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Performance Study on California Bearing Ratio Values using Geosynthetics

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ABSTRACT

The main use of geosynthetics or geofabrics is ensured in any given geotechnical engineering work or application. Sometimes, design and construction of pavement on weak soil creates many of the problems due to its load bearing capacity because of high axle loads vehicles on expansive wet soil subgrades, now we have many techniques to modify the properties of such soil. In this study we can perform the California bearing ratio testing over woven and nonwoven geotextile combined between soft subgrade and unbound gravel in an unpaved flexible pavement system is carried out experimentally on CBR testing arrangement. In order to improve the results we can take the reinforcement ratio is obtained based on the CBR load which is penetration relation of both soft subgrade-gravel and soft sugared-geotextile-gravel separately for woven and nonwoven geotextile. After performing the CBR strength test on soil we can check how much geotextiles required to cover the soil according to the bearing strength of soil shows that the performance is improved after including woven and nonwoven geotextile. The construction of roads over soft subgrade soil is a challenge for any engineer to reduce the cost and then using of geofibers effects the cost of construction and duration of highway projects due to this sometimes rescheduled the construction work in many regions where soft subgrades are common over a large area. The strength of the subgrade mostly expressed in terms of California bearing ratio (CBR), which is the ratio of test load to standard loads at a specified penetration by a specified plunger.

If we use Geosynthetics or Coir fiber as a main component used in highway construction then it is economical because additive layers like asphalt, concrete and cement concrete are not used and saves the cost of these materials. The soil samples used in CBR test were prepared with two types of soil which are Clayey and sandy contains reinforced and non- reinforced soil. The samples has the composition of three types of geotextiles with different characteristics i.e. 150, 200, 300 g/m2 and depths or heights i.e. 10, 20, 30,50, 100 mm and it can be grouped into two forms i.e. one-layered and two-layered based on the sample materials in order to requirement or perform defined tests. Using of geofibers increases the bearing load capacity of soils, we can use one layer of geotextile used in wet soils and sandy samples. From last few years geo-synthetics have joined the list of traditional civil engineering construction materials. In this whole study strength characteristics were studied using the California bearing ratio (CBR) test method.

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1. INTRODUCTION

India has one of the largest road networks in the world, aggregating to about 56.03 lacs km at present and it was 34.81 lacs km in march 2016. However four lane and six lane road networks in India is 22115 km and 2572 km respectively, length of expressways approx 1455 km but many of the existing roads are becoming structurally inadequate because of the fast growth in traffic volume and axle wheel loading. At place where the structure of highways are not adequate then we can perform the CBR test, a layer of suitable granular material can improve the bearing capacity of soil to carry the future traffic load but at highway or road sites with CBR less than 2% creates the problems of shear failure and rutting then to improve the workability of road we can introduce a material after excavation and replacement of unsuitable material or before construction of road the soil testing has to be done and after that deep compaction, polymeric geosynthetics etc can be added at some sites. Use of geosynthetic materials like geofibers, geonets, geotextiles etc. can effects the cost so they are yet to be commonly used in countries like India. Natural fiber products hold promise for rural road construction over soft clay. India is the first largest country, producing coir fiber from the husk of coconut fruit. Geotextiles are used to increase the quality of road in rural areas. In paved and unpaved road construction, geosynthetic reinforcement has been applied to improve their overall strength. Uses of geotextiles are cost effective and the main goal of using geotextile in early road construction was separation. In the laboratory test under symmetric load using nonwoven geotextiles and punched in between the sub-base and sub-grade which increase the load bearing capacity of soft subgrades. If we have to construct the road then many layers to be constructed, the basic components of these layers are wearing course, base course and sub-base course. If the bearing capacity is low, high consolidated settlement, low permeability then it is very difficult to construct any road structure. These roads are not capable to bear the modern traffic volume but suitable for low traffic volume. When road carry a large load then deformation take place so periodic maintenance of these roads are required which effects as high cost considerations. Uses of geotextiles is the new technique to increase the stability of roads. It reduce the thickness of the pavement subgrade and compact the aggregate if the woven textile is used then cushion of a thin layer of local sand was provided to avoid the complexity for flexible pavement. Geogrids reinforcement used which effects the cost of the highway and also used in retaining wall, simplygeosynthetics reinforcement improve the strength, bearing capacity and service life of any paved and unpaved road pavement.

The combination of soil, geosynthetics and aggregates effects on stresses then shear stress become less on subgrade, more load distributed on the soil subgrade layer, the granular materials displaced less in comparison to the normal pavement the reduction of shear stress on the subgrade, stiffness will be increased and layer is more compacted. Geosynthetics, including geotextiles, geomembranes, geonets, geogrids, geocomposites and geosynthetic clay liners often used in combination with conventional materials and useful in space saving, material quality control, construction quality control, cost saving, technical superiority, construction timings, material deployment, material availability and environmental sensitivity. In this whole study we can elaborate the uses of geosynthetics reinforcement in road pavements and the design procedures after performing the required tests.

2. LITERATURE REVIEW

The different types of mixes with soil used from the thousands of years ago. Geosynthetics were used in roadway construction from the Roman days to stabilize roadways and their edges. A use of natural fibers, fabrics and the vegetation product like coconut husk is used to stabilize or improve the quality of the road pavements, particularly when roads were built on unstable soil. They were also used to build steep slopes as with several pyramids in Egypt and walls as well. A fundamental problem with using natural materials (wood, cotton, etc.). Most of the geosynthetics are made from synthetic polymers of polypropylene, polyester, or polyethylene. Geotextile is a permeable geosynthetic made of textile materials. Geotextile type is determined by the method used to combine the filaments or tapes into the planar structure. It states that the first use of fabrics in reinforcing roads was attempted by the South Carolina Highway Department in 1926. A heavy cotton fabric was placed on a primed earth base, hot asphalt was applied to the fabric, and a thin layer of sand was put on the asphalt. The department published the results of this work in 1935, describing eight separate field experiments until the fabric deteriorated, the results showed that the roads were in good condition and that the fabric reduced cracking, raveling and localized road failures.

Early papers on geosynthetics (as we know them today) in the 1960s documented their use as filters in the United States and as reinforcement in Europe. A 1977 conference in Paris brought together many of the early manufacturers and practitioners. The International Geosynthetics Society (IGS) founded in 1982 has subsequently organized a worldwide conference every four years and its numerous chapters have additional conferences. Presently, separate geosynthetic institutes, trade-groups, and standards-setting groups are active.

2.1 P. B. Ullagaddi, T. K. Nagaraj presented an "Investigation on geosynthetic reinforced two layered soil system" which says that investigation has been carried out with different thickness configuration of the two soils and three types of woven and non-woven geotextiles, having different physical and mechanical properties.

2.2 Sarika B. Dhule and S. S. Valunjkar (2011) presented an "Improvement of flexible pavement with use of geo-grid" which says that Geogrid + murrum –increase CBR value and factors affecting the compaction characteristics are shear strength and low permeability. CBR value depends upon degree of compaction.

2.3 K. Rajagopal, S. Chandramouli, Anusha Parayil & K. Iniyan presented a "Studies on geosynthetic-reinforced road pavement structures" which says that by using geosynthetic material there is improvement in strength and stiffness and shows better performance under repeated loads (fatigue condition).Under monotonic loading, modulus improvement factor is higher.

2.4 Vaishali S. Gor L. S. Thakur Dr. K. R. Biyani presented a "Study of typical characteristics of expansive subgrade with geotextiles and cushion materials" which concludes that by Addition of metakaolin, swelling pressure of black cotton soil reduces but further increment in the amount of metakaolin results in increase in swell pressure.

2.5 R. Ziaie Moayed and M. Nazari studied the "Effect of Utilization of Geosynthetic on Reducing the Required Thickness of Sub base Layer of a Two Layered Soil"which says that by inclusion of geogrid improves the shear resistance at the interface by offering interlocking resistance and reduce the lateral movement of the soil. It also offers more separating function and prevent the sand layer entering into the underneath layer (clayey soil).

2.6 Ambika Kuitya, Tapas Kumar Roy presented a "Utilization of geogrid mesh for improving the soft subgrade layer with waste material mix composition" which says that by insertion of geogrid –provides better resistance against loading and also CBR value increases significantly at soaked condition. Inserting geogrid at one third height found to be optimum height and improves bearing capacity.

2.7 Dr. P. Senthil kumar and R. Rajkumar studied about "Effect of Geotextile on CBR Strength of Unpaved Road with Soft Subgrade" which concludes that it's more advantageous for unpaved road and provide more resistance at lower penetration. It also enhances CBR value.

3. METHODOLOGY

Natural gravel soil material was taken from a gravel borrow pit for a construction site near Ghaziabad. The material was being considered for use as natural gravel layers for the construction of a low volume urban road pavement. The material was air dried and tested for consistency limits, particle size distribution and compaction according to the requirements. Compaction test was carried out in the laboratory to determine the optimum moisture content and the maximum dry density of the soil sample using test method ASTM D1557 and BS 1377-4. The CBR was tested according to the test procedure and the composite material was tested in the laboratory. The experimental setup is schematically shown in Figure 1.

