ACTERISTICS OF FIBRE REINFORCED SAND AS PAVEMENT SUBGRADE

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
CIVIL ENGINEERING
(With Specialization in Transportation Engineering)

By

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SYNOPSIS

The conventional soil improvement techniques are generally expensive, involving large quantity of costly materials and construction operations, so there is a need to explore the possibility of using low cost material which can improve the properties of the soil in a better way. This is the main reason that the fibre reinforced earth is gaining popularity these days. In case of fibre reinforced soil the main advantage is the ability to maintain the strength isotropy and the absence of potential plane of weakness that can develop parallel to the oriented reinforcement.

This dissertation report presents the effects of inclusion of polypropylene fibres with local Roorkee sand. Treating the composite soil as homogeneous and isotropic material , C.B.R. tests, triaxial tests and plate load tests are selected as the basic engineering tests to investigate the effects of fibre inclusion on the strength and behaviour (California bearing ratio, cohesion, angle of internal friction, shear strength, bearing strength and modulus of subgrade reaction, of the soil. An attempt has also been made to recommend a suitable fibre-sand combination for practical applications, which would create a confidence amongst the construction agencies to adopt the new technique.

CANDIDATE'S DECLARATION

I herby certify that the work which is being presented in this dissertation entitled " **CHARACTERISTICS OF FIBRE REINFORCED SAND AS PAVEMENT SUBGRADE**" in partial fulfillment of the requirements for the award of the degree of **MASTER OF ENGINEERING IN CIVIL ENGINEERING** with specialization in **TRANSPORTATION ENGINEERING** submitted in the department of Civil Engineering, University of Roorkee, Roorkee is an authentic record of my own work carried out for a period of six months, from August 1994 to January 1995 under the supervision of Dr. R.M. Vasan, Reader in Civil Engineering, Transportation Engineering Section, Civil Engineering department, University of Roorkee, Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma.

Rakesh

Dated : January, 1995 **(RAKESH)**

CERTIFICATE

This is to certify that the above statement made by the candidate is true to the best of my knowledge and belief.

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CHAPTER - 1

INTRODUCTION

1.1 GENERAL

The transportation system in the developing country like India is of prime importance.The development of the country depends upon the efficiency of its transportation network system.India is a large country with varying terrain,weather and environment conditions.behaviour of certain soils is structurally excellent to bear the traffic load without disturbing the embankments and road crust.However,a vast area in India is covered by weak soils like black cotton soils,peats,clays etc.and at few places there are marshy lands and water logged areas.Because of this diversity in nature of sub grade it is often required to stabilize the subgrade soil by a suitable method.Engineers have always been with open mind to adopt any material available to them for its use for the construction purposes.Research facilities help them to judge the suitability of the materials.

Numerous examples exist where in-situ soils at shallow depths have inadequate strength for supporting the proposed structures.The concept of reinforcing poor soils has continued.Different types of materials are being increasingly employed in various civil engineering activities and especially in the field of highway engineering to facilitate construction,ensure better performance and reduce maintenance.Over the last decade the use of geosynthetics has recorded a tremendous increase.

Reinforced earth construction is an effective and reliable technique for improving the strength and stability of soil. This technique is used in veriety of applications ranging from retaining structures and embankments to sub grade improvement beneath pavements and footings.

Soil reinforcement may be aligned or randomly distributed. In the traditional method of aligned reinforced earth construction such as geotextiles,geogrids,geomembranes,geocomposits and metallic strip reinforcements,the inclusions are oriented in preferred direction and are introduced sequentially in alternate layers.The properties of reinforced earth in this case depends upon the weight fraction of reinforcement, number of layers of reinforcement and spacing between two layers of reinforcement.

Randomly distributed fibre-reinforced soil called `Poly Soil' (Mc. Gown, 1978) is similiar to stabilization by admixtures, in its preparation. The discrete fibres are simply added and mixed with much the same way as cement, lime or other additives. One of the main advantages of randomly distributed fibre-reinforced soil is the maintenance of strength isotropy and the absence of potential plane of weakness that can develop parallel to the oriented reinforcement.Further the fibre-reinforcement causes significant mprovement in tensile strength, shear strength, anisotropic material properties, increased effectiveness and bearing capacity as well as economy

(Bushching et.al, 1969). The main advantage of this method of construction is low cost, which can be used for good quality low cost highway and housing projects.

The conventional techniques of subgrade soil improvement are generally expansive and involve large quantity of reinforcing materials.The improvement of soil properties for both static and dynamic loading can also be easily carried out by fibre reinforcement. Under the traffic loads, the pavement layers are subjected to compression in vertical direction and tension in lateral direction. Also during dry weather condition, cracks develop at the top of the surface (village road) due to shrinkage. Use of fibre-reinforced earth improves both the compressive and tensile strength of soil for better performance of the soil. Further, the flexible nature of fibre-reinforced earth enables it to withstand large differential settlements without distress. Thus reinforced earth permits the construction of pavements over difficult subgrade soil conditions. Also, the saving in cost is of the order of 20 to 25 percent (VIDAL, 1969).[21]

Reinforced-earth is a composite construction material in which tension reinforcement members such as steel, aluminum, glass, asbestos, coir, alloys, synthetic fibres etc. are incorporated into soil mass as reinforcement in the form of disc, strips, grids, mats and rods or as randomly distributed fibres.

1.2 Advantages of Reinforcement

The existing new concept of reinforced earth construction material has emerged for the civil engineering community-and the rapidity at which the related products are being developed and used is nothing short of amazing. Some of the advantages of reinforced earth constructions are:

1. *Cost Saving* - Reinforcement helps in construction of steep slope which reduces the quantity of fill material thus reduces the cost.
2. *Increased Stability* - Reinforcement increases the strength charateristics of soils thus increases the factor of safety.
3. Reinforced soil possesses many noble characteristics that render it eminently suitable for construction of engineering structures.
4. The reinforced soil structure is flexible in nature which permits large differential settlements than conventional rigid structures. Hence the construction is possible over poor soil subgrade.
5. It avoids the need of scarce raw materials like cement.
6. They can be rapidly installed.
7. They generally replace difficult designs using conventional materials.
8. They are being aggressively marketed.
9. The soils which are not suitable as subgrade or subbase material in highway pavements may be reinforced to the desired level of CBR or K-values as specified by IRC to enable their use as pavement courses with confidence.

1.3 Applications of Fibre-Reinforced Soil

Since the first commercial use of reinforced soil, many structures have been completed in all parts of the world in variety of environmental conditions and subjected to various loading conditions including static and dynamic loads.

Some of the important structures constructed making use of fibre-reinforced earth are :

1. *Roads and Expressways* –
   - (a) Mountain roads and platforms on slopes of debris.
   - (b) Retaining walls (in embankment section or cut section).
   - (c) Road embankments in rural areas.
   - (d) Walls of highways with pavements at two different levels.
   - (e) Wing walls or bridge abutments.
   - (f) Control platform of expressways.
   - (g) Tunnel vaulting in embankments.
2. *Miscellaneous* – This includes –
   - (a) Thick protection wall with vertical facing.
   - (b) Swimming pools.
   - (c) Stepped rows of seats in stadium.

1.4 NEED FOR THE STUDY:

Traffic on Indian roads is increasing day by day not only in volume but also in terms of vehicle axle load .This requires better quality of roads.Further,for over all economic development of the country it requires a good and economical road network through out the country and specially in rural areas so that a large number of rural population should be connected to the market.The quality and performance of the roads depends upon the properties of subgrade soils.The conventional techniques of sub grade soil improvement are very expansive and require large amount of expansive and scarce materials. The improvement of subgrade soil properties for both static and dynamic loading can be carried out by *fibre reinforcement*.

Strength characteristics of subgrade may be improved by the inclusion of fibres in the subgrade soil.Thus,it is required to evaluate the effects of types of fibre,quantity of fibre and aspect ratio of the fibres on the properties and strength of the subgrade soil.

Several fibres are available for the modification of strength characteristics of soils. Therefore,the effect of different synthetic and locally available natural fibres on the strength characteristics of soils is needed,as dealt in the study.It is also needed to find out the optimum quantity of fibres so that it can be easily used in the actual field work with maximum gain in strength.

1.5 OBJECTIVE OF THE STUDY

Till recently, a very few studies have been reported on the behaviour of fibre reinforced earth with respect to either geotechnical applications or improving the strength characteristics of sub grade soils in highway pavements.The present study shall include the compilation of information on various types of fibres and their applications in different types of soils.An attempt shall be made to study the behaviour of fibre reinforced earth under CBR test ,as reported by various investigators.A very scanty information is available on fibre reinforcement in lateritic soil,black cotton soil,sandy soil and particularly no information is available on fibre reinforced sand. Under the present investigation it is there for planned to evaluate the performance of fibre reinforced sand by carrying out laboratory studies such as CBR tests,triaxial tests and plate load tests on the fibre reinforced subgrade soil for various percentage of fibres 1%,2% and 3% by weight.A max^{m} percentage of 3% has been considered in the present investigation in view of the mixing problems encountered beyond this fibre loading, the gain in strength beyond 3% fibre content by weight is not appreciable.

From the above mentioned study, it would be possible to recommend the suitable fibre sand combinations for practical applications,which would create a confidence among the construction agencies to adopt the technique.

The main objective of the present study is to evaluate the changes in the strength characteristics of subgrade soil by addition of randomly distributed discrete polypropylene fibres.It is therefore planned to study the effect of inclusion of randomly distributed discrete fibres on shear strength,bearing strength,CBR value and modulus of subgrade reaction.

CHAPTER-2

REVIEW OF LITERATURE

2.1 HISTORICAL BACKGROUND

The theoretical concept of reinforced earth was first given by Henary Vidal[21] (1966). He used the term 'Reinforced Earth' for the first time. In 1978, H.Y. Fang used bamboo mats as reinforcing material for new embankment safe against seismic loading. B.P. Verma et.al (1978) studied the strength and deformation characteristics of reinforced earth mass. S. Saran et.al (1978) studied the effect of amount of reinforcement on modulus and peak deviator stress.

Randomly distributed fibre reinforced soil also called 'Poly Soil' (Mc. Gown,[11] (1978) can also be advantageously used in improving soil properties. Vidal did a lot of work on reinforced earth. B. Satyanarayana[15] studied the effect of inclusion of glass fibres and asbestos fibres on cement stabilized soil. P.G. Bhattacharya and B.B. Pandey (1984) studied the effect of inclusion of coir fibres in lime stabilized lateritic soil. Mc. Gown (1978) studied the effect of inclusion properties on behavior of sand. Gray and Ohashi[7] (1983) studied the mechanism of fibre reinforcement in soil.

Hoare[9] (1979) studied the laboratory performance of granular soil reinforced with randomly distributed discrete fibres. Setty[17,18] (1987, 1990) did some work to determine the effects of inclusion of fibres in Black Cotton soil as well as lateritic soil.

The earliest example of soil reinforcement is found in Agar Quf Ziggarrat in Iraq is thought to be 3000 years old. The great wall of China has examples of reinforced soil construction using tamo risk trenches. Vidal was responsible for the construction of first major retaining wall using modern concept of soil reinforcement in southern France. The first reinforced soil structure was made in U.S.A. in 1972 and in U.K. in 1973.

2.2 REINFORCING MATERIALS:

Reinforcing materials used in the construction of reinforced earth may be classified into following families:geotextiles,geogrids, geomembranes,geocomposits and discrete fibres.

2.2.1 GEOTEXTILES:

Geotextiles are indeed textiles in traditional sense,but consist of synthetic fibres rather than natural once like cotton,wool and silk.The fibres are made into flexible,porous fabric by slandered weaving machinery or are matted together in a random or non woaven manner.The major point is that they are porous to water flow across their manufactured plane and also within their plane.Some typical section of geotextiles are shown in Fig.1(a).

2.2.2 GEOGRIDS:

Geogrids represent a small but rapidly growing segment in geosynthetic area.Rather than being a woven,non-woven or knit textile fabric, geogrids are plastics formed into a very open net like configuration.Some typical sections of geogrids are shown in Fig.1(b).

2.2.3 GEOMEMBRANES:

The geomembranes are impervious thin sheets of rubber or plastic materials,used primarily for lining and covers of liquid or solids storage impoundments.Some typical sections have been shown in Fig.1(c).

2.2.4 GEOCOMPOSITS:

A geocomposit consists of a combination of geotextie and geogrid,or geogrid and geomembrane,or geotextile,geogrid and geomembrane, or any one of these three materials.Some typical sections of geocomposits are shown in Fig.1(d).

2.2.5 DISCRETE FIBRES:

We may use fibres for reinforcement of soil as elements characterized by:

* their flexibility
* their tenacity
* their large length compared to their diameter
* their diameter which is sufficiently large as compared to finer particles and sufficiently small to be compatible with the

TABLE:1 TYPES OF FIBRES

NATURAL FIBRES		
VEGETABLE FIBRES	ANIMAL FIBRES	MINERAL FIBRE
1.Fibres from hairs of * seeds * cotton * kopak 2.Liber fibres * flax * hemp * jute 3.Fibres from leaves * manila * sisal 4.Fibres from fruits * coconut	1.Silk 2.Wool * marino * lamb's wool 3.hair * alpaca * vicuna	1.Asbestos

CHEMICAL FIBRES		
SYNTHETIC FIBRES	OF NATURAL POLYMERS	INORGANIC
1.Polyurethanes * spandex * lycra * rhodastic 2.Polyesters * tergal * dacron * trevira * terylene 3.Polyamids * 6-6 nylons * 6 nylons * nilson 4.Polytetra fluroethelene * teflon 5.Polyvinyle derevatives * acrylics * polyclorids * poly alcohols 6.Synthetic rubber 7.Poly olefines * polyethelene * polypropylene	1.Regenereted cellulose * viscous rayon * cypro rayon * polynosics 2.Regenerated proteins * caseins 3.Other regenerated fibres * alginate * rubber fibre * cellulose ester * acetate * triacetate	1.Metallics 2.Laminates 3.Glass

2.3 DURABILITY AND OTHER PROPERTIES OF FIBRES:

In order to minimize the cost,design of reinforced earth structures should take into account the use of locally available materials.At the same time durability of structures must be given proper importance as the collapse of reinforced earth structures can cause serious loss of life and property.

Among different natural fibres available,coir fibres have the maximum durability characteristics.It's resistance,to alkali is excellent,to the atmospheric agents is very good and to microbiological agents is also very good.It has a very good resistance to insects and termites.The table below shows the breaking stress and percentage elongation at break for both fresh coir fibres and after 15 years of storage in a hanger in Lyons.

COIR	BREAKING STRESS (MPa)	% ELONGATION AT BREAK(%)
FRESH	176	29
AFTER STORAGE	160	21

It is also noticed that the values are very close and the elongation at break for stored fibre is slightly less.That is,the fibre becomes slightly brittle and fragile.So,in absence of particular moisture and biochemical actions,mechanical properties of coir fibres can be said quasi perennial.Durability and some other properties of some of the natural fibres are given in Table-2.

TABLE:2 PROPERTIES OF NATURAL FIBRES
cont.

TYPE OF FIBRES	PROPERTIES OF FIBRES				
	MORPHOLOGICAL	CHEMICAL	PHYSICAL	MECHANICAL	
	LENGTH(mm) DIAMETER(μm) ASPECT RATIO	COMPOSITION AND DURABILITY	RIGIDITY FINENESS REAL DENSITY APPARENT DENS. ROUGHNESS	BREAKING LENGTH (km) BREAKING STRESS (MPa) ELONGATION AT BREAK (%)	
				DRY	WET
JUTE	0.8 to 4.0 15 to 25 110	cellulose:64.78% lignin:11 to 14% pentosans:10-14% waxes and fats: 0.2-0.4% to alkali leach: poor to atmospheric agents:v.good dry heat:v.good wet heat:poor putrificability: high	1.55 to 1.7 200 to 300 Nm 1.45 0.8 to 0.9 high	30-40 300-400 1	27-36 270-360 -
RAMIE	50-500 20-60 3700	cellulose:96% lignin:<1% pantic matters: <0.5% to solvents:good to dilute acids and alklis:medium to atmospheric agents:excellent resistance to insacts:poor	1.33 200-300 Nm 1.5 1.12 -	55-60 195 - -	60-65 215 - -
COTTON	15-50 15-25 700-2700	cellulose:80% textile waste:6% to steam:good to solvent:good to alkli:medium to dilute acid: medium to insects:poor	low 3000-8000 Nm 1.5 1-1.3 low	18-45 70 -	20-50 75 -

TABLE:2 PROPERTIES OF NATURAL FIBRES
cont.

SISAL	1.5-4 20-30 50-200	cellulose:62% pentosan:16% lignin:8% carbohydrates:10% —— -	2.15 350Nm 1.45 1.27 high	34-56 449 3-7
COIR	0.7 20 35	cellulose:34% lignin:44% pentosan:18% tannin,silica:3% —— to alklis:excellent to atmospheric agents:v.good to microbiological agents:v.good putrification: quasi zero to insacts:good	very high 55-110 Nm 1.15 1.08 high	- 131-175 15-40

Recent practice (Paris Conf.,1977)has shown that synthetic plastic fibres are compatible with soil for their level of deformity,size of the fibre sand for proving continuity in deformation.Further,plastic fibres are non corrosive and resistant to rotting and attack of bacteria and acids.Ionescu et.al.tested a number of plastic materials in eight different media (distilled water,iron bacteria culture,desulfovirous,levansynthesizing bacteria,liquid mineral,sea water,compost and soil)for up to 17 months and found no degradation to occur.Furthermore,the materials do not appear to be toxic to populations of aquatic life and soil microorganism.Inescu et.al.also evaluated six fibres (four polypropylene,one polyester and one composite) in eight media for a period of 5 to 17 months. The media were distilled water,sea water,compost,soil,iron bacteria,lavensynthesizing bacteria,desulfo- virous bacteria and a liquid mineral.The results showed no variation in tensile strength and no structural changes visible on the infra red spectroscopy.Also, there is a progressive loss in strength of plastic fibres with increasing temperature.Among the plastic fibres, nylon's strength,chemical inertness,durability and elongated temperature resistance are no less than polypropylene.The environmental durability of steel fibres are variable.It will rust in presence of air and water.It has a good resistance to alkalis and performs poor in presence of some acids.Stainless steel fibres have generally good environmental durability.In general,glass fibres containing ZnO_2 are alkali resistant.Glass fibres tolerate temperature up to $1500^{\circ}F$ with little harmful effect.Table-3 shows some of the important properties of some of the fibres.

