness with Geotextile $h = h_o - \Delta h$ (mm)			
			Giroud and Noiray		Krishnaswamy and Sudhakar	
C.B.R. Value	**1.0**	**1.5**	**1.0**	**1.5**	**1.0**	**1.5**
W.B.M Grade 2	75	75	56.84	68.68	57.64	69.47
W.B.M Grade 1	100	100	75.79	91.57	76.85	92.63
SUB BASE GSB	300	300	227.37	274.73	230.53	277.90
Total	475	475	360.00	435	365.02	440.00

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Conclusions:

1. The prohibitive cost of commercially available geotextiles in India can be overcome by the extensive use of discarded and used polymeric bag fabrics.
2. Discarded and used polymeric bags can be joined together either by stitching or by epoxy bonding and the same can be used as an alternative component instead of commercially available Geotextiles.
3. The thickness of the base course layer can be reduced when a Geotextile planar reinforcement layer is included between the soft subgrade soil and the base course layer.
4. The benefit of Geotextile reinforcement is significantly more for subgrade soils having CBR values less than 3. This benefit decreases with increase in CBR.
5. If the research findings of this paper are effectively implemented then it'll provide several jobs for the rural poor and will also significantly bring down the degree of pollution caused by the indiscriminate discarding of plastic wastes.
6. The results of the present study can be used for subgrade soils with CBR < 2%, in conjunction with IRC 37:2001 *Guidelines for the design of flexible pavements*.

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