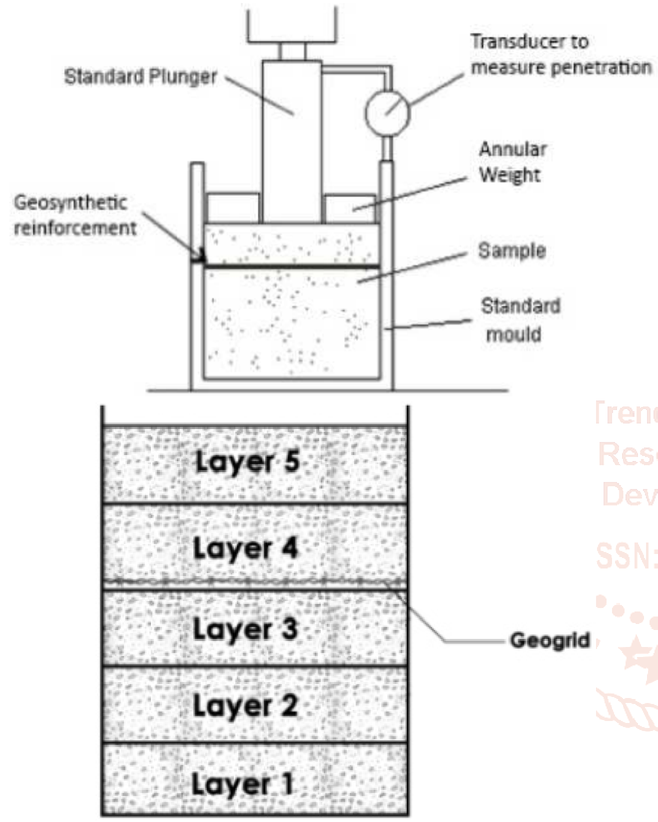


Fig-3.1

4. OBJECTIVE

The main objectives are as follows:-

- To determine the engineering and index properties of soil sample.
- To determine the CBR values of soil sample.
- To determine the CBR values of soil sample with geosynthetic materials.
- Comparative study of ordinary soil sample and soil sample with geosynthetic material.

Following Tests were conducted to investigate the properties of the soil as well as geosynthetics.

4.1. TESTS FOR SOIL SAMPLES:

4.1.1. Particle size distribution test
4.1.2. Plastic limit test
4.1.3. Shrinkage limit test
4.1.4. Direct shear test
4.1.5. Triaxial shear test
4.1.6. CBR test for soil

4.2. TESTS WITH GEOSYNTHETICS:

4.2.1. CBR strength test
4.2.2. Trapezoidal tear strength test
4.2.3. Burst Strength test
4.2.4. CBR Puncture test
4.2.5. Seam strength tests

5. DATA COLLECTION AND ITS ANALYSIS

5.1. GENERAL

Investigation of soil and geosynthetics requires various field test and lab tests as explain in previous chapter. This chapter presents material which is collected from site given below for soil-aggregates with geotextiles in detail. The present chapter divided into three main sections. First section presents the physical requirement of soil-aggregates and geotextiles. Second section presents the properties of geosynthetics or geotextiles. Third section presents the preparation of pavement by soil aggregates and geotextile for shredding on aggregates.

5.2. AGGREGATES AND SOIL COLLECTION

In this case we can use clay soil was used as a subgrade and sand was placed as surface aggregates. The aggregates were obtained from a site that is adjacent to Meerut highway project located in Meerut area, which is posited 10 km away from Delhi-Meerut road. Table 5.1 shows the physical properties of both clayey and sandy aggregates. The density curves of the aggregates are shown in Figs. 5.1 and 5.2 and Table 5.2.

Table 5.1: Clay and Soil Characteristics

Soil Type	Standards	Descriptions	Amount
	ASTM D 4318	Smooth Limit	25.2%
	ASTM D 4318	Dough Limit	17.4%
	ASTM D 4318	Dough Index	7.8%
CLAY	ASTM D 1557	Optimization Humidity	14.5%
	ASTM D 1557	Maximum Dryness(g/cm³)	1.74
	ASTM D 2862	D 10 (mm)	70
	ASTM D 2862	D 30 (mm)	30.4
	ASTM D 2862	D 60 (mm)	35.5
SAND	ASTM D 2862	Coefficient Uniformity	43
	ASTM D 2862	Coefficient Curvature	170
	1557 ASTM D	Optimization Humidity	9%
	1557 ASTM D	Maximum Dryness(g/cm³)	1.98

Table 5.2: Density amount for the studied materials

Material	Clay	Sand
Gs(ASTMD 854) g/cm3	2.62	2.67

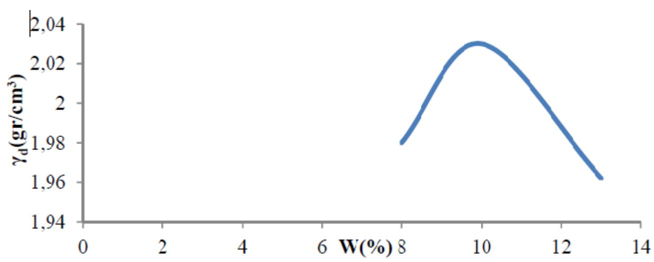


Fig-5.1: Sand Compression Curve Diagram

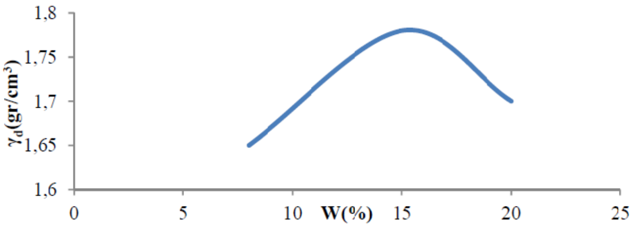


Fig-5.2: Clay Compression Curve Diagram

5.3. GEOTEXTILES

There are three types of geotextiles in different weights per square meter (150, 200, 300) were used in 5 definite depths of layers in clayey and sandy soil samples, and two sheets of geotextiles between the layers were also used as shown in Fig.5.3. CBR (California Bearing Ratio) ASTM D1883 testing program was performed to evaluate the bearing capacity of samples.

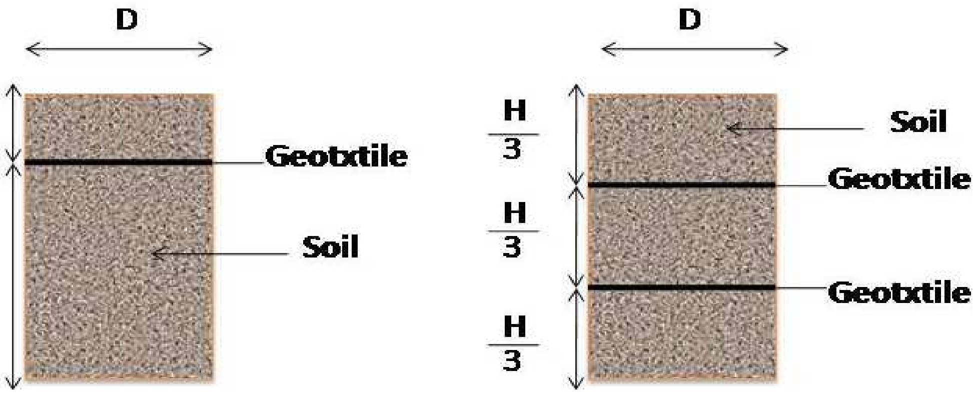


Fig-5.3: The Arrangement of Geotextile in Different Sample

The reinforcement material used is a non-woven geotextile with three different values in weights per square meters (150,200 and 300) from PAMCO. The properties of geotextiles are shown in Table 5.3.

Table 5.3: Selection of Geotextile Category Based on Performance Conditions

Specifications	Unit	Test	Direction	150-g/m	200-g/m	300-g/m
Mass per unit area	g/m	DIN EN 29073/1		150	200	300
Thickness	Mm	DIN EN 29073/2		1.9	2.6	3.4
Maximum Tensile Strength	KN/m	DIN EN 29073/3	Linear	6.7	11	19
Elongation at Maximum Tensile Strength	%	DIN EN 29073/3	Linear	50	55	55
Hole size cone drop test	Mm	EN 918		24	20	14
CBR Puncture Resistance	KN/m	DIN EN IS012236		1.6	2.5	3.4
Opening Size	Um	DIN EN IS012956		102	93	93
Vertical Water Permeability	10m/s	DIN EN IS011058		2.8	2.4	2.4
Grab Tensile Strength	N	ASTM D 4632	Linear	510	820	1220
Elongation at max. Grab Tensile Strength	%	ASTM D 4b632	Linear	62	62	59
Trapezoid Tearing Strength	N	ASTM D 4533	Linear	200	290	395
Index Puncture Resistance	N	ASTM D 4833		265	370	560

5.4. PROPERTIES OF GEOSYNTHETICS:

- Physical properties
- Mechanical properties
- Hydraulic properties
- Endurance properties

5.4.1. Physical properties:

5.4.1.1. Mass per unit area-

- Five test specimens to be weighed in a weighing machine (0.01gm) and average value is recorded.
- Test sample are of size 100mm x 100mm
- Unit is expressed as g/m^2
- The cost of geotextile is directly related to the weight of geotextile.