The soil straw mix has a very good durability and is known to all. In fact,after erosion of surface soil, the straw is exposed and forms a protective network of un-eroded substrate.This protective network is due to two reasons:

(a) sufficient density of straw.

(b) sufficient length of straw to permit an anchorage and satisfactory cover

This shows that the necessary and sufficient condition for good durability is that the length of the fibre be rather large.This length being possible to be reduced if the fibre content (f) is increased.In other words for attaining a good durability,it is essential and sufficient that certain function g(f,l) which is remained to be determined,exceeds a certain threshold,the preponderant parameter being the length (l).Thus,contrary to the case of mechanical behaviour,where the main parameter is the proportion of fibres in the mixture, for durability is length (l).

2.4 DURABILITY OF A SOIL PRODUCT:

Analysis of the main attacks liable to be suffered by soil product or civil engineering structure made from soil leads too commend five tests;a synthesis of their results help a fair precise appreciation of the durability of a product or a structure made from soil.The tests are:

(1) Absorption test

(2) Water drop test

(3) Shower test

(4) Flow test

(4) Resilience test

The experimental study on durability of soil products and structures is not very easy.The methodological obstacles are many: in fact besides the quantification of the results refereed as earlier,it is necessary to standarise the shape and dimensions of the objects to be tested,the experimental conditions and

TABLE 3. CHARACTERISTICS OF COMM NLY USED FIBRES.

Fibre type	Diameter micro meter	Length mm	Specific gravity	Young's modulus GN/m2	Poisson's ratio	Tensile strength MN/m2	* Elongation at break %	Typical volume in composites
Asbestos	0.02-20	-	1.9 - 3.37	380 - 196	-	1800-3500	2 - 3	-
Glass	9 -15	10 - 50	2.7	70 - 80	.22	1250-2500	2 - 3.5	2 - 8
Carbon	8 - 9	10-Continuous	1.90	230	.35	2600	0.5- 1	2 - 12
Steel	5 - 500	10 - 60	7.86	160	.28	2100	0.5- 3.5	0.5- 2
Polypropylene	20 - 200	20 - 75	.91	5 - 77	0.29 -0.46	500-750	20	0.2 -1.2
Kevlar	10	6 - 65	1.45	65 - 133	-	2900	2.1- 4.0	< 2
Sisal	10 - 50	10 - 330	1.50	-	-	800	3.0	-
Nylon	100 - 200	5 - 50	1.14	upto 4	0.40	-	13.50	0.1 - 6

* One percent elongation = 10.00×10^{-6} strain

precisely lay down the methods of the tests.In this way,one may hope for results that are little scattered as far as possible and hence a good reproducibility.

2.5 REVIEW OF EXPERIMENTAL INVESTIGATIONS:

A lot of work has been done till now on the characteristic evaluation of reinforced earth.But,out of all this work a very small work has yet been done on the evaluation of characteristics of randomly distributed discrete fibre reinforced earth.Most of the work that has been done on the randomly distributed discrete fibre reinforced earth are mainly on either lateritic soil or black cotton soils. Only a few work have been done on sand and the worksthat have been done on fibre reinforced sand are with respect to triaxial test.Lee et.al.(1973)in his work on sand reinforced with firewood savings,reported a significant increase in strength and rigidity under triaxial static load test.Andersland khattak (1979) reported the results of triaxial tests on kaolinite clay reinforced with paper pulp fibres and reported that addition of fibres increased both the stiffness and undrained strength of kaolinite.Horer[9] (1977) presented a series of laboratory compression and CBR tests on sandy gravel reinforced with small amount (2%by weight) of random fibres.The results show that the presence of fibres increased the soil resistance to densification.Gray and Al-refeai[5] (1986) carried out a number of triaxial tests on dry sand reinforced with randomly discrete fibres and concluded that presence of fibre increases both ultimate strength and stiffness of reinforced sand

and for same weight fraction and aspect ratio rougher fibres tend to be more effective in increasing strength at low confining pressure.The effect of type of fibres,weight fraction,aspect ratio,type of soil and soil properties like gradation,shape and size of particles,that has been studied by other investigators till now,has been described in brief in the following paragraph.

2.5.1 CHARACTERISTICS OF FIBRE REINFORCED LATERITIC SOIL USING POLYPROPYLENE

Setty and Rao(18) (1987) used polypropylene fibres to study the effect of weight fraction of the fibres on the lateritic soil.He carried out proctor's compaction test, triaxial tests,CBR tests and tensile strength tests. The soil was tested in compaction testing machine with varying amount of reinforcement.

The results show that as the percentage of reinforcement increases the dry density decreases and the optimum moisture content increases. This is due to the fact that the density of fibre is less than that of the soil.

Triaxial tests were conducted at three different lateral pressure of 100, 200 and 300 kN/sq.m. The results show that with increase in fibre content cohesion increases significantly whereas angle of internal friction decreases marginally (i.e. net effect is gain in shear strength).

The reinforced soil was tested under CBR test for both soaked and optimum moisture content conditions. The results show that the CBR value increases with the increase in percentage reinforcement. In the unsoaked test, the slope of the curve between CBR value and fibre content above 2% fibre is flat indicating that inclusion of fibre content beyond 2% is non-significant in improving CBR value. It is also observed that CBR value corresponding to 5 mm penetration is always greater than those at 2.5 mm penetration.

The soil was tested under tensile strength test for determination of tensile strength of soil corresponding to different amount of reinforcement. For sample tested at O.M.C. the value of tensile strength increases by 20%, 96.6% and 125% of that of the unreinforced soil with the variation of fibre content from 0%,1%,2% and 3%. But in case of oven dry sample the tensile strength increases up to 2% of the fibre only and then it starts decreasing.

2.5.2 BEHAVIOUR OF FIBRE-REINFORCED BLACK COTTON SOIL USING POLYPROPYLENE AS REINFORCING FIBRE

Setty and Murthy[17] (1990) used polypropylene fibres to study the effect of weight fraction on black cotton soil.He carried out proctor's compaction test,triaxial test,tensile strength test and flexural strength test to study the characteristics of black cotton soil.

The compaction test was done on fibre reinforced soil and the results show that the maximum dry density and O.M.C.decreases with increase in fibre content. The decrease in the value of O.M.C. is mainly due to non absorbing quality of the fibre used. The triaxial test was conducted as recommended by Bishop and Henkel (1978). The test was conducted at cell pressure of 50, 100, 150, 200 and 250 kPa. As the amount of reinforcement increases the cohesion increases significantly whereas angle of internal friction decreases marginally due to smooth surface of fibre but ultimately the shear strength of soil is increased.

The briquette mould of the reinforced soil was tested for tensile strength at O.M.C. for different percentages of reinforcement. The result shows that tensile strength increases with fibre content.

The flexural strength of reinforced black cotton soil beam specimen (75x75x300 mm) moulded at O.M.C. is tested under two point loadings. The result shows that with increase in reinforcement the flexural strength decreases. This is due to reduction in density and angle of internal friction. Also, the fibres are randomly distributed so they are not able to take the bending stress.

2.5.3 BEHAVIOUR OF FIBRE-REINFORCED LATERITIC SOIL USING COIR AS REINFORCING FIBRE

Coir from the coconut is the fibrous portion extracted from coconut. It has good strength, reasonable bond strength and stability. Coir fibres possess a remarkable resistance to both fungal and bacterial decomposition.

To investigate the suitability of coir reinforced soil, lateritic soil, brown coloured matured coconut fibres were used and tested for CBR value and tensile strength.

The test result shows that up to 10% of the coir content CBR value increases and further increase in coir content results in decrease in CBR value. The tensile strength increases with the increase in coir content.

2.5.4 STRENGTH AND CHARACTERISTICS OF FIBRE-REINFORCED SAND

Maher and Gray[10] in 1989 took different types of sands and different types of fibres and tested them in triaxial test to determine the effect of granulometry and fibre properties on the strength of soil.

The results of the experiment shows that principal stress envelop for uniform, rounded sand is curvilinear whereas well graded granular sand shows bilinear behaviour . The break in bilinear curve or transition from curve to straight occurs at confining stress. This depends upon aspect ratio, grain, shape and gradation.

The amount of increase in strength due to reinforcement depends upon fibre aspect ratio, grain size, gradation and shape.As the aspect ratio increases the critical confining pressure increases.As the effective grain size increases the major principal stress at failure increases at constant confining pressure.

2.5.4.0 Strength and Characteristics of Fibre-Reinforced Sand Using Plastic Fibre

Locally available sand classified as poorly graded fine sand as per unified soil classification system was used by H.D.Charan[13] (1994) to study the characteristics of reinforced sand. Plastic fibre was used for reinforcement.

Consolidated undrained triaxial test was done on partially saturated reinforced samples at axial strain rate of 1.25 mm/min. and the results are analysed to understand different properties of soil.

2.5.4.D.1 Stress-Strain behaviour

Stress-strain curve for the soil for different fibre contents indicates that for unreinforced sand peak stress is reached at 10% strain which remains constant up to 20% strain, whereas reinforced sand indicate an increasing trend even at 20% strain level. Also, as the fibre content increases, the increase in stress for same magnitude of increase in strain is much higher.

2.5.4.D.2 Strength of Fibre-Reinforced sand

It is affected by the amount of fibre, aspect ratio and confining pressure. The strength of fibre-reinforced sand increased with the increase in fibre content. The rate of increase is appreciable up to fibre content of 2%.The strength of fibre-reinforced sand increases with increase in aspect ratio.

2.5.4.D.3 Stiffness

A plot between axial strain and ratio of secant modulas of reinforced sand to unreinforced sand indicates that discrete fibre reinforced sand exhibits an increase in stiffness at all level of strains unlike traditional layered reinforced earth which shows a decrease in stiffness at small strain.

2.5.5 STRENGTH AND CHARACTERISTICS OF PLAIN AND FIBRE-REINFORCED LIME TREATED EXPANSIVE SOIL

Ramashashtry and Satyakumary investigated the effect of inclusion of coconut fibres as reinforcing material in lime stabilized expansive soil.

I.S. light compaction test was conducted on the soil, soil-lime and soil-lime-fibre mixes to determine the O.M.C. and max^m dry density of various dry mixes. Test results show that the max^m dry density decreases and the O.M.C. increases as the lime content increases. Further at constant value of lime content as the fibre content increases the max^m dry density decreases and O.M.C. increases. Also, for any fibre content, soils with 5% lime have lower dry density and higher O.M.C. then the corresponding soil with 3% lime.

The unconfined compression test was carried to evaluate the unconfined compressive strength of various stabilized mixes. The unconfined compressive strength of any soil-lime-fibre mix increases with increase in curing time almost linearly. For any curing period and fibre content, mixes with 5% lime content have higher strength than with 3% lime content. Further, for same curing period and lime content, with the increase in fibre content, increase in strength is in the range of 5 to 20 percent.

The tensile strength test was carried out on the soil-lime-fibre mix using cement mortar briquette testing machine. The result show that curing period has considerable effect on the tensile strength of the mix. Also, the tensile strength corresponding to 5% lime content for constant curing period and fibre content is much higher than 3% lime content. Further, the tensile strength of compacted soil-lime-fibre mix increases with increase in fibre percentage.

2.6 MECHANISM OF FIBRE-REINFORCED SOIL:

The deformation under load and the consequent failure mechanism of fibre reinforced soil is different from that of,soil reinforced with traditional inclusions such as sheets,bars,grits etc .Mc Gown[11](1978)classified soil reinforcement into two major categories: namely ideally extensible inclusions and ideally in extensible inclusions.Fibre-reinforcement falls under the category of ideally extensible inclusions.

Several models have been developed to study the mechanism of reinforced soils.Some of them are:

* force-equilibrium model
* rigid-plastic soil model
* force-equilibrium cum statistical approach model

2.6.1 FORCE-EQUILIBRIUM MODEL:

The force equilibrium model was initially proposed by Waldron (1977)to describe the load-deformation behavior of soil reinforced with plant roots.This concept was utilized by Gray and Ohashi[7] (1983), Gray and Al-Refeai(1986)and Fatani et al[3] (1991)to describe the deformation and failure mechanism of fibre-reinforced soil and estimated the contribution of fibre-reinforcement in increasing the shear strength of soil.Among the various other methods this method with proper estimation of shear zone is recommended for the analysis of oriented fibre-reinforced soil.In this method it was found that the tensile stress developed in the fibre at the shear plane is a function of fibre properties(i.e.skin friction,length,diameter,modulus etc.)and the test variables (i.e.confining pressure).The increase in shear strength and factors affecting it,as predicted by force-equilibrium model have been found to be similiar to the experimental results obtained from direct shear test.

The following are the assumptions made in this method:

(1)fibres are long elastic and extend to an equal length on either side of shear plane.

(2)fibres are very thin so that no bending resistance is developed.

(3)the tensile stress distribution is linear and is maximum at the shear failure plane.

2.6.2 *RIGID-PLASTIC SOIL MODEL:*

The model was proposed by Shewbridge and Sitar(1989,1990)taking into account the development of both tension and bending stresses in the reinforcement during deformation.He used large size direct shear device to quantify the width of shear zone.

2.6.3 FORCE-EQUILIBRIUM CUM STATISTICAL APPROACH MODEL:

This model was proposed by Maher and Gray[10] (1990)based on the results of triaxial compression tests for randomly distributed discrete fibre-reinforced sand.The model predicts the orientation and the quantity of fibres at any chosen plane,by statistical theory of composite materials(Naaman et al,1974)and the increase in strength of the fibre-reinforced earth is estimated by force-equilibrium method(Gray and Ohashi,1983). The distribution of fibres in unit volume was assumed to follow a poisson's distribution.Thus the probability,P(N) of occurrence of N fibres in unit volume is given by:

$$P(N)=\frac{\lambda^{n}\ e^{\lambda}}{\underline{|n}}$$

where,

λ=average fibers per unit volume.

Average number of fibres (N_f)crossing a unit area is given

$$N_f = \frac{2V_f}{\pi\ D^2}$$

where,

V_f=volume of fibres per unit volume of soil mass.

The failure plane was assumed the same as given by Mohr-Coulomb failure criteria and the fibres were assumed to be oriented perpendicular to the plane of shear failure.

Maher and Gray(1990)studied the effect of confining stress and soil granulometry on the strength of fibre-reinforced soil.The failure envelop was curvilinear or bilinear with break occurring at critical confining pressure.Based on this, Maher and Gray(1990)suggested following equations for strength of fibre-reinforced soils:

$$\Delta S_R = \frac{N_f \ \pi \ D^2}{4} \left[2 \ \sigma_{conf} \ \tan \delta \right] \left[\sin \theta + \cos \theta \tan \phi \right] \xi$$

For $0 < \sigma_{conf} < \sigma_{crit}$ and

$$\Delta S_R = \frac{N_f \Pi \ D^2}{4} \left[2 \ \sigma_{crit} \ \tan \delta \right] \left[\sin \theta + \cos \theta \tan \phi \right] \xi$$

For $\sigma_{conf} > \sigma_{crit}$

where,

ΔS_R=shear strength increase due to reinforcement.

N_f=average number.of fibres crossing unit area

D=diameter of fibres.

σ_{conf}=confining stress

σ_{crit}=critical confining stress

δ=angle of skin friction of reinforcement

θ=angle of distortion of vertical reinforcement due to shear

ϕ=angle of internal friction of unreinforced soil

ξ=an emperical co-efficient depending upon sand granulometry (i.e. average grain size,D_{50},particle sphericity,coefficient of uniformity) and fibre parameters(i.e. aspect ratio and skin friction)

CHAPTER-3

EXPERIMENTAL PROGRAMME

3.1 MATERIALS:

The different materials utilised in the present investigation are described in the following paragraphs:

3.1.1 SOIL :

Locally available Roorkee soil is used in the present investigation. The physical and engineering properties of the same are given in Table-4. The soil used can be classified as poorly graded fine sand (SP-SM) as per unified soil classification system. The grain size distribution curve is shown in Fig.-2. The results of proctor's compaction test are shown in Fig.-3. The results show that optimum moisture content is 10.9% ,maximum dry density is 1.836 KN/m3 and maximum bulk density is 2.036 KN/m3.

3.1.2 REINFORCEMENT:

Synthetic plastic fibres used in the present investigation were cut from locally available continuous fibres. The physical and engineering properties of the fibres are shown in Table-5. Plate-1 shows continuous fibres and discrete fibres with aspect ratio 100.