Fig-5.4

5.4.1.2. Thickness-

- Geotextiles exhibit different thickness according to different pressures.
- The thickness is measured to an accuracy of 0.02mm under a specified pressure of 2.0 MPa.
- The sample size of 200mm x 200mm. The thickness is generally in the range of 0.25 to 8.5mm.
- The thickness of geogrid and geomembranes are measured under a normal stress of 20 MPa.

Fig-5.5: Thickness Measurement of Geotextiles

5.4.1.3. Specific gravity-

- Specific gravity can be defined as the ratio of the unit weight of material to the unit weight of distilled water at 4^{o} C.

Table 5.4: Specific Gravity of Different Geosynthetic Materials

Materials	Specific Gravity
Polypropylene	0.91
Polyethylene	0.9 to 0.96
Polyester	1.22 to 1.38
Polyvinyl Chloride	1.69
Nylon	1.05 to 1.14

5.4.1.4 Stiffness or flexural rigidity or flexural stiffness-

- The geotextile specimen is 25mm wide strip.
- The geotextile is placed along the length of a horizontal plane and bends gravitationally under its own weight on ainclined plane making an angle of 41.5 degree with the horizontal.

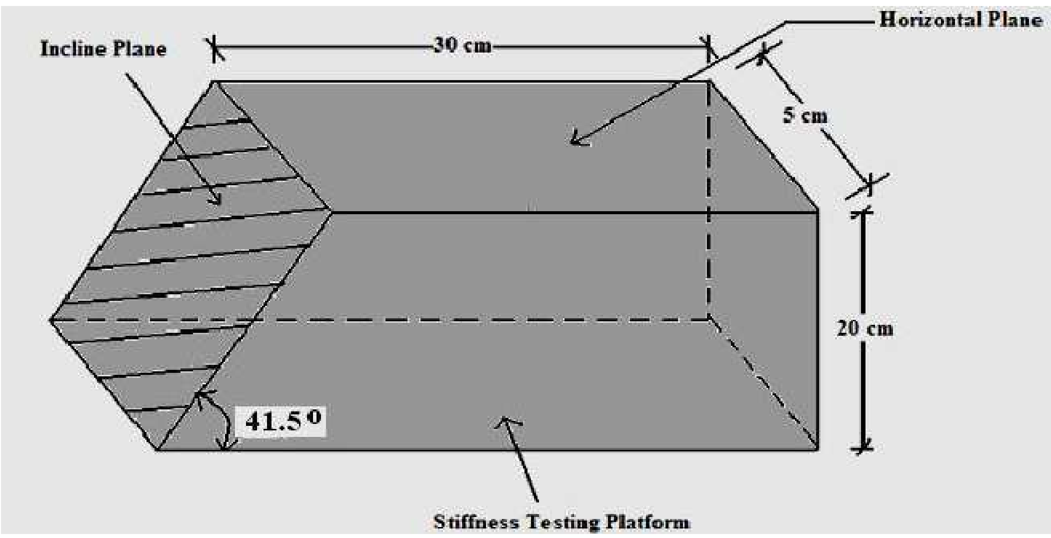


Fig-5.6

- Stiffness of the geotextile = (l/2)3 x W
- l = length of overhang geotextile and bending length = l/2(cm), w = mass per unit area(mg/cm2)
- The unit of stiffness is mg-cm.
- The minimum stiffness of geotextile depends on the various degree of required workability (Haliburton et al., 1980)
- The property is important in field workability requirementsfor installation of geotextile.
- If the soil is very poor or California bearing ratio value isvery less, the stiffness of geotextile required is very high.

5.4.2. Mechanical properties:

5.4.2.1. Compressibility-

- Compressibility indicates the reduction in thickness under applied pressure.
- Compressibility of geotextile depends on its thickness and mass per unit area.
- As the pressure increases, thickness of non-woven needle punched (NW-NP) and resin bonded geotextiles gets reduced significantly and accordingly, the transmissivity gets reduced.
- Compressibility of woven and non-woven heat bonded geotextile (NW-HB) is low.
- Compressibility of nonwoven needle-punched geotextile plays a very important role as most of the time we use these type of geotextiles to pass the liquid along their plane.

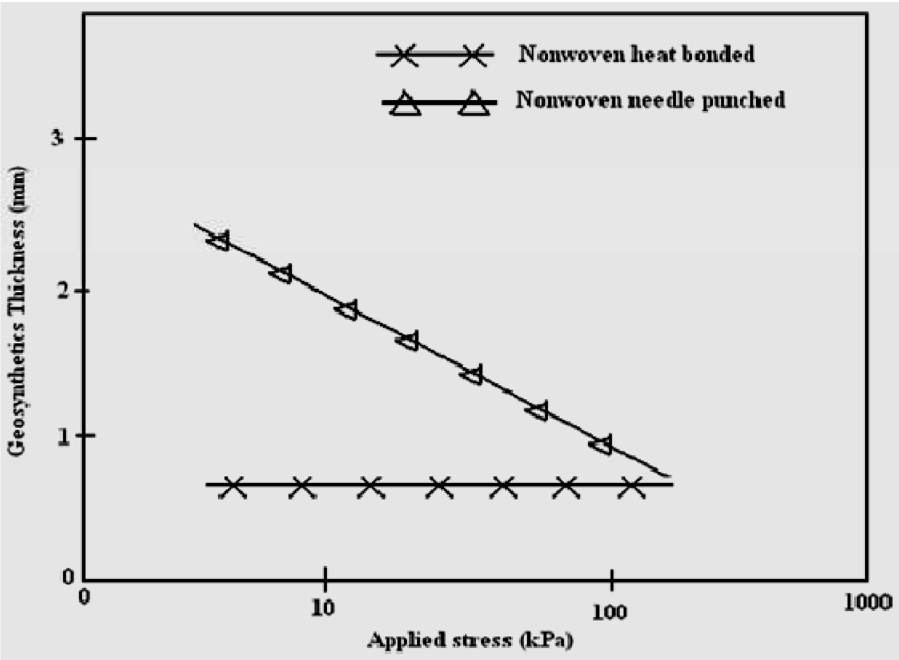


Fig-5.7: Variation in Thickness of Geosynthetics with Change in Pressure

- It is clearly observed that nonwoven needle punched geosynthetics are more compressible.

5.4.2.2. Tensile strength test of Geosynthetics-

- Wide width tensile strength
- Very wide width tensile strength test
- Narrow strip tensile strength (ASTM D4751)
- Sewn seam strength of geotextile
- Grab tensile strength (ASTM D4632)
- Trapezoidal tear strength test

WIDE WIDTH TENSILE STRESSTEST

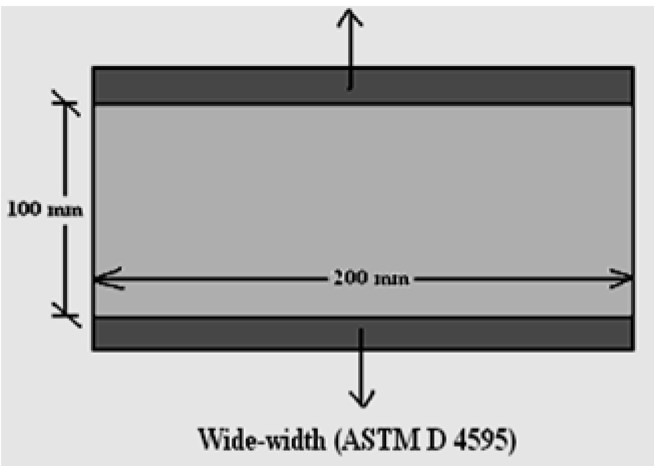


Fig-5.8

Fig-5.9

Fig-5.10

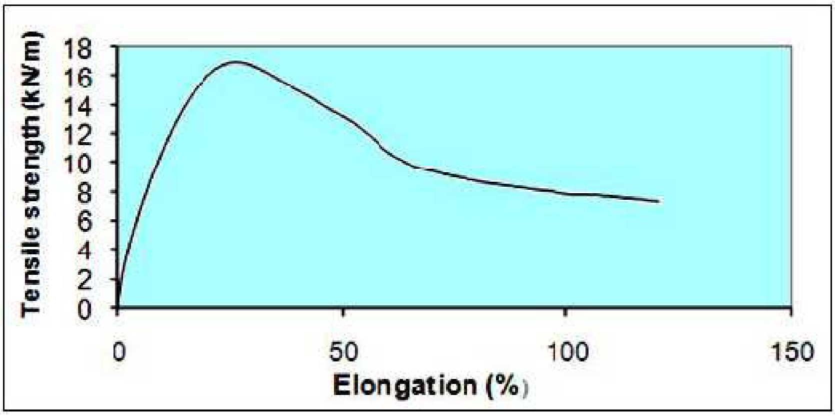


Fig-5.11: Test Result on a Thermally Bonded Nonwoven Geotextile

- The machine strain rate is 10 ± 3 %.
- The reason for the necessity of wide-width specimens is that geotextiles (particularly non-woven) achieve high poison's ratio value from narrow strip test.
- Tensile strength of geotextile ($T_{geotextile}$) can be expressed as force per unit width.

$T_{geotextile} = F_b / W$ (kN/m)

F_b = Observed breaking force (kN), and

W = Specimen width (meter)

VERY WIDE WIDTH TENSILE STRESS TEST

For design purpose, the very wide width tensile test is not recommended.

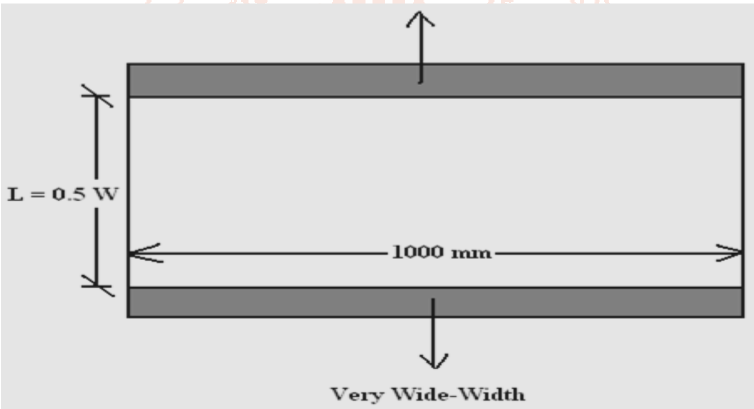


Fig-5.12: Size of Sample for Very Wide Width Tensile Stress Test

NARROW STRIP TENSILE STRESS TEST

Fig-5.13: Size of test sample with the test assembly at = 300 mm/ min

- Tensile strength appears low compared to wide width tensile strength test.
- Not recommended as design value.

SEWN SEAM STRENGTH OF GEOTEXTILE
- Strain Rate=10±3%/min, Unit in KN/m
- Butterfly seam is recommended for sewing.
- The seam strength efficiency can be expressed as,

$S_E=(T_{seam}/T_g)x100$ %

Where, T_{seam}= Wide width seam strength and

T_g= Wide width geosynthetic strength without seam

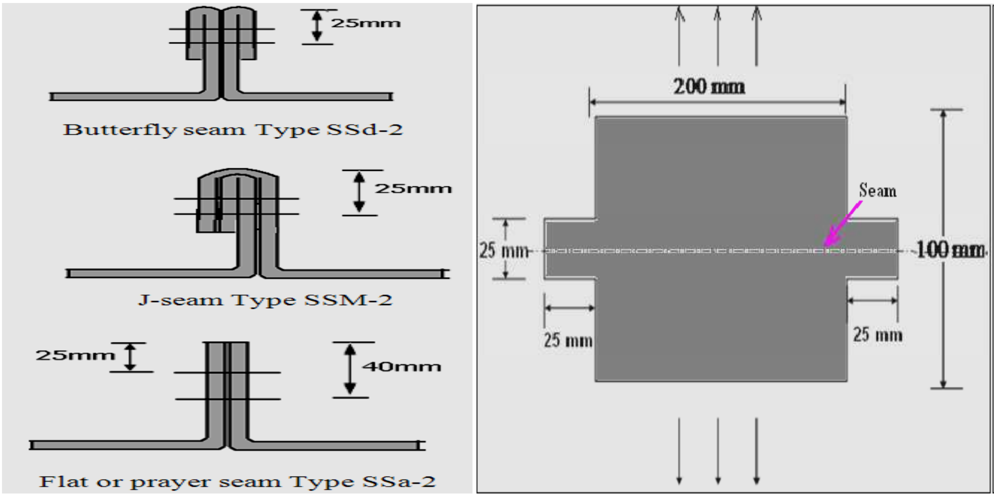


Fig-5.14: Size of test sample for sewn seam strength

GRAB TENSILE TEST (ASTM D 1682)

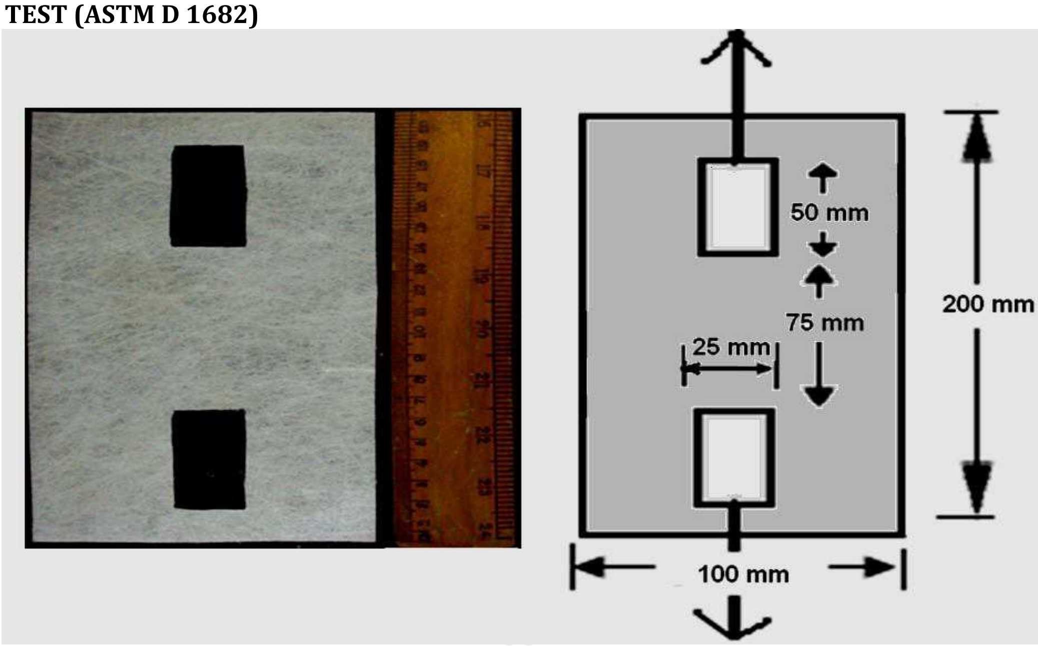
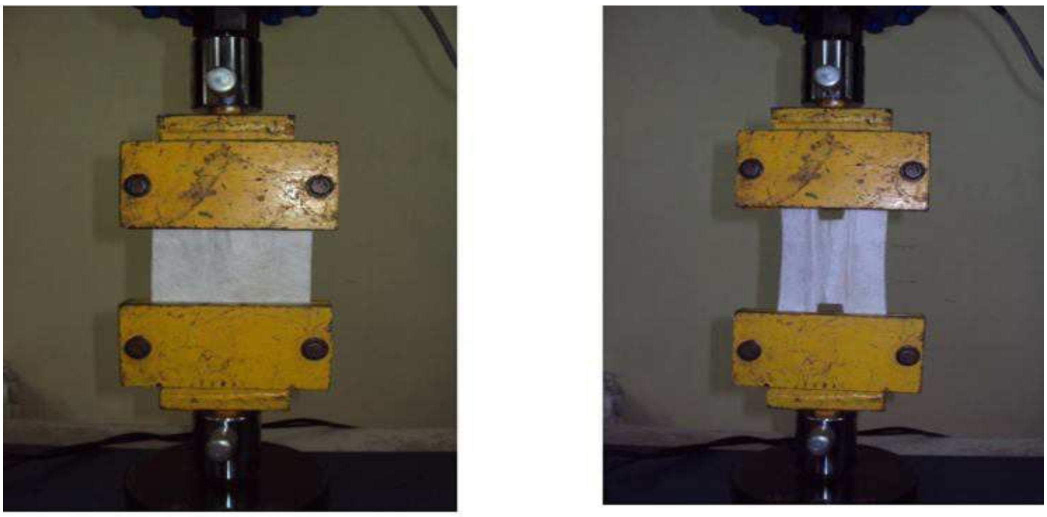


Fig-5.15: Grab Tensile Test Specimen



a) Before test b) After test

Fig-5.16: Laboratory Grab Tensile Test

- The test relies on filament interaction in geotextile. For non woven textile, the effects are more then woven textile.
- As the sample is partially clamped, stress is not propagated in entire width of the sample. This test may be misused.

Analytical analysis of grab tensile strength:

- Grab tensile strength is required to design the geotextiles for separation. When pressure is applied to the upper stone, it spreads the two lower stones laterally. As a result, tension is mobilized in the geotextile. It is analogous to thegrab tensile strength test.