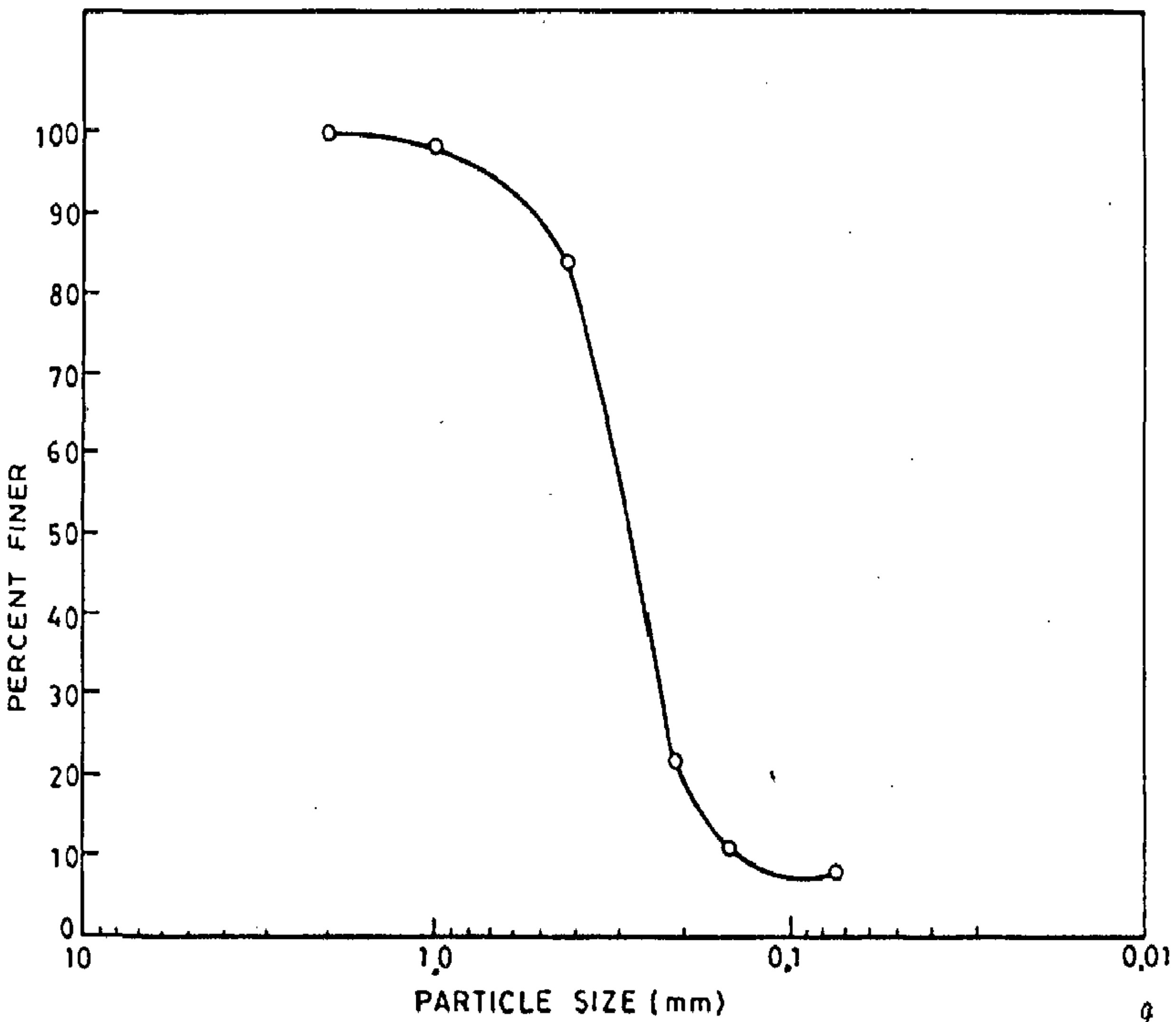
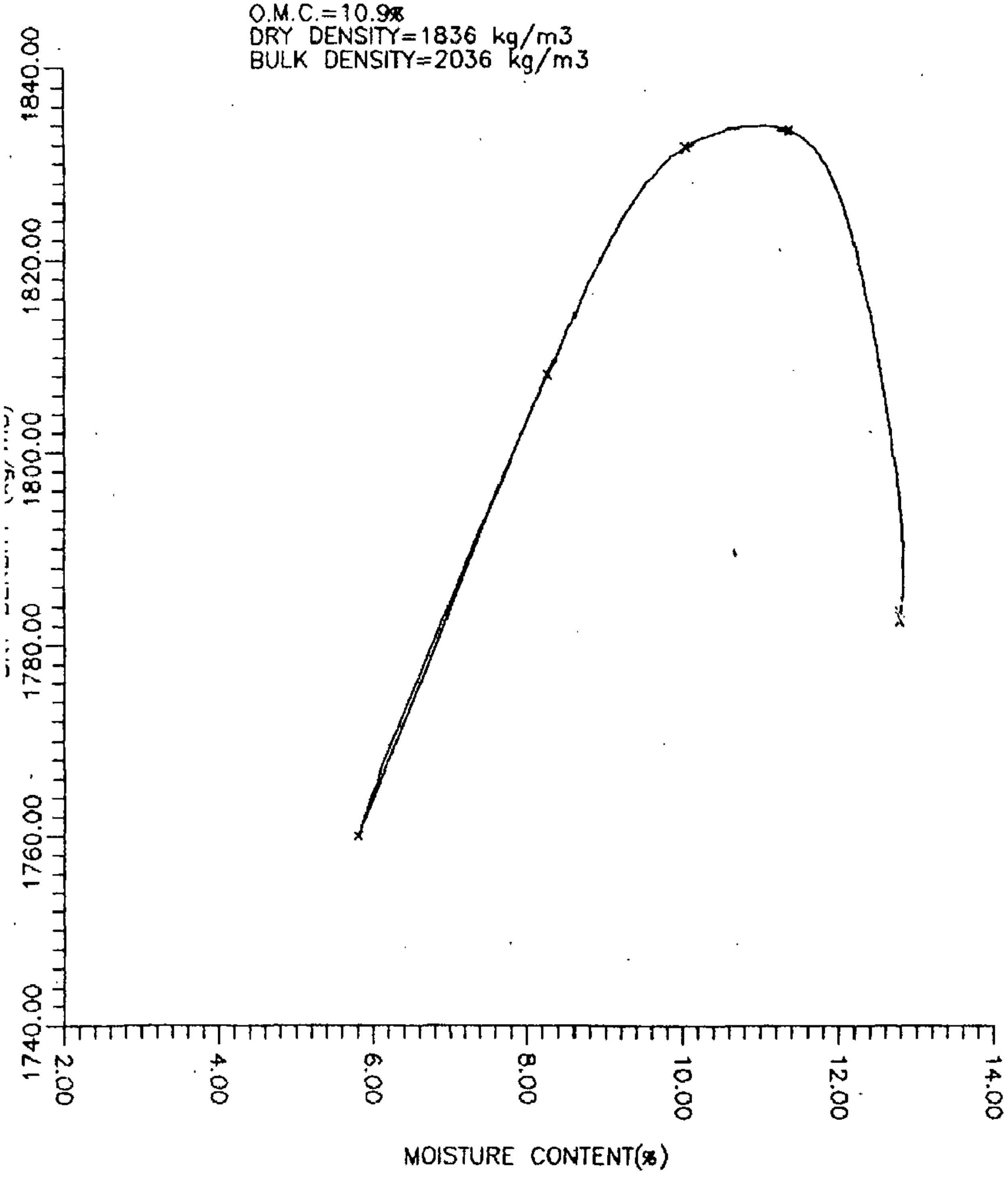


FIG. 1 : PARTICLE SIZE DISTRIBUTION CURVE OF FINE SAND



IOISTURE CONTENT Vs DRY DENSITY CURVE

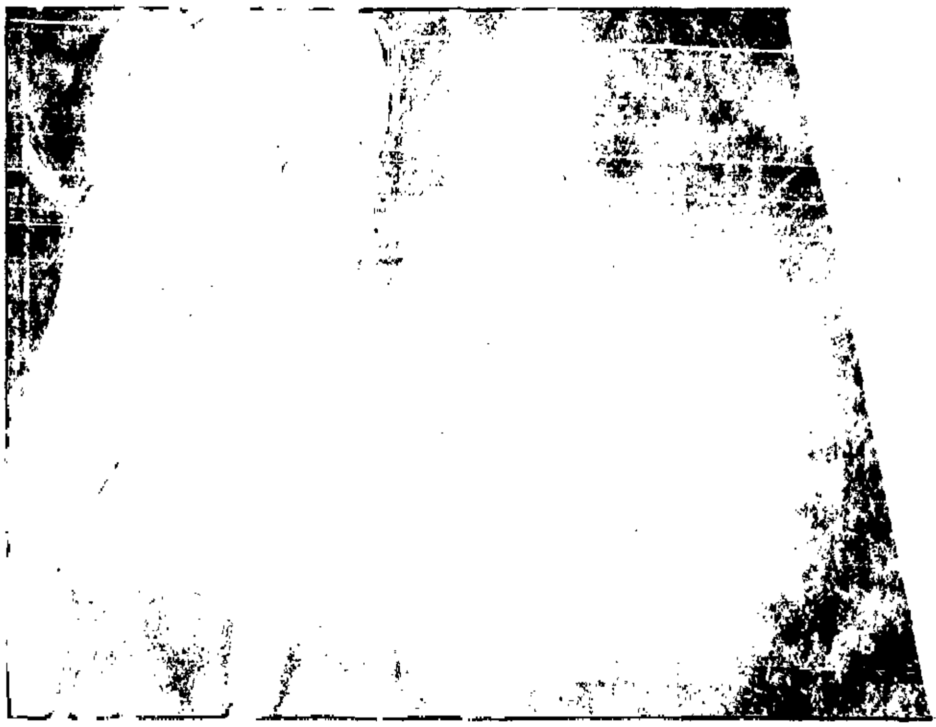


PLATE 1 : CONTINUOUS AND DESCRETE POLYPROPYLENE FIBRES

Table - 4

Properties of Roorkee Sand

Effective grain size, D_{10}	0.14 mm
Median grain size, D_{50}	0.29 mm
Coefficient of uniformity, C_u	2.28
Specific gravity of solids, G_s	2.60
Maximum void ratio, e_{max}	1.08
Minimum void ratio, e_{min}	0.495
c-ϕ parameters	
- c (kPa)	9.0
- ϕ (degree)	36.05°

Table - 5

Physical and Engineering Properties of Synthetic Fibre

Sl.No.	Particulars	Value
1.	Molecular formula (Hannant, 1978)	$(CH_2-CH_2)_n$
2.	Young's Modulus (Hannant, 1978), GN/m^2	7.00
3.	Melting Point, $^{\circ}C$	85.00
4.	Unit Weight, kN/m^3	9.20
5.	Tensile Strength, N/mm^2 (0.5 mm Garware Twine)	127.40
6.	Special Qualities : 'Garware Twine' is manufactured from high density polythene and polypropylene. It is totally reistant to sea water, acids, alkalies and chemicals. It has high breaking strength and high abrasion resistance and is less prone to wear and tear.	

3.2 SELECTION OF THE TESTS:

The main objective of the present study is to determine the change in the strength and structural properties of poorly graded fine sand due to addition of fibres,so that it can be effectively used as pavement subgrade or base.

Shear strength is the major structural property of soil.To predict the shear strength,triaxial test was conducted.Further,design of flexible pavement mainly depends upon the CBR value of the sub grade,for this reason which CBR test was conducted for both soaked and unsoaked conditions.Design of rigid pavement mainly depends upon the k-value of the soil sub grade.So for the determination of k-value, plate load test was conducted on the reinforced and unreinforced soil sub grade. To determine the performance of the pavement itself by using randomly distributed fibre reinforcement ,plate load tests were also performed on WBM over fibre reinforced soil subgrade.

3.2.1 CBR TEST:

The california bearing ratio test,usually abbreviated to CBR test,is a penetration test,developed by California State Highway Department for the evaluation of sub grade strength,in which load required to cause a plunger of standard size to penetrate a specimen of soil at a standards rate is measured either before or after the soil has been soaked for four days.However,the deformation of the soil specimen being predominantly shear deformation,CBR can be regarded as an indirect measure of shear strength.CBR test is a method of classifying and evaluating soil sub grade and sub-base course materials for design of flexible pavements.

CBR value is defined as load taken by the specimen at defined penetration level to the load taken by standards crushed aggregates for the same penetration level.The CBR value is the measure of resistance of a material to penetration under controlled density and moisture content.The test can be carried out in field or in lab,on undisturbed or disturbed samples for confined or unconfined condition for varying moisture content.

APPARATUS REQUIRED:

(1)*MOULD:*A phosphor-bronze mould of internal diameter 150mm and internal height 175mm with a detachable base which can be fitted on either side and a collar of 50mm height is used.A bronze displaser disc 148mm diameter and 47.7mm thickness is used to obtain a specimen of exactly 127.3mm height.

(2)*COMPACTING HAMMER:*The specimen is compacted by static or dynamic compaction.The details for the dynamic compaction as suggested by IRC are:

TYPE OF COMPACTION	NO. OF LAYERS	Wt. OF HAMMER (kg)	FALL (cm)	NO. OF BLOWS
LIGHT	3	2.60	31	56
HEAVY	5	4.89	45	56

(3)*LOADING EQUIPMENT:* A testing machine having a constant rate of strain of 1.25 mm/min is used.

(4)*SURCHARGE WEIGHT:* In order to simulate the effect of field conditions, like the load of pavement above the subgrade. Generally a surcharge wt. of 5kg is placed which corresponds to 13cm of compaction.

TEST PROCEDURE:

The soil to be tested is sieved through 2.4mm 20mm sieve. The soil is mixed with water at O.M.C. and compacted to the corresponding max^{m} dry density. The surcharge weight is placed at the top and a proving ring and a dial gauge is attached to it. The load is applied through the plunger and the reading of the proving ring and dial gauge is measured and plotted on the graph paper. The load corresponding to 2.5 and 5mm penetration is measured and CBR value is calculated. The higher of the two values gives the actual CBR value.

The test was performed with unreinforced sand and reinforced sand. The reinforcement was varied to 1, 2 and 3 % by wt. of the soil. The aspect ratio was kept constant at 60. The specimen was compacted to heavy compaction to achieve max^{m} dry density both for soaked and unsoaked conditions. Plate-2 shows the test set up for CBR test.

3.2.2 TRIAXIAL TEST:

In the triaxial test a specimen of soil is subjected to three compressive stresses at right angle to one another and one

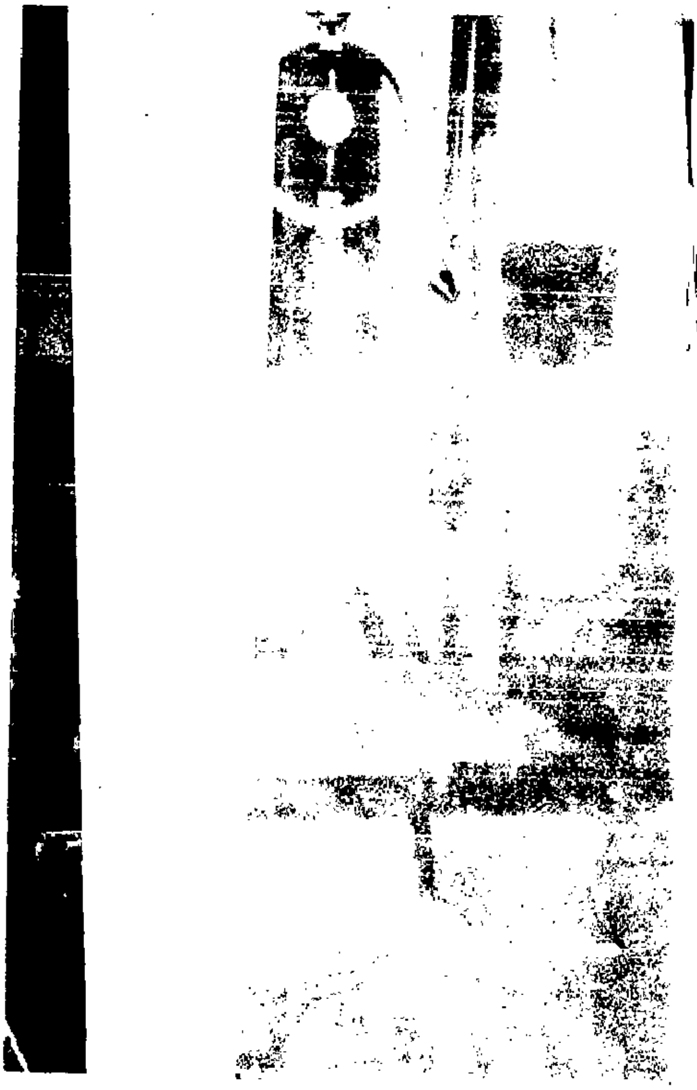


PLATE [illegible]

of these stresses is increased until the specimen fails in shear.The purpose of the triaxial test is to determine the shear strength of the soil under lateral pressure.Shear strength of the soil is the resistance to deformation by continuous shear displacement of the soil particles due to the action of a shear stress.Shear strength of a soil is calculated by Mohr-Coloumb's eqn.:

$$\tau_f = c + \sigma \tan \phi$$

where,

τ_f=shear strength

σ=principal stress

ϕ=angle of internal friction

c=cohesion

APPARATUS REQUIRED:

(1)Triaxial Pressure Cell:

(2)Loading Equipment: Testing machine having a constant strain is used.

TEST PROCEDURE:

In triaxial test cylindrical specimen of length 2 to 2.5 times the diameter are subjected to constant radial stress generated by the fluid pressure and an axial stress is generated by the loading equipment.The axial stress applied is increased until each specimen fails and the stress condition at failure are analyzed by Mohr's circle so that apparent cohesion and angle of internal friction can be calculated.The experiment can be done in three different conditions:

(1)IMMEDIATE,UNDRAINED or QUICK CONDITION:

In this type of tests the specimen sealed in rubber membrane,is capped at top and bottom with impervious plates so that no pour water can escape through out the test.

(2)CONSOLIDATED QUICK OR CONSOLIDATED UNDRAINED TEST:

In this type of test the specimen is first freed to drain out the pore water under constant lateral pressure and then the pore water outlet is kept closed through out the test.