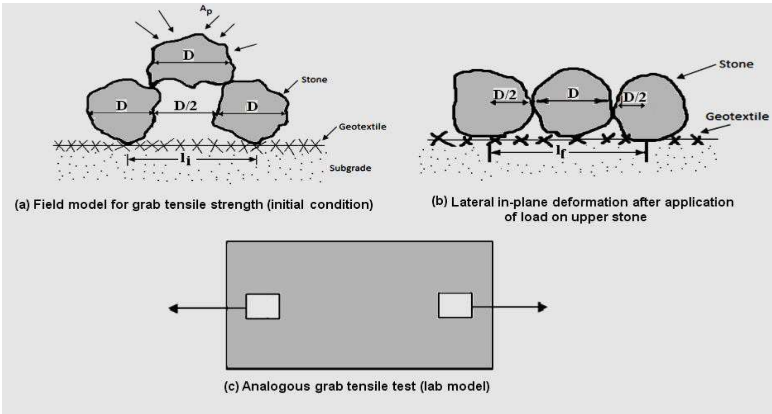


Fig-5.17: Analytical Laboratory Grab Tensile Test

D= Diameter of stone
L_i= Initial length of geotextile= **D/2+ D/2+D/2**
L_f= Final length of geotextile= **D+ 2. D/2**

Without any stone breakage and slippage, maximum in geotextile strain can be expressed as **$€= L_f - L_i / L_i$ = 33%**
$T_{reqd}= A_p.(D_v)^2.€$

Where,
T_{reqd} = Required Grab Strength
A_P =Applied Pressure
D_v = Maximum Void Diameter = 0.33 D_a ,
D_a = Average Stone Diameter

TRAPEZOIDAL TEAR STRENGTH TEST (ASTM D4533 and ISO 13434)

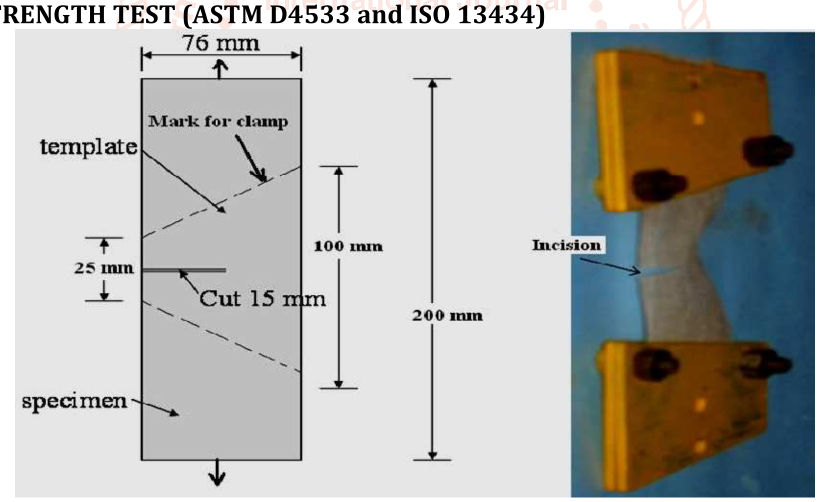


Fig-5.18

- Trapezoidal tear strength measured in Newton.
- This test is done to tear the test specimen from the point of incision.
- Tear strength is important when the geosynthetic is damaged.

6. PREPARATION OF GEOSYNTHETICS MATERIAL

6.1. Geosynthetic Advantages

Geosynthetics, including geotextiles, geomembranes, geonets, geogrids, geocomposites and geosynthetic clay liners, often used in combination with conventional materials, offer the following advantages over traditional materials:

- **Space Savings -** Sheet-like, geosynthetics take up much less space in a landfill than do comparable soil and aggregate layers.
- **Material Quality Control -** Soil and aggregate are generally heterogeneous materials that may vary significantly across a site or borrow area. Geosynthetics on the other hand are relatively homogeneous because they are manufactured under tightly controlled conditions in a factory. They undergo rigorous quality control to minimize material variation.
- **Construction Quality Control -** Geosynthetics are manufactured and often factory "prefabricated" into large sheets. This minimizes the required number of field connections, or seams. Both factory and field seams are made and tested by trained technicians. Conversely, soil and aggregate layers are constructed in place and are subject to variations caused by weather, handling and placement.

- **Cost Savings -** Geosynthetic materials are generally less costly to purchase, transport and install than soils and aggregates.
- **Technical Superiority -** Geosynthetics have been engineered for optimal performance in the desired application.
- **Construction Timing -** Geosynthetics can be installed quickly, providing the flexibility to construct during short construction seasons, breaks in inclement weather, or without the need to demobilize and remobilize the earthwork contractor.
- **Material Deployment -** Layers of geosynthetics are deployed sequentially, but with a minimum of stagger between layers, allowing a single crew to efficiently deploy multiple geosynthetic layers.
- **Material Availability -** Numerous suppliers of most geosynthetics and ease of shipping insure competitive pricing and ready availability of materials.
- **Environmental Sensitivity –** Geosynthetic systems reduce the use of natural resources and the environmental damage associated quarrying, trucking, and other material handling activities.

6.2. Preparation of Various types of Geosynthetics:

6.2.1. Geotextile polymers

In these days all the geotextiles available in India are manufactured from either polyester or polypropylene. Polypropylene is lighter than water has the specific gravity of 0.9) and it is also very strong and durable so the Polypropylene filaments and staple fibers are used in manufacturing woven yarns and nonwoven geotextiles.

Polyester is heavier than water but it has excellent strength and creep properties so it is compatible with most common soil environments.

6.2.1.1. Geotextiles structure:

There are two types of geotextile or Structures i.e. wovens and nonwovens.

Nonwovens

Nonwoven geotextiles are manufactured from either staple fibers (staple fibers are short, usually 1 to 4 inches in length) or continuous filaments randomly distributed in layers onto a moving belt to form a felt-like "web". Nonwoven geotextiles are highly desirable for subsurface drainage and erosion controlled.

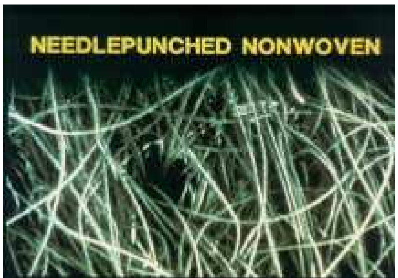
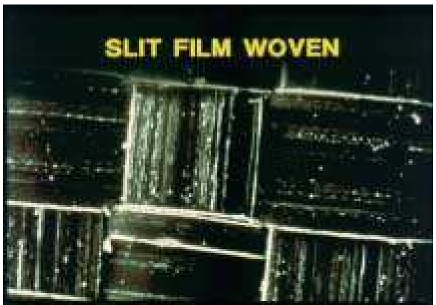


Fig-6.1 Fig-6.2

Wovens

If by weaving of geotextile we can make the yarns or fabrics or Woven geotextiles are made from weaving monofilament, multifilament, or slit film yarns. Slit film yarns can be further subdivided into flat tapes and fibrillated yarns like spider shape. Firstly we can manufacture of the filaments or slitting the film to create yarns and after that weaving the yarns to form the geotextile material. Slit film fabrics used as the sediment control i.e. for silt fence, road stabilization applications, for drainage work and for erosion control applications.



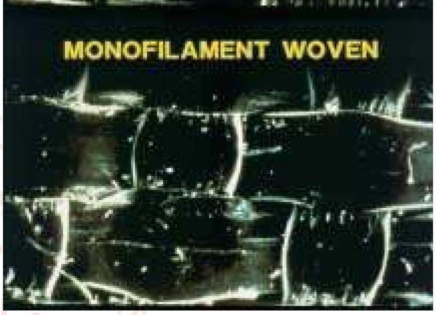


Fig-6.3 Fig-6.4

6.2.2. Geogrids

Geogrids are single or multi-layer materials usually made from extruding and stretching high-density polyethylene or polypropylene or by weaving or knitting. The resulting grid structure possesses large openings called apertures that improve the interaction with the soil or aggregate.

The high tensile strength or stiffness of geogrid which effects especially assoil aggregate and reinforcement.

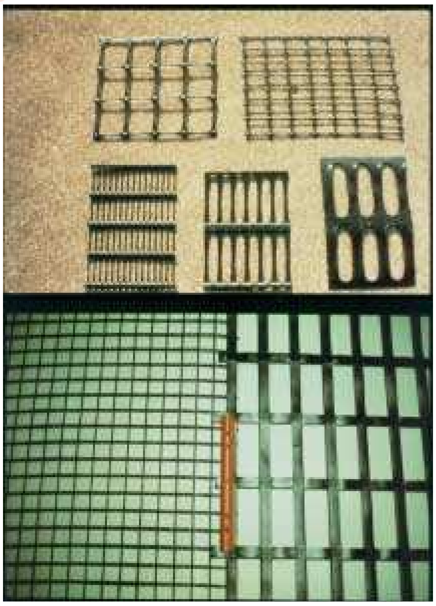


Fig-6.5

6.2.3. Geonets

Geonets are made of stacked, criss-crossing polymer strands that provide in-plane drainage. Nearly all geonets are made of polyethylene. The molten polymer is extruded through slits in counter-rotating dies which forms a matrix, or netof closely spaced stacked strands. Two layers of strands are called "bi-planar" and three layers are called "tri-planar".

Fig-6.6

6.2.4. Geocomposites

The possibility of combining the superior features of various geosynthetics and improve the quality of geotextile materials is called "geocomposite" materials. There are many possibilities in assembling different materials to the geotextiles and increase the stability and durability of material used in road pavements.

6.2.4.1. Drainage Geocomposites

The most common geocomposite configuration is known as a drainage geocomposite. Drainage geocomposites are composed of a geotextile filter surrounding either a geonet (blanket drain), a thick preformed core (panel or edge drain), or a thin preformed core (wick drain). Some applications of drainage geocomposites are blanket drains, panel drains, edge drains and wick drains.

Fig-6.7 Fig-6.8Blanket DrainDouble- and single-sided geocomposite drains

6.2.4.2. Blanket Drains

Blanket drains are commonlyused as leachate or infiltration collection and removal layers within landfills. Recently, geocomposite blanket drains have been used to enhance road base drainage.

6.2.4.3. Panel Drains

Panel drains can be placed adjacent to structures to reduce hydrostatic pressures.

6.2.4.4. Edge Drains

Edge drains are often used adjacent to pavement structures to collect and remove lateral seepage from the road base.

Fig-6.9 Panel Drain

Fig-6.10 Edge Drain

6.2.4.5. Wick Drains

Wick drains are pushed deep into the ground, providing drainage paths to expedite the consolidation of saturated soils, significantly decreasing the settlement time of embankments over soft soils.

Fig-6.11 Wick Drain

6.2.5. Geomembranes

Geomembranes are impermeable sheets of plastic and it has two general categories of geomembranes, they are calendered and extruded.

6.2.5.1. Calendered Geomembranes

Calendered geomembranes are formed by working and flattening a molten viscous formulation between counterrotating rollers. Polyvinyl chloride (PVC), chlorosulfonated polyethylene (CSPE), chlorinated polyethylene (CPE), and, more recently, polypropylene (PP) are the most common calendered geomembranes.

Fig-6.12 Calendered Geomembrane

Fig-6.13 Extruded Geomembrane

6.2.5.2. Extruded Geomembranes
Extruded geomembranes are manufactured by melting polymer resin, or chips, and forcing the molten polymer through a die using a screw extruder. The sheet is formed either by a flat horizontal die or through a vertically oriented circular die to form either a flat wide sheet advanced on a conveyor belt, or cylindrical tube of "blown film'', filled with air which is collapsed and pulled by nip rollers mounted high above the die.

7. EXPERIMENTAL INVESTIGATIONS
7.1. TESTS ON SOIL SAMPLES
7.1.1. Particle size distribution test:
Introduction: Particle Size Distribution is usually expressed from the technique by which it is determined. Particle Technology Labs (PTL) uses a variety of different techniques in order to produce the most accurate particle size analysis possible. This test is performed to determine the percentage of different grain sizes contained within a soil and the mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles.

Scope: The grain size analysis is widely used in classification of soils. The data obtained from grain size distribution curves is used in the design of filters for earth dams and to determine suitability of soil for road construction, air field etc. Information obtained from grain size analysis can be used to predict soil water movement although permeability tests are more generally used.

Object: To determine the Particle size distribution of soil by grain analysis.

Apparatus:
- **Balance:** A balance of capacity not less than 500 gm to weigh accurate up to 0.1 gm**.**
- **Set of sieves:** According to IS Size of sieves are4.75, 2.00, 1.18,0.6, 0.425, 0.3, 0.15, 0.075 (in mm) and a pan.
- **Riffler:** Used to riffle the sample.
- **Thermostatically Controlled oven-** Used to dry the soil sample collected from the field.
- **Trays-** Used to collect the soil sample from the field.
- **Cleaning Brush:** Used to clean the sieves after shaking
- **Mechanical Sieve Shaker:** Equipment used to shake the set of sieves.

Knowledge of Equipment:
- The balance to be used must be sensitive to the extent of 0.1% of total weight of sample taken.
- I.S 460-1962 are to used. The sieves for soil tests: 4.75 mm to 75 microns.

Observations and Recordings:
- Weight of soil sample: 1000 gm
- Moisture content: 2.4%
- The moisture content of soil if above 5% it is to be measured and recorded.

Table 7.1: Results

S. No.	I.S sieve number or size in mm	Wt. Retained in each sieve (gm)	Percentage on each sieve	Cumulative %age retained on each sieve	% finer
1.	4.75	16	1.6	1.6	98.4
2.	2	33	3.3	4.9	95.1
3.	1.18	124	12.4	17.3	82.7
4.	0.6	134	13.4	30.7	69.3
5.	0.425	206	20.6	51.3	48.7
6.	0.3	218	21.8	73.1	26.9
7.	0.15	208	20.8	93.9	6.1
8.	0.075	18	1.8	95.7	4.3

Therefore Percentage of soil retained on 75 micron sieve = 1.8%

And, Cumulative Percentage of soil retained on 75 micron sieve = 4.3%

7.1.2. Liquid limit test:
Introduction: The liquid limit of a soil is the moisture content, expressed as a percentage of the weight of the oven-dried soil, at the boundary between the liquid and plastic states of consistency. The moisture content at this boundary is arbitrarily defined as the water content at which two halves of a soil cake will flow together

Scope: Liquid limit is significant to know the stress history and general properties of the soil met with construction. From the results of liquid limit the compression index may be estimated. The compression index value will help us in settlement analysis. If the natural moisture content of soil is closer to liquid limit, the soil can be considered as soft if the moisture content is lesser than liquids limit, the soil can be considered as soft if the moisture content is lesser than liquid limit. The soil is brittle and stiffer.

Object: To determine the liquid limit of the soil sample.

Apparatus:
- **Mechanical liquid limit device**
- **Grooving tools-** Casagrande type and ASTM type tool
- **Porcelain evaporating dish**
- **Spatula**
- **Balance:** 10 kg capacity – sensitivity 0.01 gm.
- **Thermostatically controlled oven**
- **Wash bottle containing distilled water**
- **Sample containers**
- **425 micron IS sieve**

Observations and Recordings:
- Weight of soil sample: 120 gm
- Natural Moisture content: 2.4%
- Room temperature: 25°-27° C
- The moisture content of soil if above 5% it is to be measured and recorded.

Table-7.2: Results

Determination Number	1	2	3
Number of blows	18	24	28
Container Number	I	II	III
Weight of Container, w_0 gm	20.08	21.47	24.38
Weight of Container + Wet soil, w_1 gm	38.14	36.20	40.24
Weight of Container + oven dry soil, w_2 gm	33.42	32.56	36.53
Weight of Water, $(w_1$-$w_2)$ gm	4.72	3.64	3.71
Weight of oven dry soil $(w_2$-$w_0)$ gm	13.34	11.09	12.15
Water Content= w_1-$w_{2/}$ w_2-w_0 x 100 %	35.38	32.82	30.52

Therefore, Average Liquid Limit = 32.90%

7.1.3. Plastic limit test:

Introduction: The plastic limit of a soil is the moisture content which expressed as a percentage of the weight of the oven-dry soil and at the boundary between the plastic and semisolid states of consistency. It is the moisture content at which a soil will just begin to crumble when rolled into a thread 3mm diameter using a ground glass plate or other acceptable surface.

Object: To determine the plastic limit of the soil sample.

Scope: Soil is used for making bricks, tiles, soil cement blocks in addition to its use as foundation for structures.

Apparatus:
- **Porcelain evaporating dish**
- **Ground- Glass plate**
- **Metallic Rod:** 3mm diameter rod
- **Spatula**
- **Balance:** 10 kg capacity – sensitivity 0.01 gm.
- **Thermostatically controlled oven**
- **Sample containers**
- **425 micron IS sieve**

Observations and Recordings:
- Compare the diameter of thread at intervals with the rod. When the diameter reduces to 3 mm, note the surface of the thread for cracks.
- Weight of soil sample: 120 gm
- Moisture content: 2.4%
- The moisture content of soil if above 5% it is to be measured and recorded.

Table-7.3: Results

Determination Number	1	2	3
Container Number	I	II	III
Weight of Container, w_0 gm	26.10	21.86	23.91
Weight of Container + Wet soil, w_1 gm	32.29	34.74	30.15
Weight of Container + oven dry soil, w_2 gm	31.20	32.51	29.06
Weight of Water, $(w_1$-$w_2)$ gm	1.09	2.23	1.09
Weight of oven dry soil $(w_2$-$w_0)$ gm	5.10	10.65	5.15
Water Content= w_1-$w_{2/}$ w_2-w_0 x 100 %	21.37	20.94	21.17

Therefore, Averageplastic limit = 21.16%

Plasticity index:

Introduction: The plasticity index of a soil is the numerical difference between its liquid limit and its plastic limit, and is a dimensionless number. Both the liquid and plastic limits are moisture contents.