(3)SLOW OR DRAIN TEST:

In this type of test the specimen is allowed to consolidate under constant lateral pressure.The axial load is then applied slowly for all further consolidation to take place before the specimen fails.

The present test is performed on 50mm. * 100mm. cylindrical specimen with varying amount of fibre content from 0% to 3%.The cell pressure was varied 100,200 and 300 KPa.The test was performed at O.M.C.and max^{m} dry density and the values of loads corresponding to different deflection values were plotted on the paper.Plate-3 shows the test set up for the triaxial test.

3.2.3 PLATE LOAD TEST:

Plate load test is conducted to evaluate the supporting power of sub grades,bases and in some cases complete pavements,by utilizing relatively large diameter plates.Data obtained from the tests are applicable for the design of both flexible and rigid pavements.In this test circular plates are used and to ensure an even bearing surface,bearing plates are embaded in clean mixture of sand or plaster of paris.The deflection dial gauge are placed near the outer periphery of the largest plate,preferably at one third position on the circumference of the plate.Standard 75cm plates are used for the determination of k-value for rigid pavement design.In some cases smaller plate can also be used but the result has to be modified for the plate size.In case of flexible pavement design the size of the plate is determined on the basis of design wheel load.

APPARATUS REQUIRED:

(1)hydraulic jack and proving ring assembly

(2)bearing plate

(3)a set of dial gauge and support device

(4)Troxker moisture and density gauge

TEST PROCEDURE:

Plate load test can be done either in the field or in the laboratory.In each case when a load is applied on the plate, deflection occurs.This deflection is measured by the dial gauges attached to the larger plate.To minimize the bending of the plate a series of stacked plates are used.The test can be direct or repetitive in nature.In each case first a seating load of 0.007 N/mm^2 is applied and released after a few seconds to give a deflection of 0.25mm and dial gauge is set to zero.Now the load is applied in small increments.For best result the max^m increment should not exceed 10% of the max^m wheel load.Each increment should be maintained until the rate of settlement is less than 0.025 mm/min..

In case of cyclic plate load test to measure the elastic properties of the soil and the elastic and plastic deformation,when loads of varying intensities are applied and maintained until the rate of deformation is less than 0.025mm/min..The load is then removed and higher load is applied and each time deflection in the dial gauge is noted.

CORRECTION IN K-VALUE:

(1)CORRECTION FOR SUBSEQUENT SOAKING OF SUB GRADE:

The modules of sub grade reaction for soaked condition is obtained by:

$$K_S = \frac{P_S}{P} K$$

where,

K=modules of sub grade reaction at F.M.C.

P=pressure in the plate load test corresponding to 1.25mm deflection for unsoaked specimen.

P_S=pressure of soaked specimen to cause 1.25mm deflection.

(2)CORRECTION FOR PLATE SIZE:

If dia of the plate is less than 75cm,the k-value corresponding to 75cm plate is calculated by:

$$k_1 a_1 = k_2 a_2$$

where,

k=modules of sub grade reaction

a=radius of the plate

In the present study the sub grade of 75cm * 75cm * 45cm was prepared by compacting in three layers of 15cm each.Finally the density and moisture content were measured at the four corners at

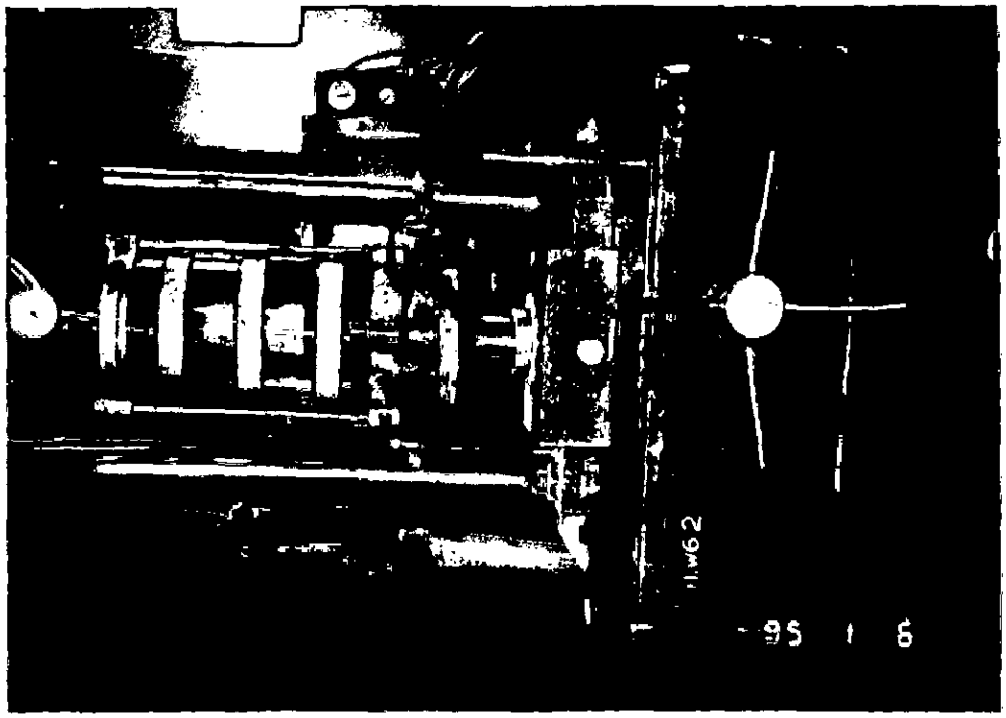


PLATE 3 : TEST SET UP FOR TRIAXIAL TEST

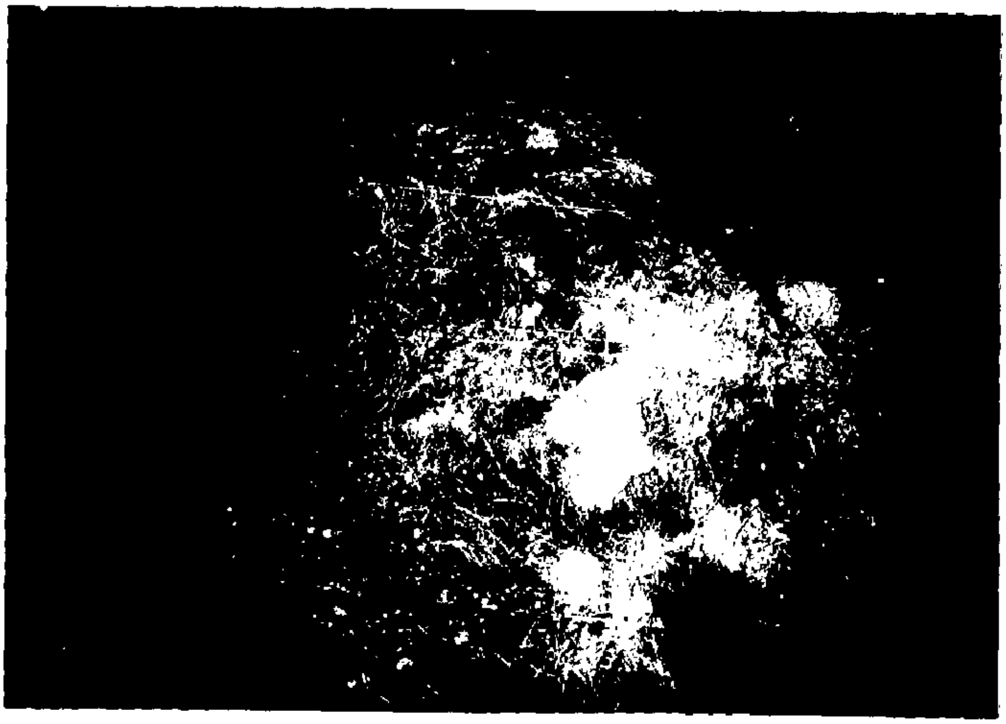


PLATE 4 : FIBRE REINFORCED SAND

different depths using Troxler Moisture and Density Gauge. The test was performed using 30cm plate and 10 tones screw jack Firstly 30 tonnes hydraulic jack was used, but it did not perform well as in case of hydraulic jack the load starts decreasing rapidely just after the application of the load. The fibres were mixed with the soil by hand mixing. Plate-4 shows the reinforced soil.

CHAPTER-4

EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 GENERAL

In the present investigation CBR tests triaxial test and plate load tests were conducted on unreinforced virgin soil as well as reinforced soil. In this chapter the results obtained from the different testa are shown and are analyzed in detail. the results obtained are also compared with the results obtained by other investigators.

4.2 CALIFORNIA BEARING RATIO TEST :

CBR tests were carried out on the unreinforced soil as well as reinforced soil. In case of reinforced soil the fibre content applied were 1%, 2% and 3% by weight of the soil and a constant aspect ratio of 100. The test were conducted for light compaction as refered by IRC and the moisture content was taken as optimum moisture content to achieve maximum dry density. The tests were done both for unsoaked as well as soaked conditions. The fibre content was varied from 0% to 3% only, the reason is that it is very difficult to mix the fibres and the prior studies done with higher fibre contents show that the increase in the strength and properties of the soil is very less and some times it decreases also. The aspect ratio (l/d) is kept constant at 100. this is because the present investigation is to determine the effect of amount of reinforcement on the strength and properties of reinforced soil. The value of the aspect ratio (100) was selected as the work published by H.D. charan (1994) shows that optimum value of the aspect ratio is in between 90 to 120 and after that, the gain in strength starts decreasing.

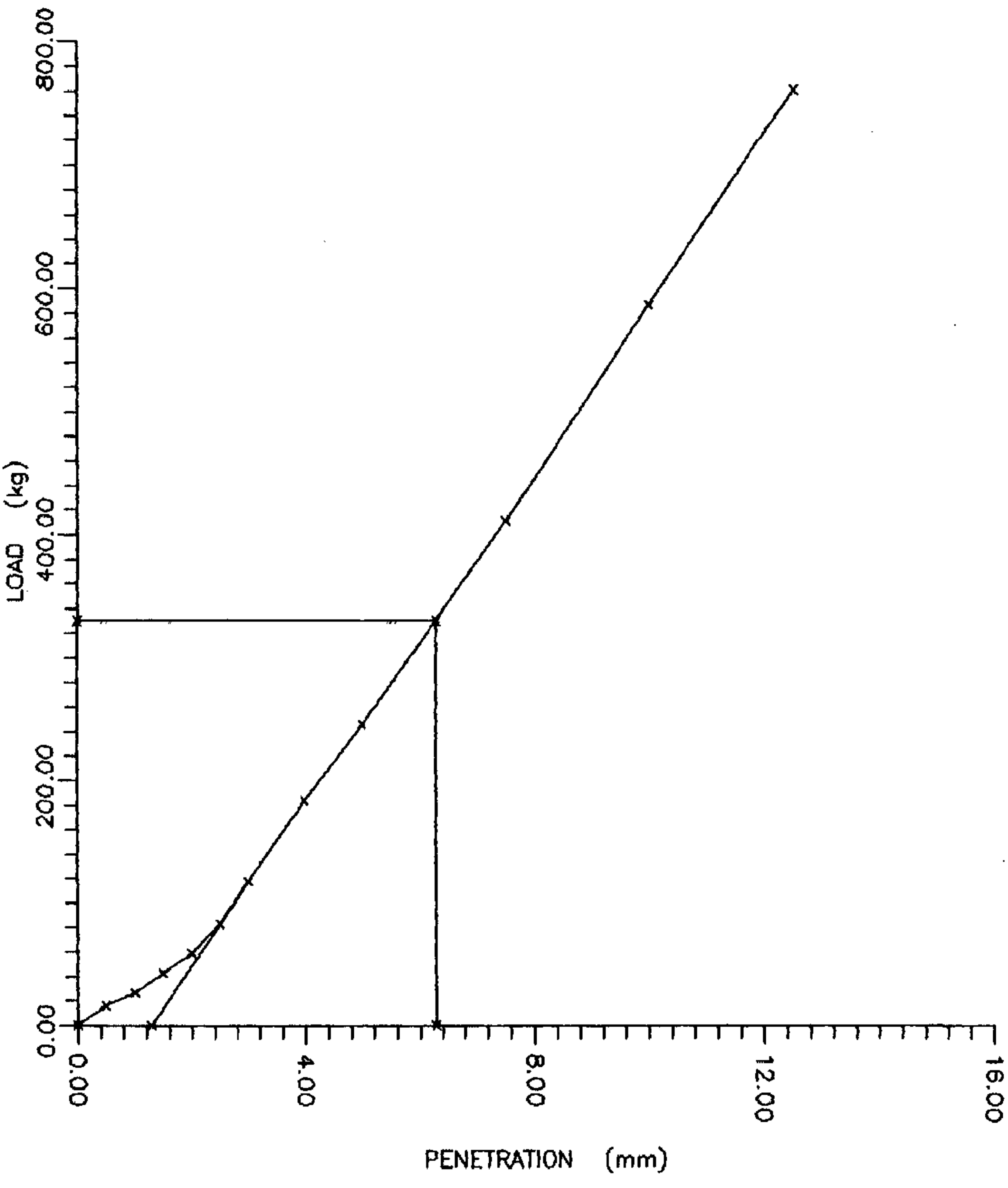
The load and corresponding penetration for each test were noted and plotted. The load penetration curves for unsoaked CBR test performed with rainforced soil having 0%, 1%, 2% and 3% fibres by weight are shown in Fig. 4, Fig. 5, Fig. 6 and Fig. 7 respectively. the load penetration curves for soaked CBR tests performed with reinforced soil having 0%,1%,2% and 3% fibres by weight are shown in Fig. 8, Fig. 9, Fig.10 and Fig.11 respectively. The curves shows an initial concavity of the load penetration curve for which correction needs to be applied. This concavity may be due to the fact that either the top of the soil is not horizontal or the bottom of the plunger is not horizontal and as a result the plunger surface does not remain fully in contact with the soil. This concavity may also be if the top layer at the specimen is too soft or irregular. The CBR values for both 2.5 mm and 5mm penetration were calculated from the curves. These CBR values for reinforced soil having varying amount of reinforcement from 0% to 3% for both soaked and unsoaked conditions are tabulated in table 6.

TABLE-6

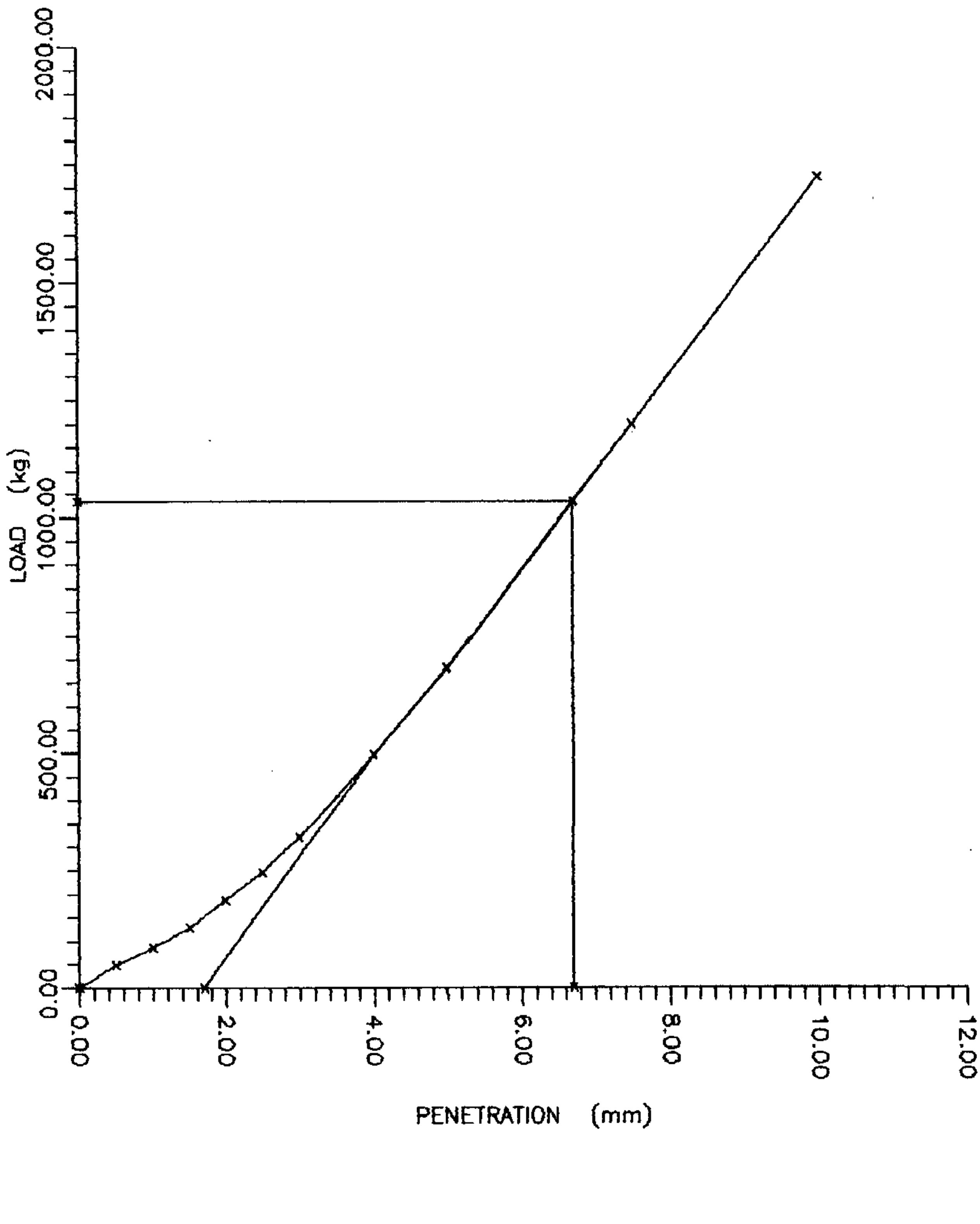
VARIATION OF CBR VALUES FOR 2.5 AND 5 mm WITH FIBRE CONTENT