Calculations: Plasticity Index = Liquid Limit - Plastic Limit = 32.90-21.16= 11.74%

Therefore, Plasticity Index =11.74%

7.1.4. Direct shear test (IS 2720: 13):

Introduction: Shear strength of the soil is the resistance to deformation of soil particles upon the action of the shear stress. In direct shear is simple and mostly recommended for granular soils sometimes on soils containing some cohesive soil content and sometimes on normal soil. The cohesive soils have issues regarding controlling the strain rates to drained or undrainedloading then In granular soils, loading can always assumed to be drained.

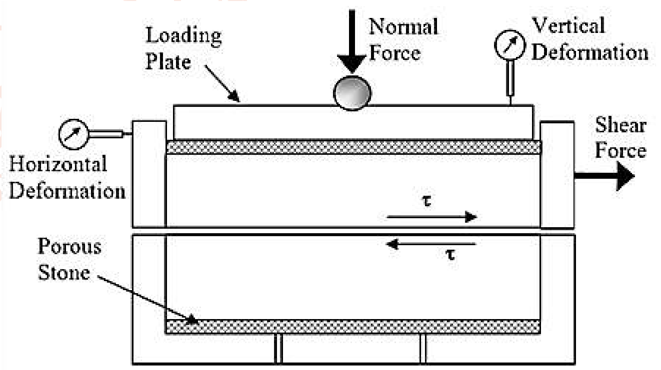


Fig-7.1

Scope: The value internal friction angle and cohesion of the soil are required for design of many engineering problems such as foundations, retaining walls, bridges, sheet piling. Direct shear test can predict these parameters quickly.

Knowledge of equipment:
Strain controlled direct shear machine consists of shear box, soil container, loading unit, proving ring, dial gauge to measure shear deformation and volume changes. A two piece square shear box is one type of soil container used. Aproving ring is used to indicate the shear load taken by the soil initiated in the shearing plane.

Object: To determine the shearing strength of the soil using the direct shear apparatus.

Apparatus:
- **Direct shear box apparatus- Horizontally divided in two parts**
- **Loading frame (motor attached)**
- **Dial gauge**
- **Proving ring**
- **Tamper**
- **Straight edge**
- **Balance to weigh upto 200 mg**
- **Aluminum container**
- **Spatula**

Observations and Recordings:
- Proving Ring constant.......
- Least count of the dial........
- Calibration factor.......
- Leverage factor........
- Dimensions of shear box 60 x 60 mm
- Empty weight of shear box........
- Least count of dial gauge.........
- Volume change.......

Table-7.4: Results

Test No.	Normal stress Kg/cm^2	Shear Stress at failure Kg/cm^2	Shear displacement at failure
1.	0.5	0.37	
2.	1.0	0.55	
3.	1.5	0.77	

7.2. TESTS ON AGGREGATES:
7.2.1. Aggregate Impact Value Test (IS: 2386 – PART – 4)

Introduction: Toughness is the property of a material to resist impact. Due to traffic loads, the road stones are subjected to the pounding action or impact and there is possibility of stones breaking into smaller pieces. The road stones should therefore be tough enough to resist fracture under impact. A test designed to evaluate the toughness of stones i.e., the resistance of the fracture under repeated impacts may be called an impact test for road stones.

Object: To determine the toughness of road stone materials by Impact test.

Apparatus:
A. **Impact testing machine**: The machine consists of a metal base with a plane lower surface supported well on a firm floor, without rocking. A detachable cylindrical steel cup of internal diameter 102mm and depth 50mm is rigidly fastened centrally to the base plate. A metal hammer of weight between 13.5 and 14.0 kg having the lower end cylindrical in shape, 100mm in diameter and 50mm long, with 2mm chamfer at the lower edge is capable of sliding freely between vertical guides, and fall concentric over the cup. There is an arrangement for raising the hammer and allowing it to fall freely between vertical guides from a height of 380mm on the test sample in the cup, the height of fall being adjustable up to 5mm. A key is provided for supporting the hammer while fastening or removing the cup.
B. **Measure**: A cylindrical metal measure having internal diameter 75mm and depth 50mm for measuring aggregates.
C. **Tamping rod**: A straight metal tamping rod of circular cross section, 10mm indiameter and 230mm long, rounded at one end.
D. **Sieve**: IS sieve of sizes 12.5mm, 10mm, and 2.36mm for sieving the aggregates.
E. **Balance**: A balance of capacity not less than 500 gm to weigh accurate up to 0.1 gm.
F. **Oven**: A thermostatically controlled drying oven capable of maintaining constant temperature between 100°C-110°C

Limits:
< 10% exceptionally strong.
10 – 20% Strong.
20 – 30% Satisfactory for road surfacing.
> 35% Weak for road surfacing

Table 7.7: Results

S. No.	Details	Trial no. 1	2	3	Average
1	Total wt. of aggregate sample filling thecylindrical measure = w_1 g	600	600	600	600
2	Wt. of agg. Passing 2.36 mm sieve after the test = w_2 g	60	56	61	59
3	Wt. of agg. Retained on 2.36 mm sieve after the test = w_3 g	510	502	507	506.33.
4	Difference in weight = w_1 - (w_2 + w_3) g	40	42	32	38
5	Agg. Impact value = percent fines = (w_2/ w_1) x 100	11.76	9.33	10.17	10.42

Therefore aggregate impact value = 10.42%

7.2.2. Los Angles Abrasion Test (IS: 2386 – PART – 4)

Introduction: Due to the movement of traffic, the road stones used in the surfacing course are subjected to wearing action at the top. Resistance to wear or hardness is hence an essential property for road aggregates, especially when used in wearing course. Thus road stones should be hard enough to resist the abrasion due to the traffic. When fast moving traffic fitted with pneumatic tyres move on the road, the soil particles present between the wheel and road surface causes abrasion on the road stone. Steel tyres of animal drawn vehicles, which rub against the stones, can cause considerable abrasion of the stones on the road surface. Hence in order to test the suitability of road stones to resist the abrading action due to traffic.

Object: To determine the aggregates abrasion test by Los Angles Abrasion method.

Apparatus:
A. **Los Angles Abrasion Machine**: The Los Angles Machine consists of a hollow steel cylinder, closed at both ends, having an inside diameter 700mm and an inside length of 500mm, mounted on stub shafts about which it rotates on a horizontal axis, and rotating arrangement for speed of 30 to 33 revolutions per minute. An opening is provided in the cylinder for the introduction of the test sample. A removable cover of the opening is provided in such a way that when

closed and fixed by bolts and nuts, it is dust-tight and the interior surface is perfectly cylindrical. A removable steel shelf projecting radially 88mm in to the cylinder and extending to the full length of it, is mounted on the interior surface of the cylinder rigidly, parallel to the axis. The shelf is fixed at a distance of 1250mm from the opening, measured along the circumference in the direction of rotation.

Abrasion charge, consisting of cast iron spheres approximately 48mm in diameter and 390 to 445gm in weight are used.

B. **Balance** -10 kg capacity – sensitivity 0.1 gm.
C. **Test Sieve –** 1.70 mm IS sieve.
D. **Oven.**

Table 7.8: Specifications for conducting Los Angeles test

Grading	Weight of test sample in grams for different gradings , in the size range,mm (passing and retained on aggregate test sieves)										Abrasive charge	
	80-63	63-50	50-40	40-25	25-20	20-12.5	12.5-10	10-6.3	6.3-4.75	4.75-2.36	No. of spheres	Weight of charge in grams
A	-	-	-	1250	1250	1250	1250	-	-	-	12	5000±25
B	-	-	-	-	-	2500	2500	-	-	-	11	4584±25
C	-	-	-	-	-	-	-	2500	2500	-	8	3330±20
D	-	-	-	-	-	-	-	-	-	5000	6	2500±25
E	2500*	2500*	5000*	-	-	-	-	-	-	-	12	5000±25
F	-	-	5000*	5000*	-	-	-	-	-	-	12	5000±25
G	-	-	-	5000*	5000*	-	-	-	-	-	12	5000±25

*** Tolerance of ±2% is permitted.**

Results:
1. Type aggregate = Crushed angular aggregates
2. Grading = C
3. No of spheres used = 8
4. Weight of charge = 400gm
5. No of revolutions = 500

Table 7.9

Sr. No.	Test values and calculation	Test no			Avereage
		1	2	3	
1	Weight of specimen	5000	5000	5000	5000
2	Weight of specimen after abrasion test retained on 1.70mm test sieve, w2 gm	3900	3700	3600	3733.33
3	Los Angeles abrasion value= Percentage wear= $(w_1-w_2)/w_1$	22	26	28	25.33

Therefore, Los Angeles abrasion value is = 25.33%

7.2.3. Aggregate Crushing Value Test. (IS: 2386 – PART – 4)

Introduction: The principal mechanical properties required in stones are (i) satisfactory resistance to crushing under the roller during construction and (ii) adequate resistance to surface abrasion under traffic.