FIBRE CONTENT (%)	CBR VALUE FOR SOAKED CONDITION FOR		CBR VALUE FOR UNSOAKED CONDITION FOR	
	2.5 mm PENETRATION	5 MM PENETRATION	2.5 MM PENETRATION	5 MM PENETRATION
0	9.67	12.89	12.82	17.09
1	33.47	44.62	37.71	50.35
2	36.39	48.52	43.43	57.90
3	39.71	52.43	47.50	62.82

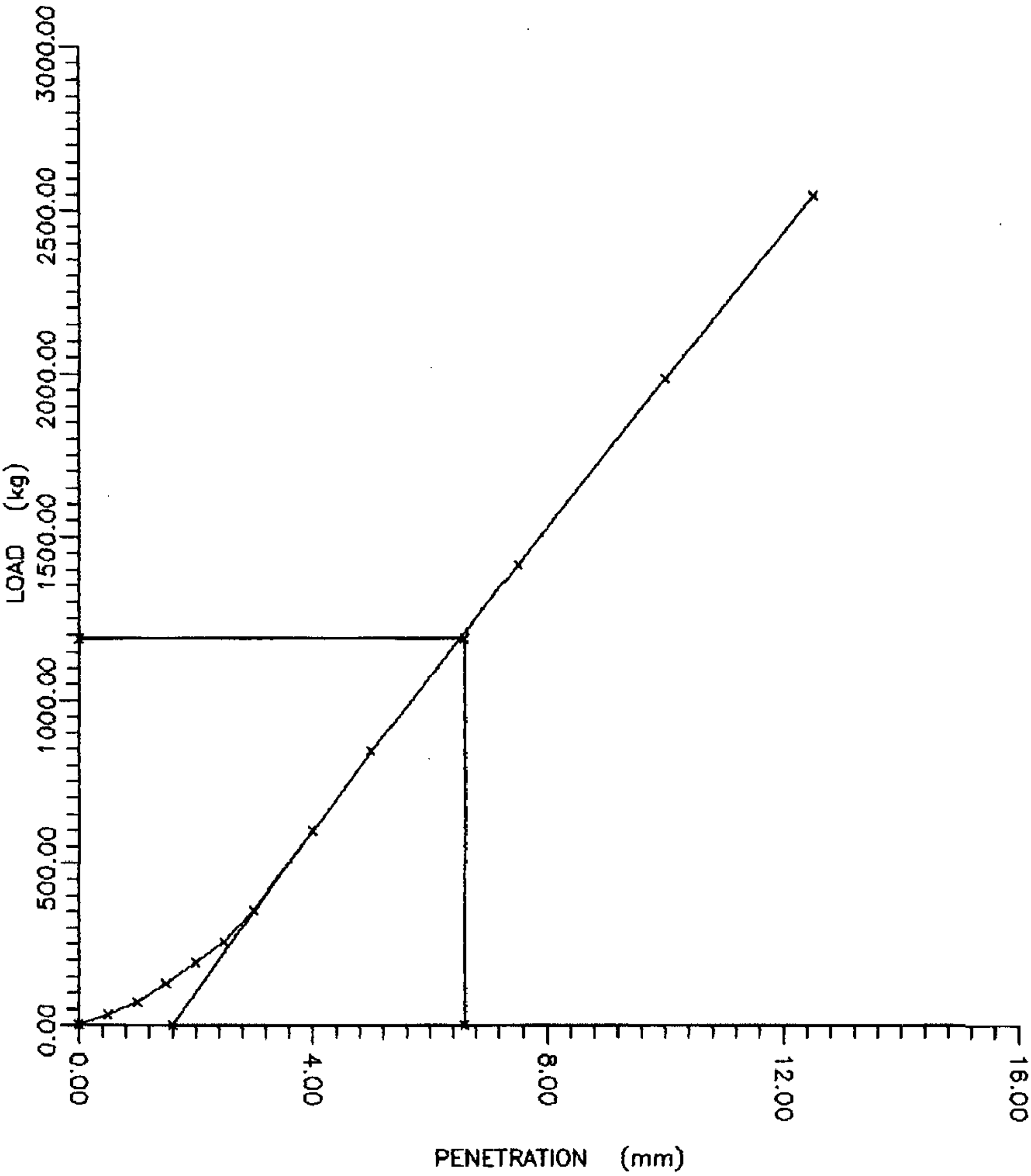
The Table-6 shows that for all values of fibre content,CBR value, corresponding to 5 mm penetration is always greater than CBR values corresponding to 2.5 mm penetration. Further the CBR value for unsoaked condition is always greater than CBR value for soaked condition for the same amount of reinforcement and one more observation is that, the CBR values for both soaked and unsoaked condition go on increasing with the increase in the fibre content in the soil. The actual CBR value taken is the higher value among CBR values corresponding to 2.5 and 5 mm penetration. Table 7 shows the actual CBR values for reinforced soil having different percentages of fibre reinforcement and the percentage increase in the CBR value with the addition of fibre reinforcement.



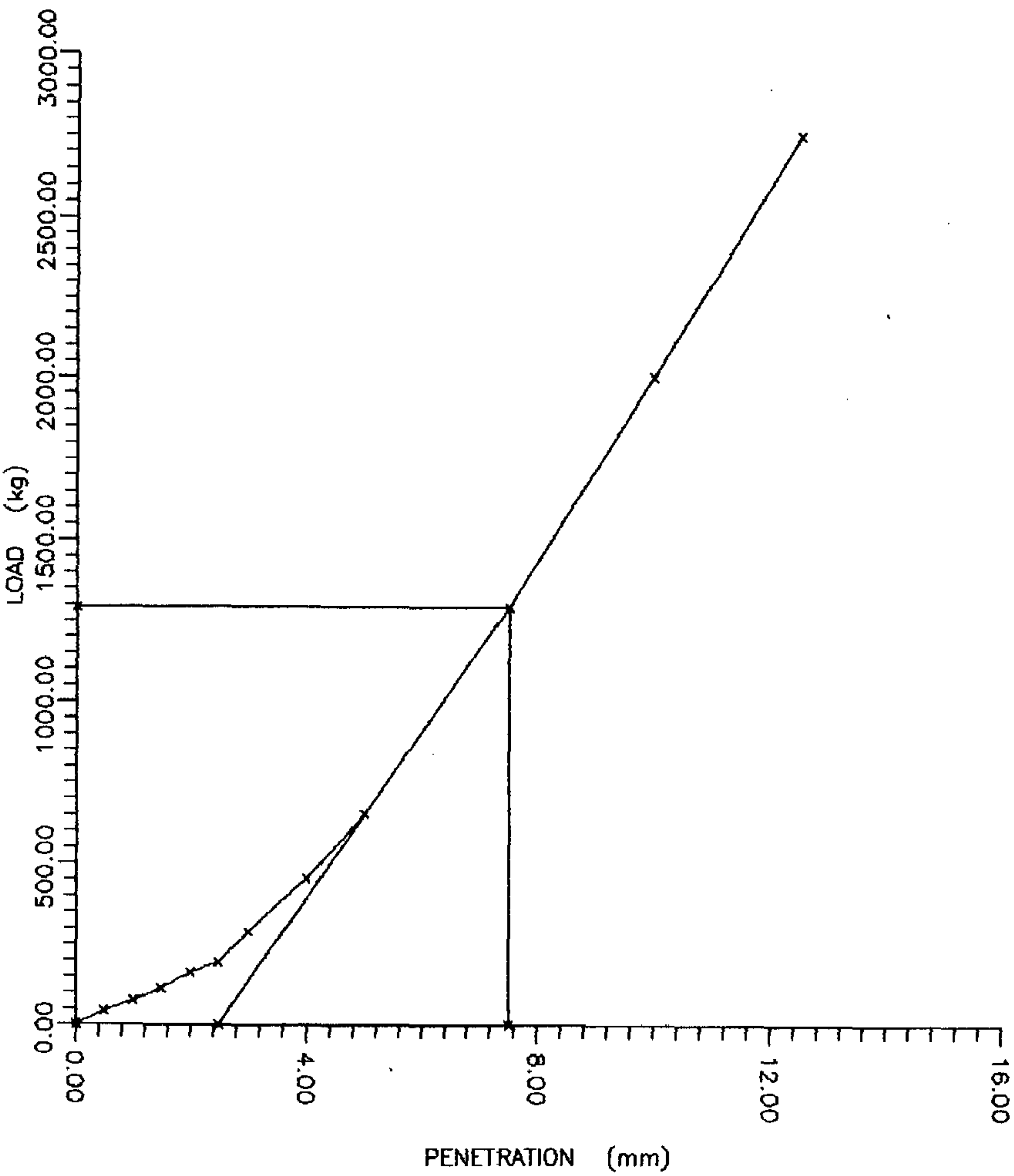
LOAD PENETRATION CURVE IN UNSOAKED CBR TEST
WITH 0% FIBRE CONTENT AND ASPECT RATIO 60
Fig.4



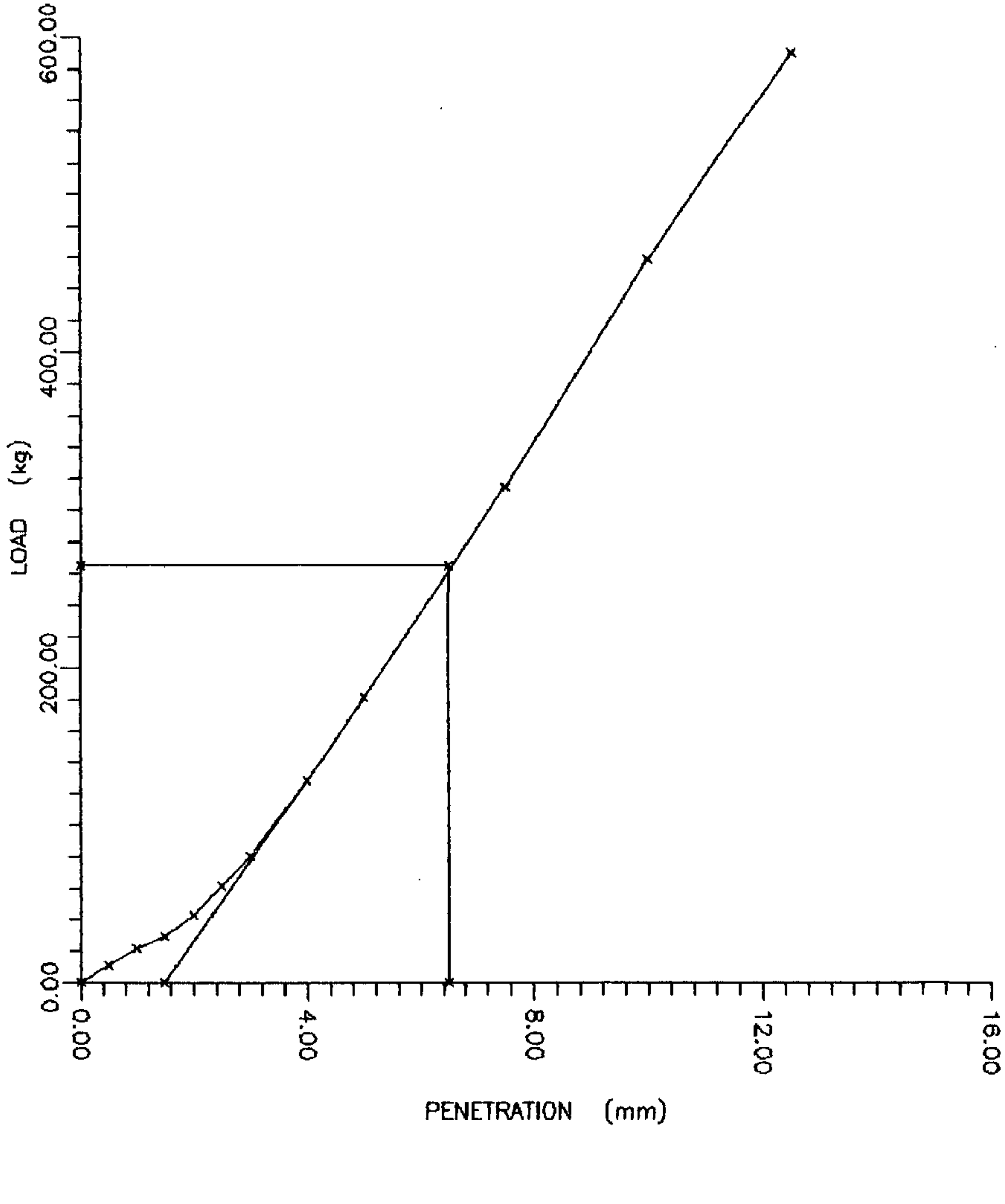
LOAD PENETRATION CURVE IN UNSOAKED CBR TEST
WITH 1% FIBRE CONTENT AND ASPECT RATIO 100
Fig.5



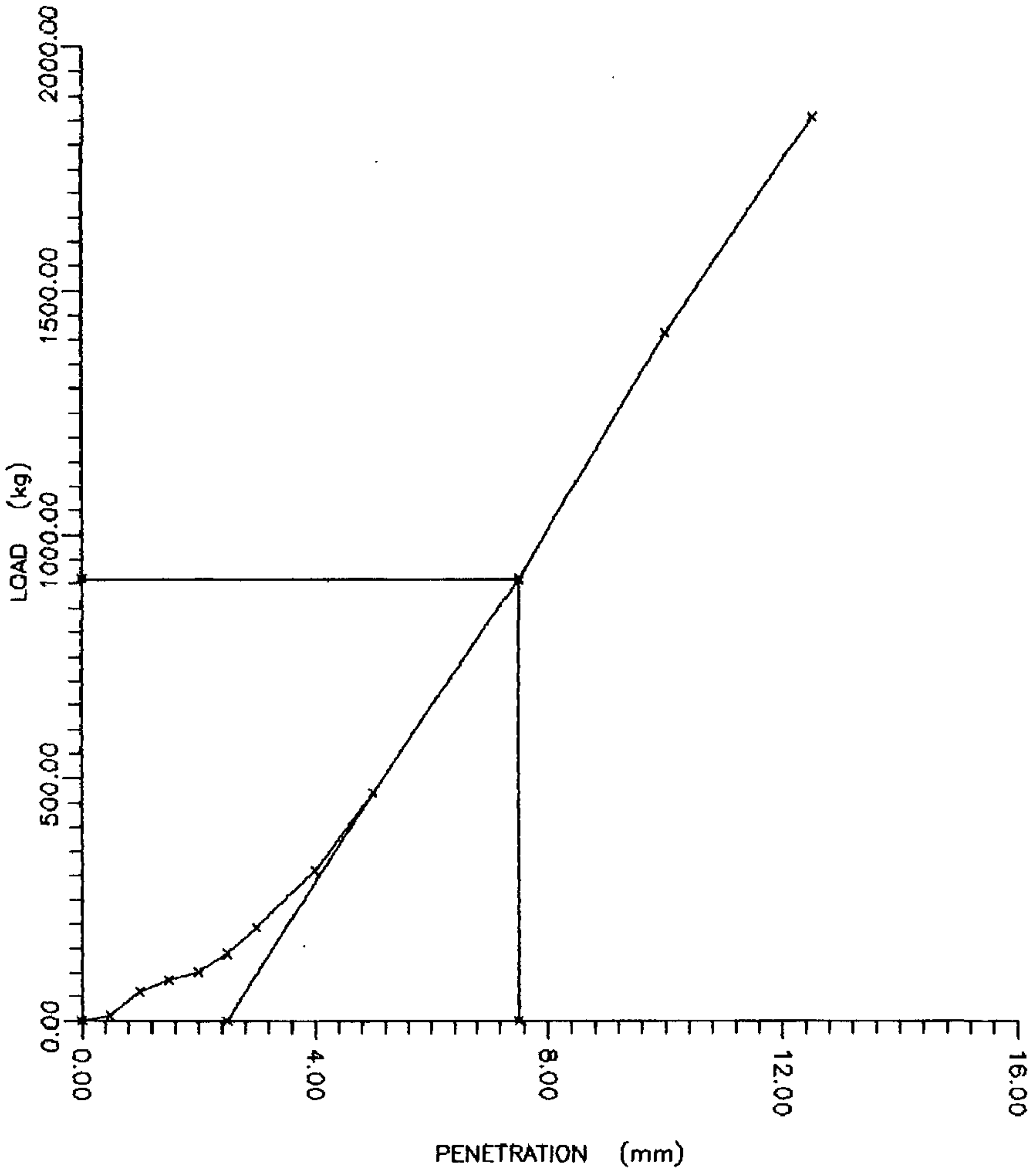
LOAD PENETRATION CURVE IN UNSOAKED CBR TEST
WITH 2% FIBRE CONTENT AND ASPECT RATIO 100
Fig.6



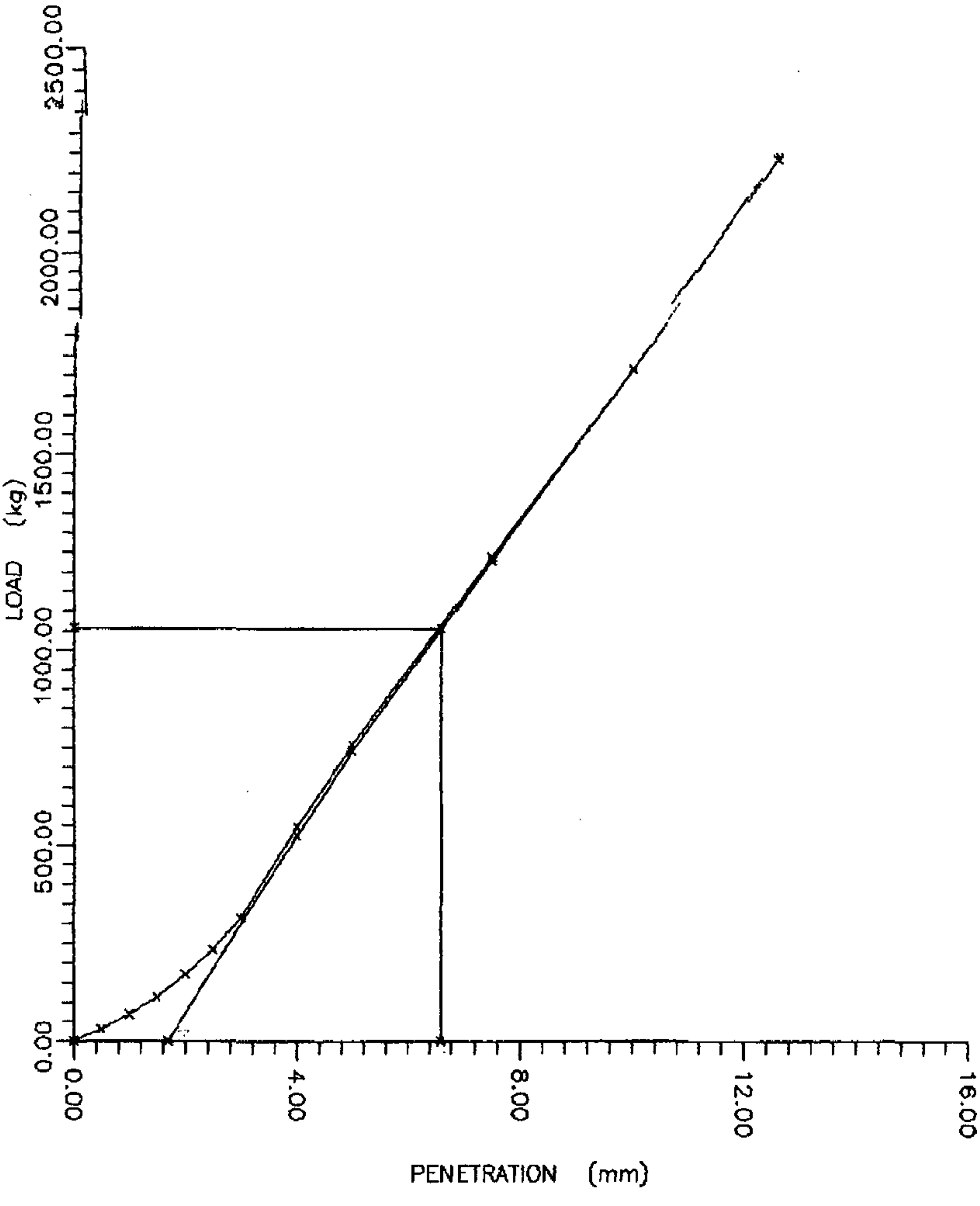
LOAD PENETRATION CURVE IN UNSOAKED CBR TEST
WITH 3% FIBRE CONTENT AND ASPECT RATIO 100
Fig.7



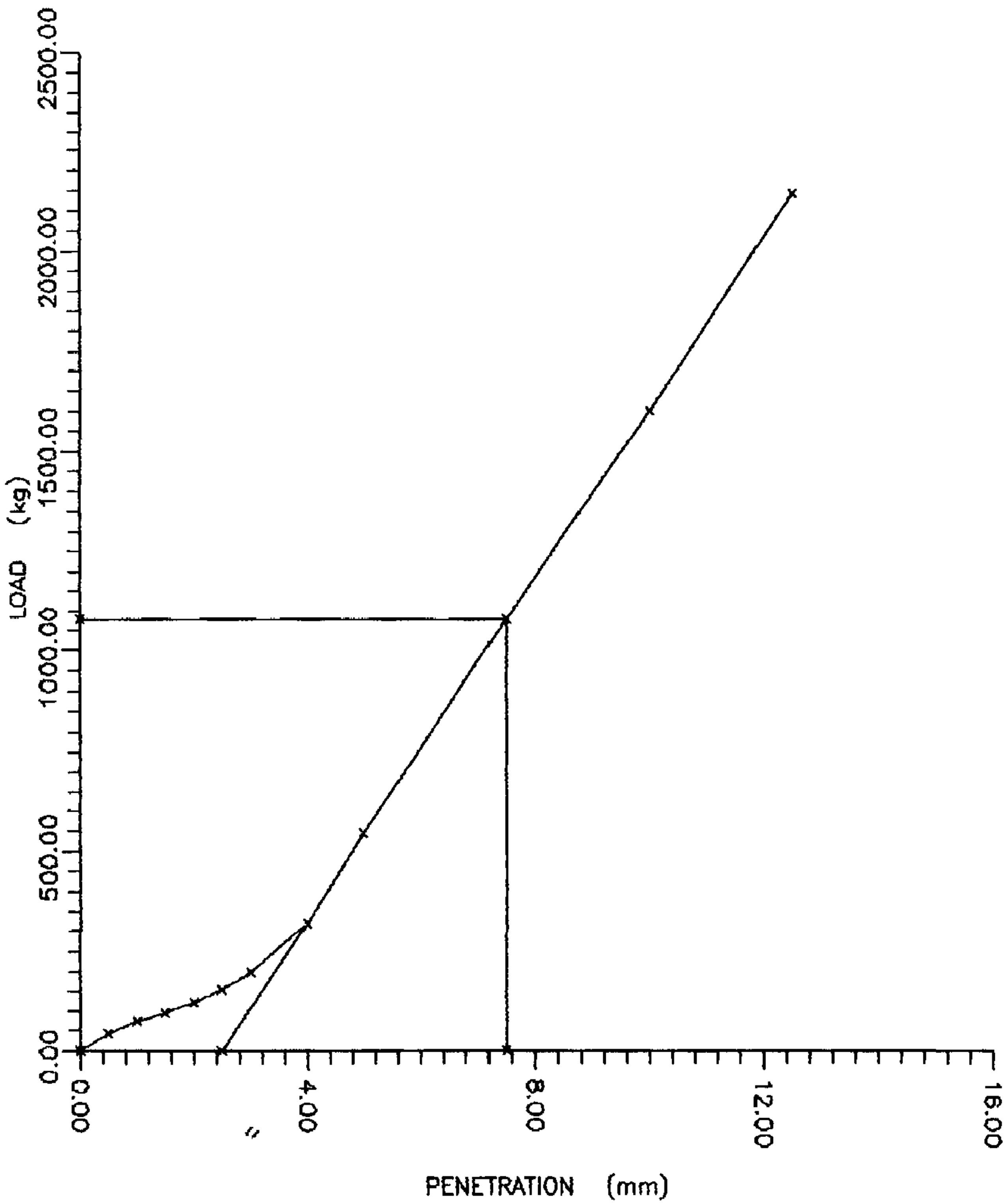
LOAD PENETRATION CURVE IN SOAKED CBR TEST
WITH 0% FIBRE CONTENT AND ASPECT RATIO 100
Fig.8



LOAD PENETRATION CURVE IN SOAKED CBR TEST
WITH 1% FIBRE CONTENT AND ASPECT RATIO 100
Fig.9



LOAD PENETRATION CURVE IN SOAKED CBR TEST
WITH 2% FIBRE CONTENT AND ASPECT RATIO 100



LOAD PENETRATION CURVE IN SOAKED CBR TEST
WITH 3% FIBRE CONTENT AND ASPECT RATIO 100
Fig.11

TABLE-7

SOAKED AND UNSOAKED CBR VALUES WITH FIBRE CONTENT

at Pen. 5mm

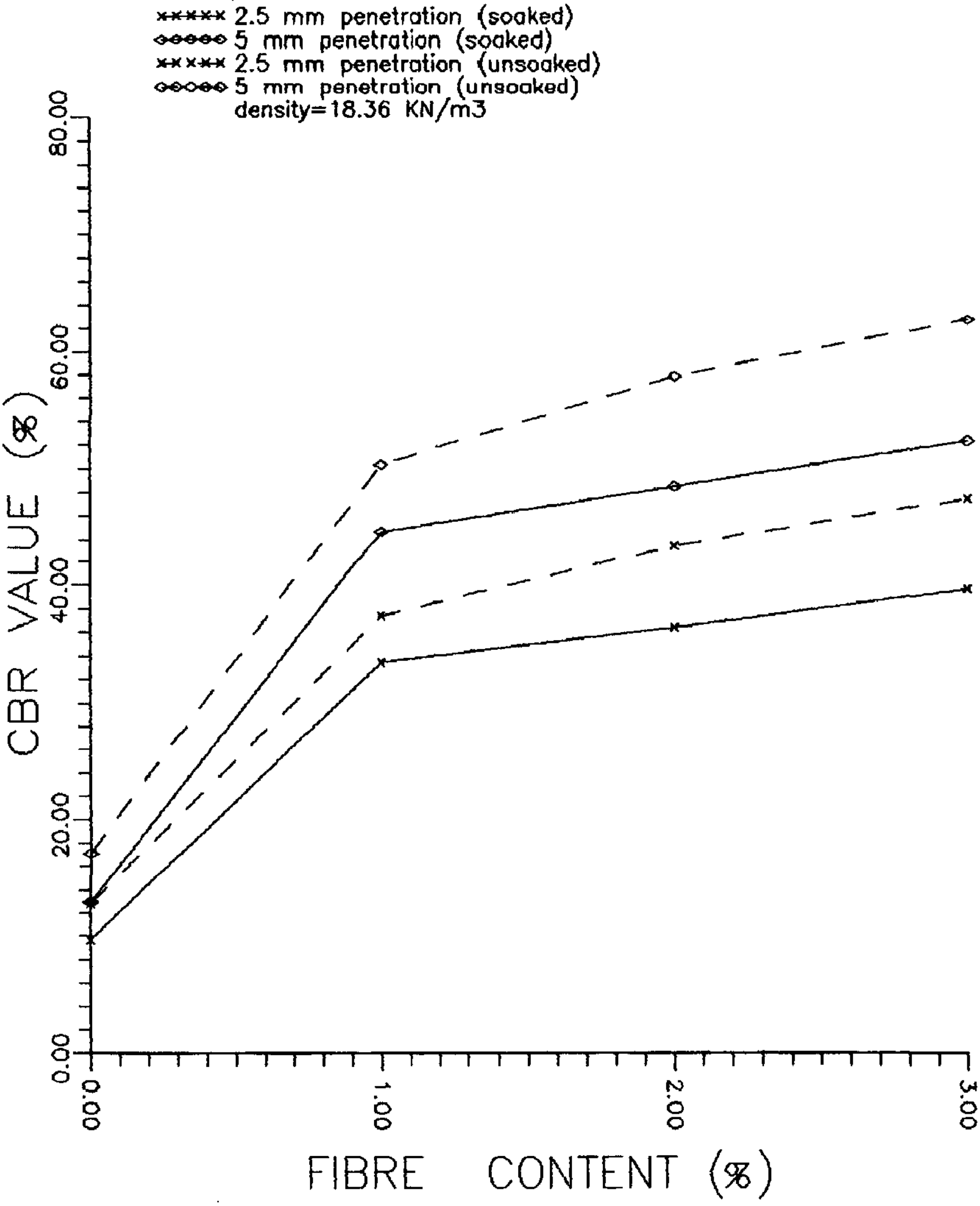
FIBRE CONTENT	CBR VALUES (%)		% INCREASE IN CBR	
	SOAKED	UNSOAKED	SOAKED	UNSOAKED
0	12.89	17.09	......	......
1	44.62	50.35	246.16	194.62
2	48.52	57.90	276.42	238.79
3	52.42	62.82	306.75	267.58

Table 7 shows that percentage increase in CBR value for soaked condition for 1%, 2% and 3% fibre by weight is 246.16% 276.42%and 306.75%respectively and for unsoaked condition is 194.62% 238.79%and 267.58%respectively. This shows that the percentage increase in CBR value in soaked condition is more than that of the unsoaked condition. Further, the increase in CBR value is much higher up to 1% fibre content and after that the rate of increase decreases.

For better visualization of the results a curve has been plotted between CBR value and fibre content for both soaked and unsoaked conditions for both CBR value corresponding to 2.5 mm penetration as well as 5 mm penetration as shown in Fig. 12. It can be easily visualized from the curve that CBR value corresponding to 5 mm penetration is always greater than CBR value corresponding to 2.5 mm penetration for both soaked and unsoaked conditions. Further the increase in CBR value is significant up to 1% fibre content and for the concentration more than 1% the increase is not so significant. This may be due to the fact that with higher fibre content the volume of fibre increases significantly and due to the fact that there is insignificant quantity of soil matrix present to hold the fibres and develop an effective bond between the fibre and the soil. A similiar finding has been reported by Setty and Rao (1987). They used Lateritic soil and polypropylene fibres. The only deviation is that in this case the increase in CBR value is much higher up to 2% fibre content and then it becomes almost constant for unsoaked condition and in case of soaked condition the CBR value goes on increasing with the same rate even at 3% fibre content whereas the results of present investigation show that for both soaked and unsoaked condition the CBR value increases rapidly up to 1% fibre content and then the increase is not significant.

4.3 TRIAXIAL TEXT :

Triaxial tests were conducted on unreinforced soil as well as reinforced soil with a view to determine the change in strength properties of the soil by the addition of fibres. The size of the sample prepared was 50 mm diameter and 100 mm height. The sample were prepared in split mould. The quantity of fibres added in the reinforced soil were 1%, 2%, and 3% by weight of the soil. The samples were prepared at optimum moisture content to achieve maximum dry density. During the test no pore water was allowed to



VARIATION OF CBR WITH FIBRE CONTENT FOR BOTH SOAKED AND UNSOAKED CONDITIONS
Fig.12

escape, thus the test can be said as unconsolidated undrained test or quick test. In case of reinforced soil samples,the amount of fibres were varied up to 3% beyond which the mixing of fibres became very difficult.Prior study done by H.D.Charan[13] (1994) shows that actually the further addition of fibres beyond 3% is not effective as the gain in strength is very less. In this case also the aspect ratio was kept constant at 100 as our aim is to determine the gain or changes in the strength properties of the soil. the values of deviatorial stress corresponding to the different axial strain values were measured and are tabulated in Table 8 and Table 9.

TABLE-8

RESULTS OF TRIAXIAL TESTS ON UNREINFORCED AND REINFORCED SOIL

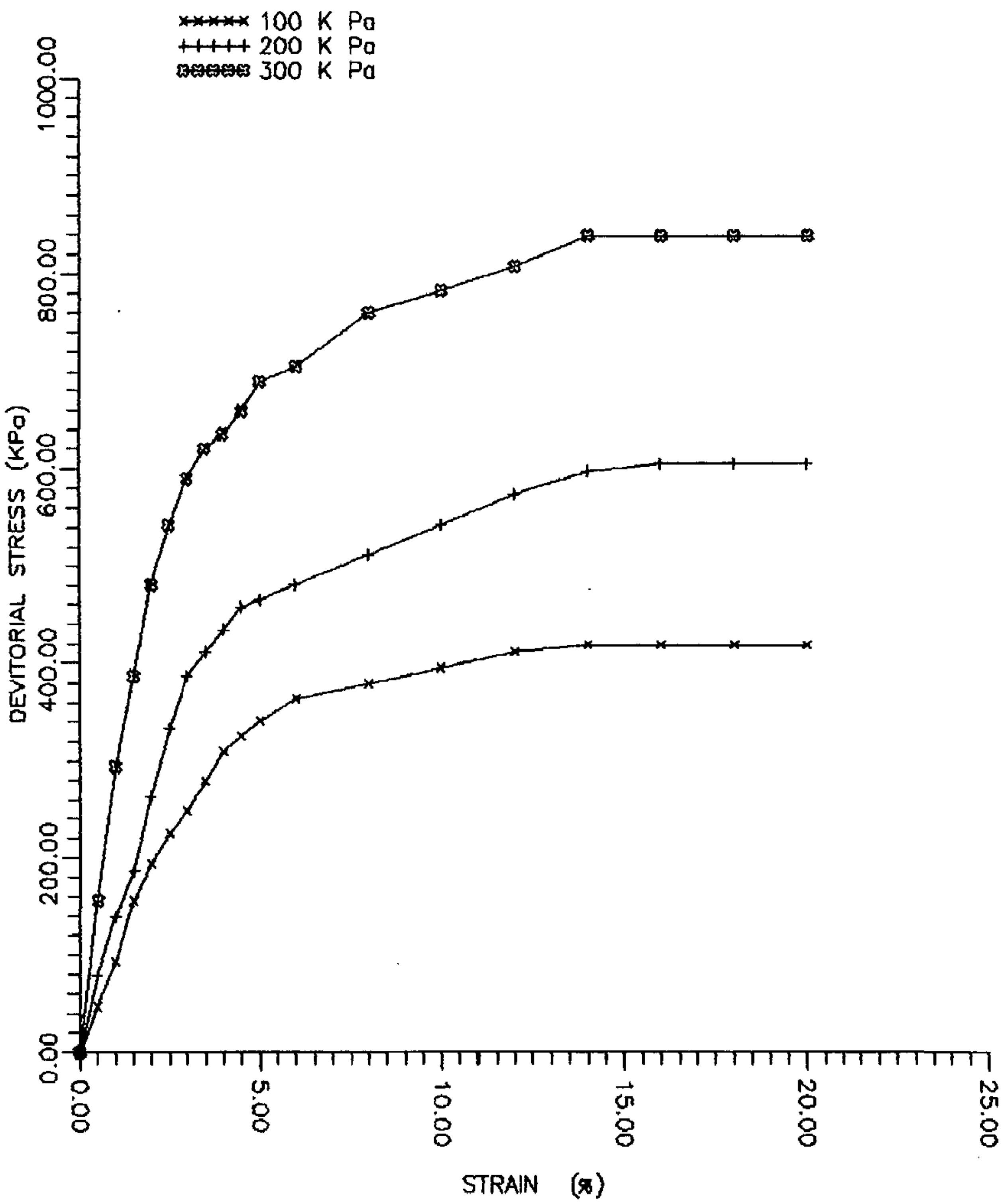
FIBRE CONTENT	0%			1%		
STRAIN (%)	DEVIATORIAL STRESS (KPa)					
	CONFINING PRESSURE (KPa)			CONFINING PRESSURE (KPa)		
	100	200	300	100	300	200
0.0	0	0	0	0	0	0
0.5	47	78	155	93	170	93
1.0	93	139	294	178	434	178
1.5	155	186	387	279	573	279
2.0	194	263	480	325	697	356
2.5	225	333	542	356	759	403
3.0	248	387	589	395	837	480
3.5	279	411	620	418	899	558
4.0	310	434	635	426	945	620
4.5	325	457	658	434	984	666
5.0	341	465	689	442	1023	697
6.0	364	480	705	449	1069	759
8.0	379	511	759	457	1154	806
10.0	395	542	782	465	1224	852
12.0	411	573	806	473	1309	876
14.0	418	596	837	480	1379	914
16.0	418	604	837	488	1418	930
18.0	418	604	837	496	1463	945
20.0	418	604	837	504	1488	960