Aggregates used in road construction, should be strong enough to resist crushing under traffic wheel loads. If the aggregates are weak, the stability of the pavement structure is likely to be adversely affected. The strength of coarse aggregates is assessed by aggregates crushing test. The aggregate crushing value provides a relative measure of resistance to crushing under a gradually applied compressive load. To achieve a high quality of pavement, aggregate possessing low aggregate crushing value should be preferred.

Object: To determine the aggregate crushing value by compressive testing machine.

Apparatus:
A. Steel cylinder with open ends, and internal diameter 152mm, square base plate, plunger having a piston of diameter 150mm, with a hole provided across the stem of the plunger so that a rod could be inserted for lifting or placing the plunger in the cylinder.
B. Cylindrical measure having internal diameter of 115mm and height 180mm.
C. Steel tamping rod with one rounded end, having a diameter of 16mm and length 450 to 600mm.
D. Balance of capacity 3 kg with accuracy up to 1gm.
E. Compressive testing machine capable of applying load of 40 tones, at a uniform rate of loading of 4 ton per minute.

Limits:
The aggregate crushing value for cement concrete pavement shall not exceed 30%.
The aggregate crushing value for wearing surfaces shall not exceed 45%.

Table 7.10: Results

Sr. no	Test values	Test no. 1	2	3	Average
1	Total weight of dry sample of aggregates taken, w_1 g	1500	1500	1500	1500
2	Weight of the portion of crushed materiel passing through 2.36mm test sieve, w_2 g	315	318	321	318
3	Aggregate crushing value = 100x (w_2/w_1)	21	21.2	21.4	21.2

Therefore, aggregates crushing value = 21.2%

7.2.4. Flakiness and elongation index test (IS: 2386 – PART – 1)

Introduction: The particle shape of aggregates is determined by the percentages of flaky and elongated particles contained in it. For base course and construction of bituminous and cement concrete types, the presence of flaky and elongated particles are considered undesirable as they may cause inherent weakness with possibilities of breaking down under heavy loads. The angularity number i.e., flaky and elongation has considerable importance in the gradation requirements of various types of mixes such as bituminous concrete, cement concrete and soil aggregate mixes.

Object: To determine the flakiness and elongation of the aggregates by standard flakiness gauge and elongation gauges.

Apparatus:

A. **Flakiness gauge (Thickness gauge):** The Flakiness index of aggregates is the percentages by weight of particles whose least dimension is less than three-fifths (0.6) of their mean dimension. The test is not applicable to sizes smaller than 6.3mm. The apparatus consists of a standard thickness gauge of IS sieve sizes 63, 50, 40, 31.5, 25, 20,16, 12.5, 10 and 6.3mm and a balance to weigh the samples.
B. **Elongation gauge (Length gauge):** The elongation index of aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than one and four fifth times (1.8) their mean dimension. The elongation test is not applicable to sizes smaller than 6.3mm. The apparatus consists of a standard length gauge of IS sieve sizes 50, 40, 31.5, 25, 20, 16, 12.5, 10 and 6.3mm.

Calculation: The weights of the separated size range of aggregate sample during the sieve analysis are recorded as w_1, w_2,w_3, etc. The total weight of samples of coarse aggregates is then equal to (w_1+w_2+w_3+w_4….) g = Wg. The wt. of the separated aggregates in each size range are then expressed as percentage of total wt of the sample such as X_1=100 x (w_1/W), X_2 =100(w_2/W)

C. **Elongation Index:** The sample is sieved through the IS sieves specified as above. A minimum of 200 pieces of each fraction is taken and weighed. In order to separate elongated material, each fraction is then gauged individually for length in a length gauge. The pieces of aggregates from each fraction tested which could not pass through the specified gauge length with its long side are elongated particles and are collected separately to find the total weight of aggregates retained on the length gauge from each fraction. The total amount of elongated material retained by the length gauge is weighed to an accuracy of at least 0.1 percent of the weight of the sample.

Combined Flakiness & Elongation Index: To determine this combined proportion, the flaky stone from a representative sample should first be separated out. Flakiness index is weight of flaky stone metal divided by weight of stone sample. Only the elongated particle is separated out from the remaining (non flaky) stone metal. Elongation index is weight of elongated particles divided by total non-flaky particles. The value of flakiness index and elongation index so found are added up.

Limits:
1. Flakiness Index for Bituminous and Non-bituminous Mixes = Max. 15%
2. Elongation Index for Bituminous and Non-bituminous mixes = Max. 15%
3. Combined Flakiness and Elongation Index for Bituminous and Non-bituminous mixes = Max.30%
4. Flakiness Index for Concrete mixes = Max.35%

7.2.5. Soundness Test (IS: 2386 – PART – 5)

Introduction: This test is intended to study the resistance of aggregates to weathering action.

In order to quicken the effect of weathering due to alternate wet-dry and or freeze-thaw cycles in the laboratory, the resistance to disintegration of aggregate is determined bysoaking the specimen in saturated solution of sodium sulphate or magnesium sulphate.

Object: Determination of the soundness of aggregates.

Apparatus: The apparatus required for the test are containers for aggregates, sieves (63, 50, 40, 31.5,20, 16, 10, 8, 4.75 and 4mm), balance of capacity 5kg to weight accurate to at least 0.1gand oven to maintain 105°C-110°C

Table 7.11

Size of aggregate	Sieve size used to determine loss	Weight, g
63 to 40 mm	31.5 mm	3000
40 to 20 mm	16.0 mm	1500
20 to 10 mm	8.0 mm	1000
10 to 4.75 mm	4.0 mm	300

Limits:
Soundness of aggregates: Loss with Sodium Sulphate – 5 cycles Max.12%.

Loss with Magnesium Sulphate – 5 cycles Max.18%

Table 7.12: Results

Sieve size, mm		Grading of original sample in %	Wt. of test fraction before test, g	% passing Specified finer sieve after test (actual % loss)	Weighted avg. (corrected % loss)
passing	retained				
1	2	3	4	5	6 = (5 x 3)/100
63	40	20	3000	4.8	.96
40	20	45	1500	8.0	3.6
20	10	23	1000	9.63	2.2
10	4.75	12	300	11.2	1.34
Total		100	5800		8.1

7.2.6. Specific gravity and water absorption test (IS: 2386 – PART – 3)

Introduction: The specific gravity of an aggregate is considered to be a measure of strength or qualityof the material. The specific gravity test helps in the identification of stone.

Water absorption gives an idea of strength of aggregate. Aggregates having more waterabsorption are more porous in nature and are generally considered unsuitable unless theyare found to be acceptable based on strength, impact and hardness tests.

Object: To determine the specific gravity and water absorption of aggregates by perforatedBasket.

Apparatus:

A. A wire basket of not more than 6.3mm mesh or a perforated container of convenientsize with thin wire hangers for suspending it from the balance.
B. A thermostatically controlled oven to maintain temperature of 1000 to 1100°C
C. A container for filling water and suspending the basket.
D. An airtight container of capacity similar to that of the basket.
E. A balance of capacity about 5 kg, to weigh accurate to 0.5 g, and of such a type andshape as to permit weighing of the sample container when suspended in water.
F. A shallow tray and two dry absorbent clothes, each not less than 750 X 450 mm.

Calculations:
Weight of saturated aggregate suspended in water with the basket = W_1 g
Weight of basket suspended in water = W_2 g
Weight of saturated aggregate in water = $(W_1\text{-}W_2)$ = Ws g.
Weight of saturated surface dry aggregate in air = W_4 g
Weight of water equal to the volume of the aggregate = $(W_3\text{-}W_s)$ g

Dry weight of aggregate

1. Specific gravity $=\frac{w4}{w4-(w1)}$

Weight of equal volume of water,

Dry weight of aggregate

2. Apparent Sp.gr. $=\frac{w4}{w3-(w1)}$

(Weight of equal volume of water excluding air voids in aggregates)

3. Water absorption = percent by weight of water absorbed in terms oven dried weightof aggregates.$=\frac{(w3-w4)100}{w4}\%$

Limits: The specific gravity of aggregates ranges from 2.5 to 3.0

Table 7.13: Results

S. No.	Details	Test No.		
		1.	2	Average
1	Wt. of saturated agg. and basket in water = w_1 g	2293	2285	2289
2	Wt of basket in water = w_2 g	1357.5	1357.5	1357.5
3	Wt of saturated surface dry agg. In air = w_3 g	3650.3	3642.5	3646.4
4	Wt of oven dried agg. In air = w_4 g	3625.5	3621.5	3623.5
5	Specific gravity = $\frac{w4}{w4-(w1)}$	2.671	2.709	2.69
6	Apparent S.G. = $\frac{w4}{w3-(w1)}$	2.721	2.676	2.698
7	Water Absorption = $\frac{(w3-w4)100}{w4}\%$	0.68	0.58	0.63

9. REFRENCES

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