TABLE-9

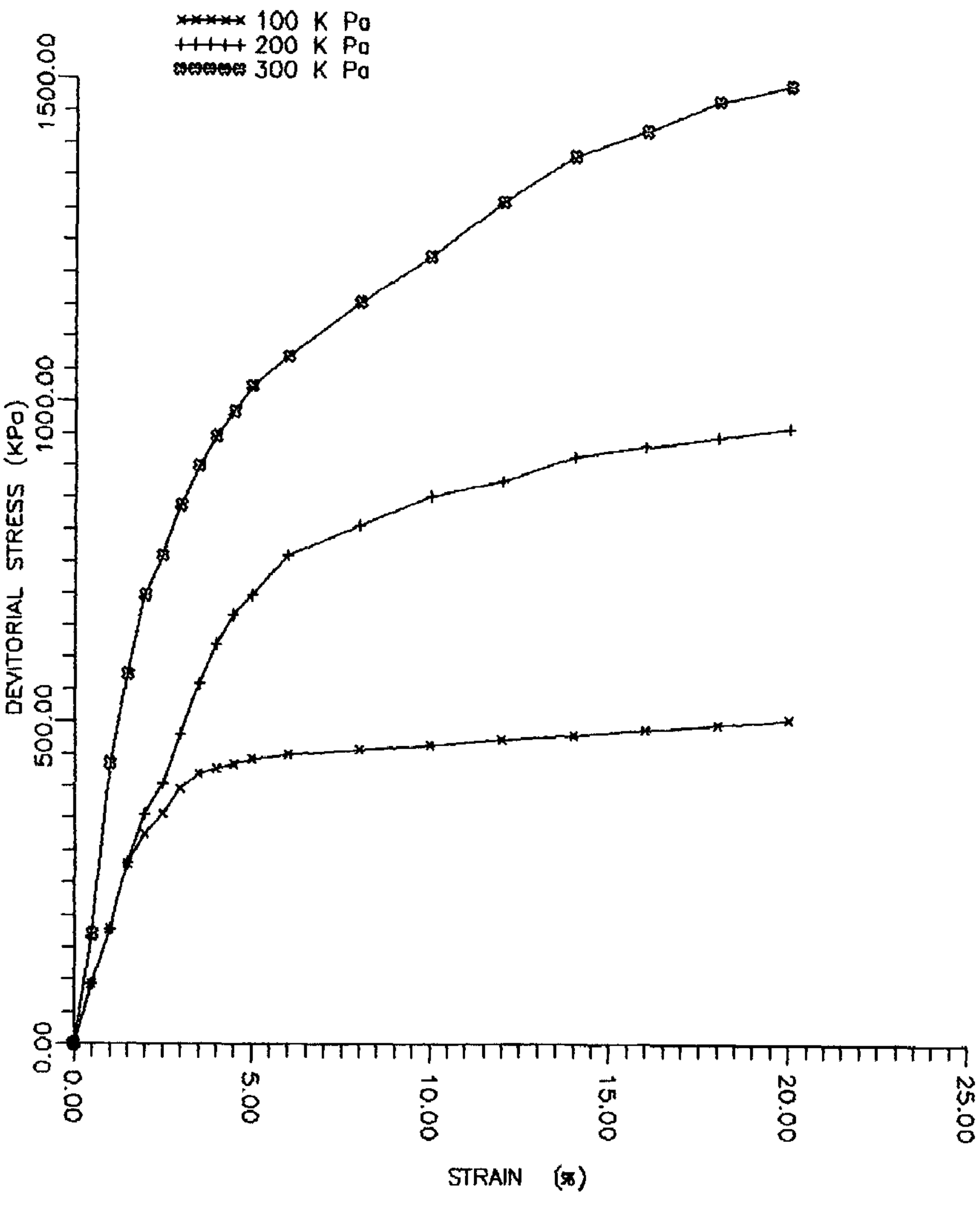
RESULTS OF TRIAXIAL TESTS ON REINFORCED SOIL

FIBRE CONTENT	2%			3%		
STRAIN (%)	DEVIATORIAL STRESS (KPa)					
	CONFINING PRESSURE (KPa)			CONFINING PRESSURE (KPa)		
	100	200	300	100	200	300
0.0	0	0	0	0	0	0
0.5	109	155	240	124	163	263
1.0	217	279	503	248	318	534
1.5	310	403	674	341	449	744
2.0	372	496	821	403	573	898
2.5	434	589	960	465	651	1022
3.0	480	666	1077	511	744	1201
3.5	519	736	1170	542	836	1301
4.0	542	790	1255	558	899	1379
4.5	550	852	1324	566	953	1479
5.0	558	899	1425	581	1000	1580
6.0	573	969	1588	612	1077	1650
8.0	589	1077	1657	643	1201	1719
10.0	604	1154	1750	666	1302	1859
12.0	620	1209	1828	697	1379	1944
14.0	628	1247	1890	721	1441	2052
16.0	635	1278	1952	744	1488	2145
18.0	643	1302	2014	767	1519	2231
20.0	651	1333	2076	790	1550	2331

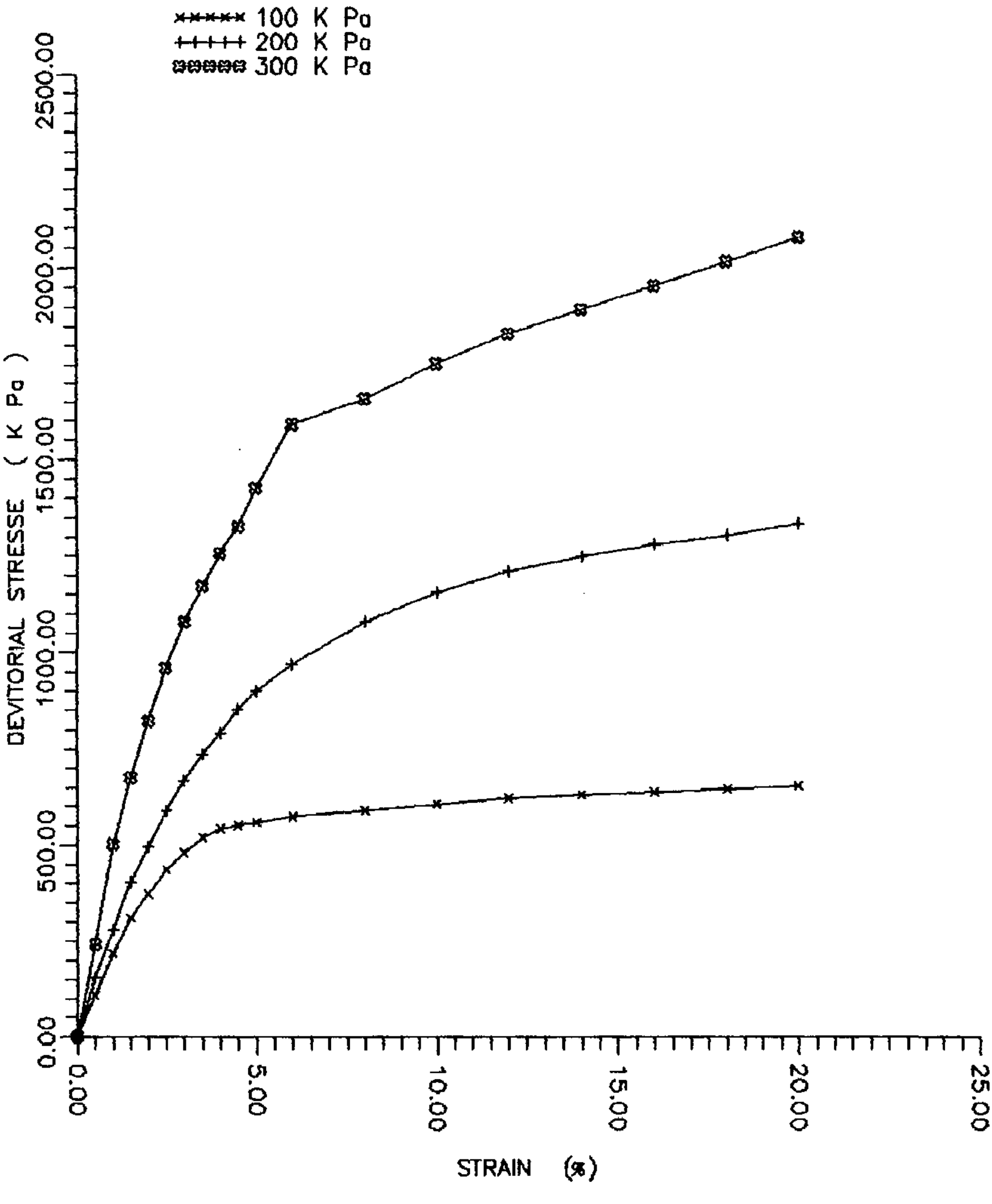
The stress strain curves were plotted with these results. Fig. 13 shows the stress strain curves for unreinforced soil. The three curves in the fig.13 are for different values of confining pressure varying as 100 kpa, 200 kpa and 300 kpa. The curves show that as the confining pressure increases the values of deviatorial stress increases for all strain levels. The curve also shows that for a constant value of confining pressure,the deviatorial stress increases with the increase in axial strain and peak stress is reached at about 14% of the axial strain and after that the stress becomes constant even up to 20% of the axial strain. A similar result is found in case of reinforced soil having reinforcement equal to 1%, 2% and 3% by weight of the soil. The stress strain curves for these reinforced soil are shown in fig. 14,15and 16 respectively. The curves show that in this case also, the deviatorial stress increases with the increase in confining pressure for all strain levels and for constant value of confining pressure but no peak stress in reached. In this case the deviatorial stress goes on increasing even at 20% strain level. A similar result has been reported by H.D. Charan[13] (1994). The used fine sand and plastic fibres for his experiments. These results are similar to results present investigation with the only difference that according to charan (1994) in case of unreinforced sand the peak stress is reached at 10% axial strain and then after words it starts deceasing but in this study the peak stress is reached at 14% strain level and then it becomes constant and does not decrease. The reason my be that the density achieved in that work was quite less as compared to current work.



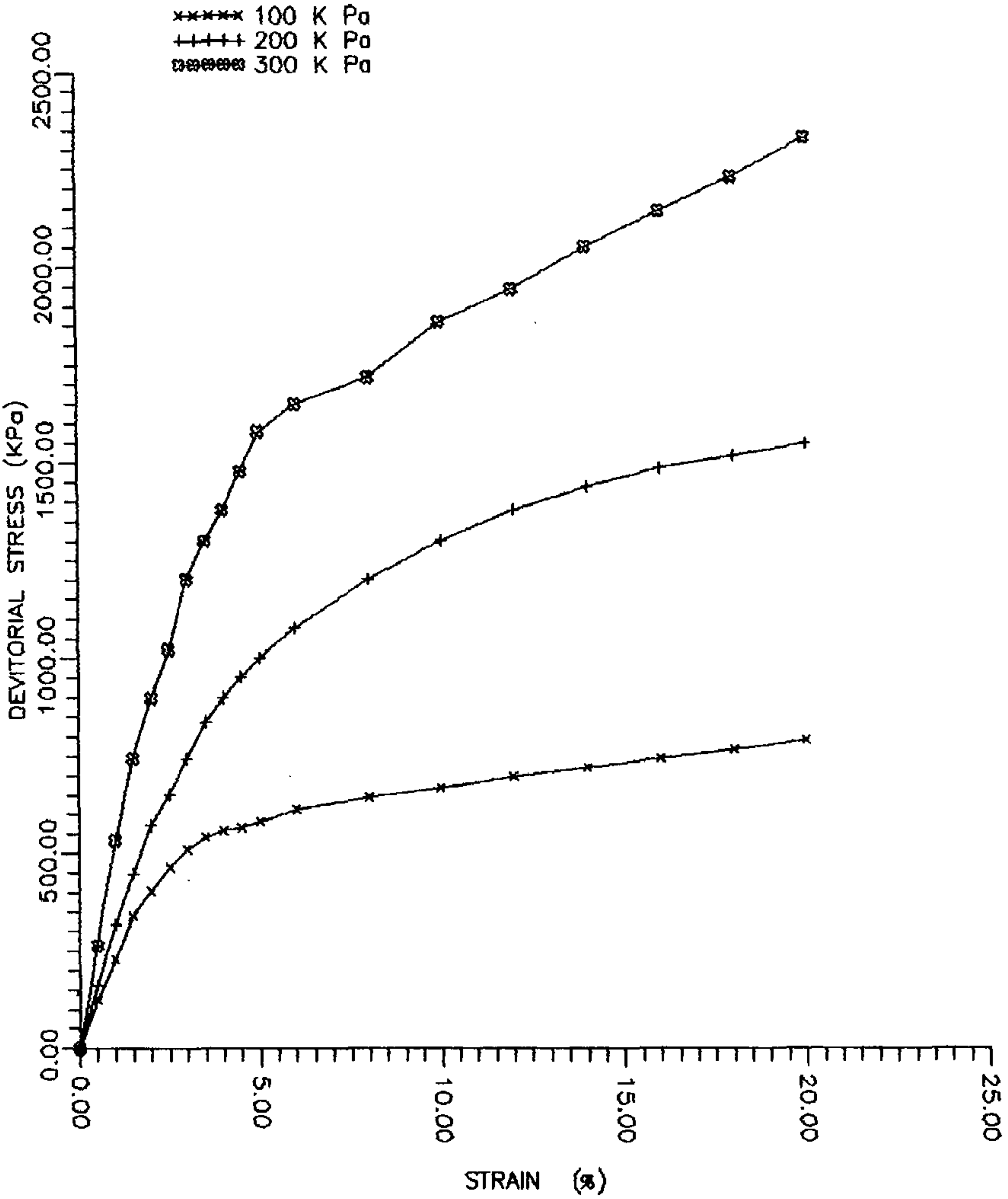
STRESS–STRAIN CURVE IN TRIAXIAL TEST
FOR 0.0% FIBRE CONTENT AND l/d=100
Fig.13



STRESS-STRAIN CURVE IN TRIAXIAL TEST
FOR 1.0% FIBRE CONTENT AND l/d=100
Fig.14



STRESS–STRAIN CURVE IN TRIAXIAL TEST
FOR 2.0% FIBRE CONTENT AND l/d=100
Fig.15



STRESS-STRAIN CURVE IN TRIAXIAL TEST
FOR 3.0% FIBRE CONTENT AND l/d=100
Fig.16

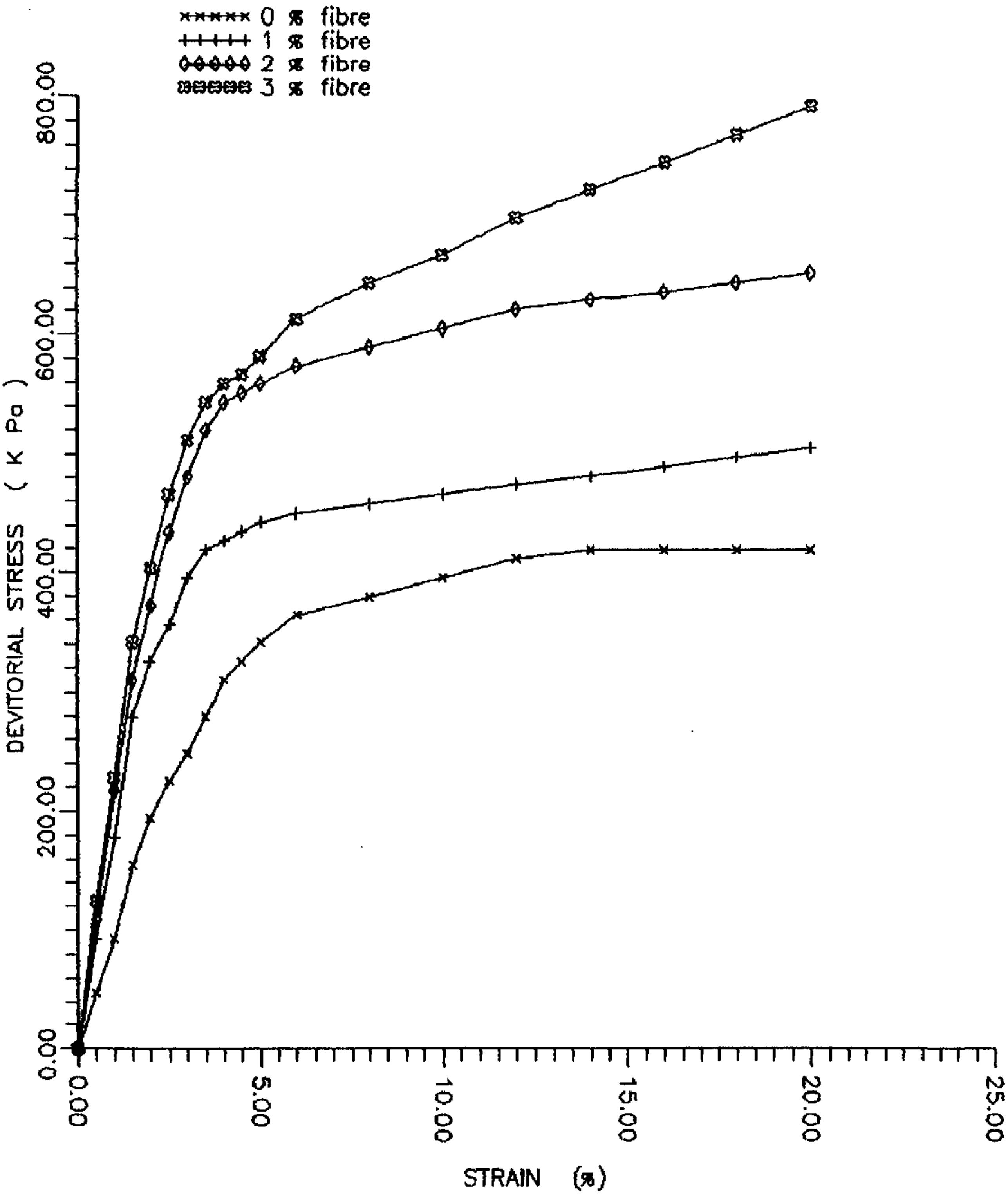
To visualize the effect of fibre content on the stress strain behaviour during the triaxial testing of reinforced soil the stress strain curves for unreinforced as well as reinforced soil having fibre concentration equal to 1%, 2%, and 3% by weight are plotted for constant value of confining pressure. The confining pressure was varied as 100 kpa, 200 kpa, and 300 kpa and plotted on the paper as shown in Fig. 17,18 and 19 respectively. The curves show that for constant value of confining pressure and fibre constant stress increases with the axial strain. the curves also show that the value of stress increases with the increase in fibre content at constant value of confining pressure at all strain levels. Further,the increase in stress with increase in axial strain is large up to 8% axial strain for fibre content up to 2% for all confining pressure beyond which the increase in stress with the increase in strain is quite less. But in case of 3% fibre reinforcement the increase in stress with increase in axial strain is much higher as compared to that with 1% and 2% reinforced soil even after 8% axial strain.

The main objective of the triaxial test was to obtain the shear strength of the of the soil.Shear strength of the soil can be represented in two ways. Firstly,it can be represented as the major principal stress at failure, i.e. the shear strength may be defined as the maximum axial stress taken by the sample at failure.The unreinforced soil shows a defined failure stress at about 14% strain level after which the sample fails and at constant value of stress the strain goes on increasing. But, in case of reinforced soil the soil does not show any defined failure stress and the stress goes on increasing even after 20% strain level. The value of major principal stress at failure (σ_{1f}) was measured from the curves. Fig. 20 shows the variation of major principal stress at failure with the fibre content and confining pressure. The curve shows that the major principal stress at failure continuously goes on increasing as the fibre content increases from 0% to 3%. The curve also shows that the major principal stress at failure increases more rapidly up to 2% fibre content and after that with further fibre content the increase is not appreciable. Further the curve also shows that for constant value of fibre content, the major principal stress at failure increases with the increase in confining pressure. Table 10 shows the values of major principal stress at failure (σ_{1f}) for confining pressure equal to 100 kpa, 200 kpa and 300 kpa and fibre content equal to 0%, 1%, 2% and 3%.

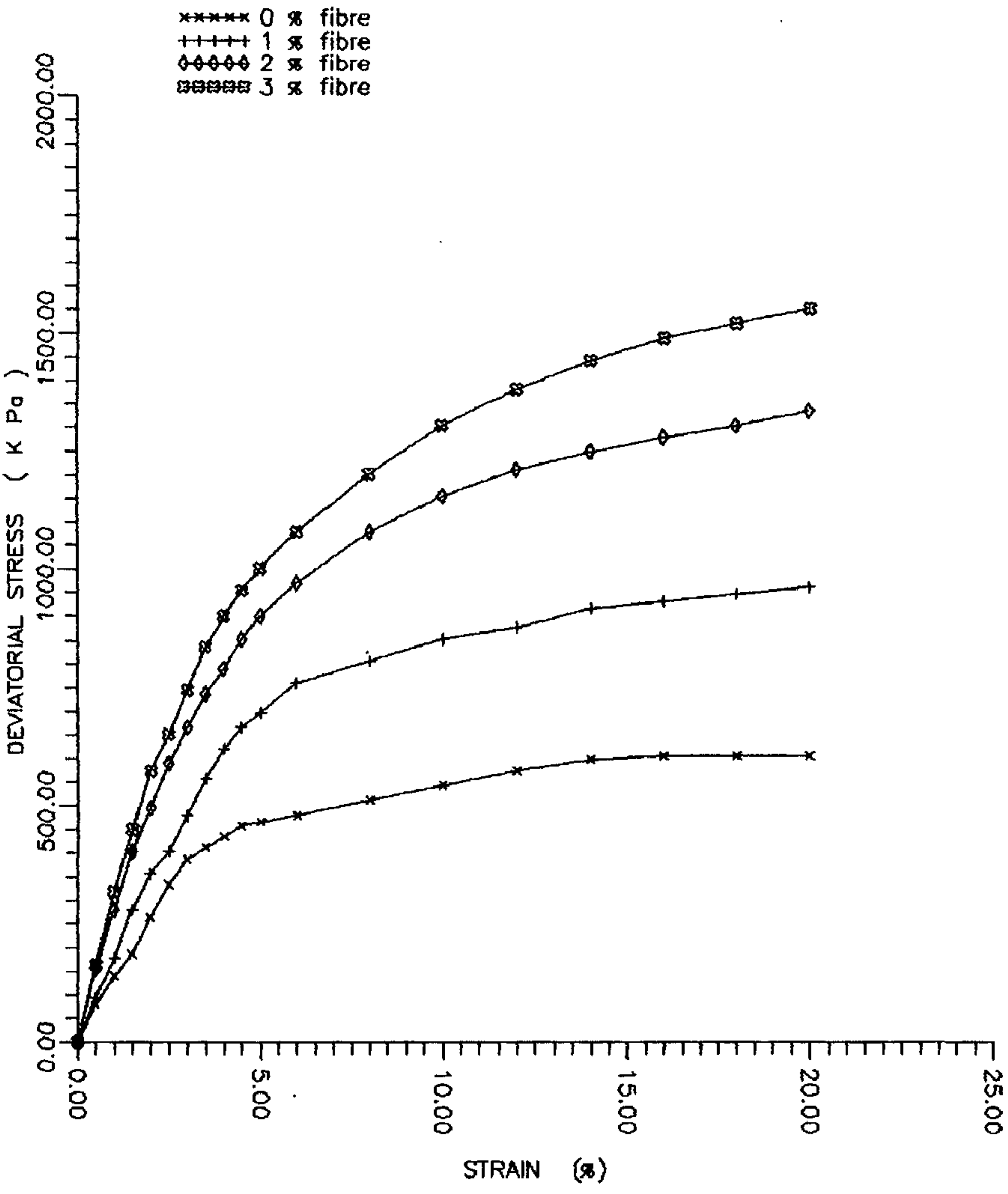
TABLE-10
VARIATION OF MAJOR PRINCIPAL STRESS AT FAILURE WITH FIBRE CONTENT AND CONFINING PRESSURE

FIBRE CONTENT (%)	MAJOR PRINCIPAL STRESS AT FAILURE σ_{1f}		
	CONFINING PRESSURE (KPa)		
	100	200	300
0	518	804	1137
1	604	1160	1788
2	751	1533	2376
3	890	1750	2631

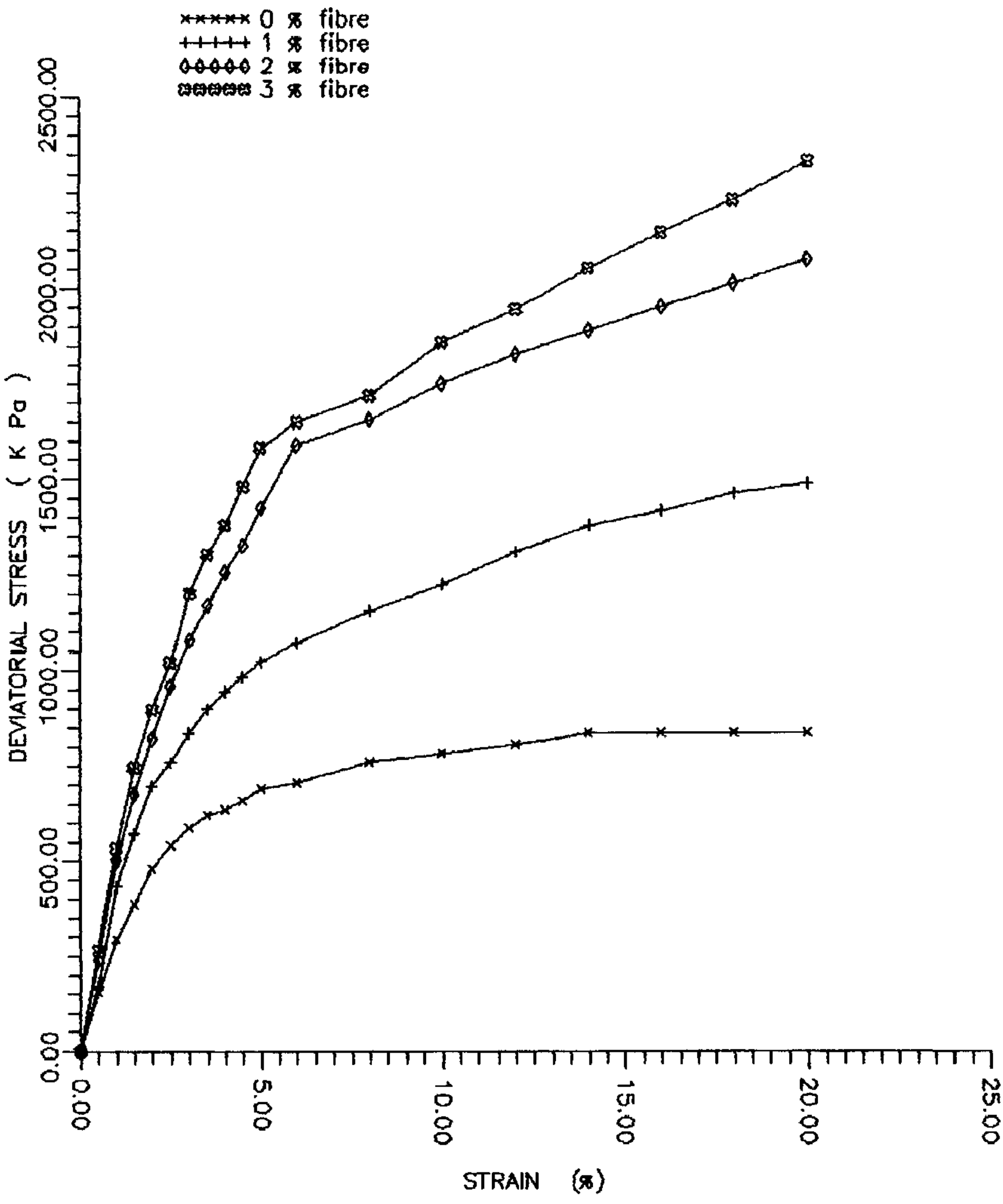
The table shows that at 100 kpa confining pressure with the



STRESS–STRAIN CURVE IN TRIAXIAL TEST
FOR 100 KPa CONFINING PRESSURE
Fig.17

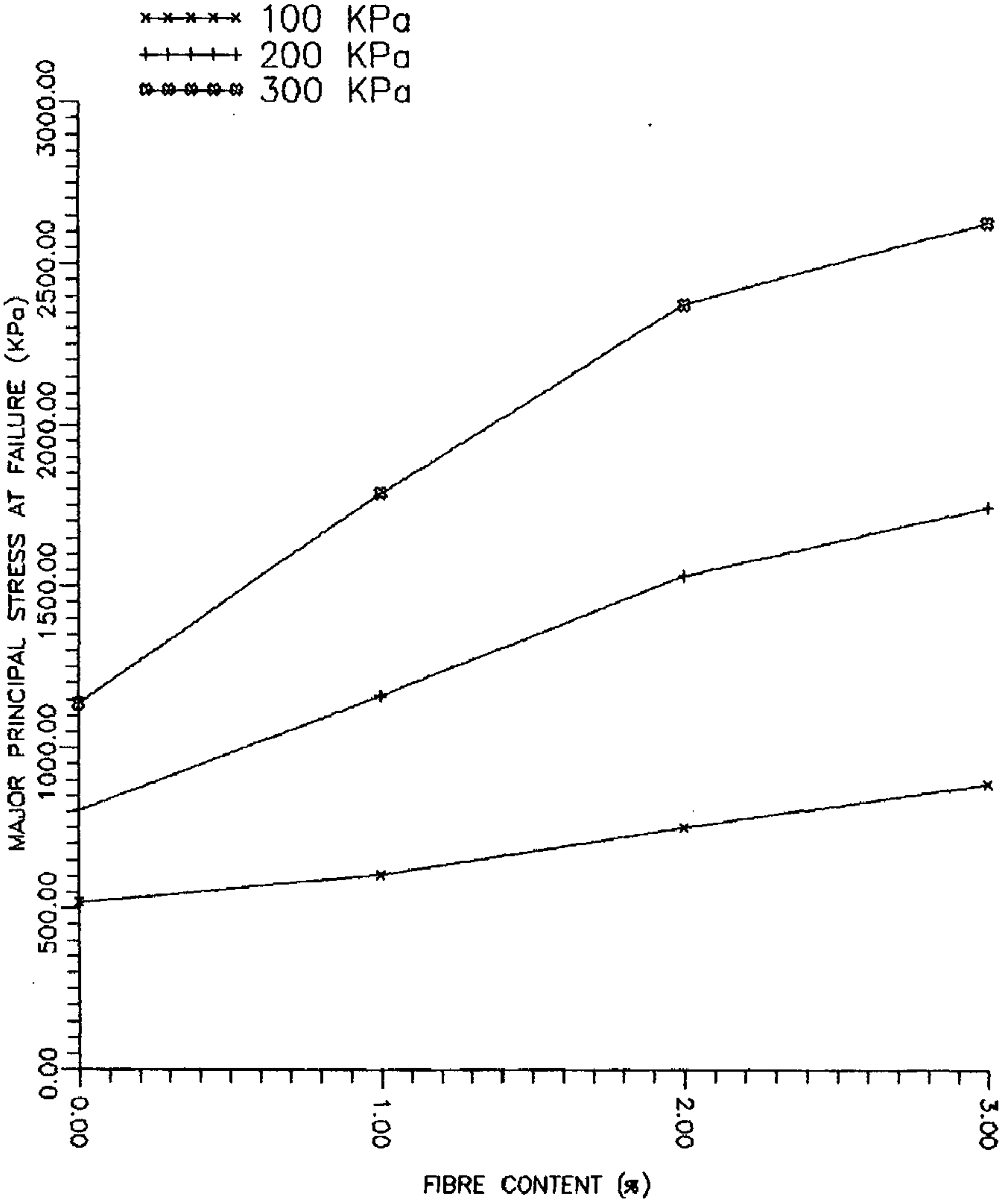


STRESS–STRAIN CURVE IN TRIAXIAL TEST
FOR 200 KPa CONFINING PRESSURE
Fig.18



STRESS-STRAIN CURVE IN TRIAXIAL TEST
FOR 300 KPa CONFINING PRESSURE
Fig.19

100 KPa



VARIATION OF PRINCIPAL STRESS AT FAILURE
WITH CONF.PRESSURE AND FIBRE CONTENT
Fig.20

fibre content 1%, 2% and 3% the σ_{1f} increases by 16.6%, 44.98% and 71.81% respectively. This shows almost straight line variation between σ_{1f} and fibre content up to 3% fibre content. For confining pressure of 200 kpa the percentage increase in σ_{1f} with fibre content 1%, 2% and 3% are respectively 44.28%, 90.67% and 117.67% respectively. This shows that straight line variation up to 2% fibre content but the rate of increase in σ_{1f} decreases after 2% fibre content. For confining pressure 300 kpa the percentage increase in σ_{1f} for fibre content 1%, 2% and 3% is 57.26%, 108.98% and 131.4% respectively. the results also show that the percentage increase in strength with increase in fibre content is more for higher confining pressure values. Further, it can be seen is that the increase in σ_{1f} by increasing the confining pressure is more that the increase in σ_{1f} by increasing the fibre content. A similar result has been reported by H.D. Charan[13] for fine sand and polypropylene fibres for aspect ratio of 75 and 90.

Table 11 shows the values of cohesion and angle of internal friction for reinforced as well as unreinforced soil. The values of cohesion and angle of internal friction were calculated by firstly taking three values of major principal stress at failure corresponding to confining pressure of 100 kpa, 200 kpa and 300 kpa and than it was plotted to get the modified failure envelop by plotting $(\sigma_1 + \sigma_3)/2$ on X-axis and $(\sigma_1 - \sigma_3)/2$ on Y-axis.From the curve the value of d and ψ were obtained. The angle of internal friction (ϕ) calculated as $\sin\phi = \tan\psi$ and cohesion is calculated as $C = d/\cos\phi$. The values are tabulated in Table-11.

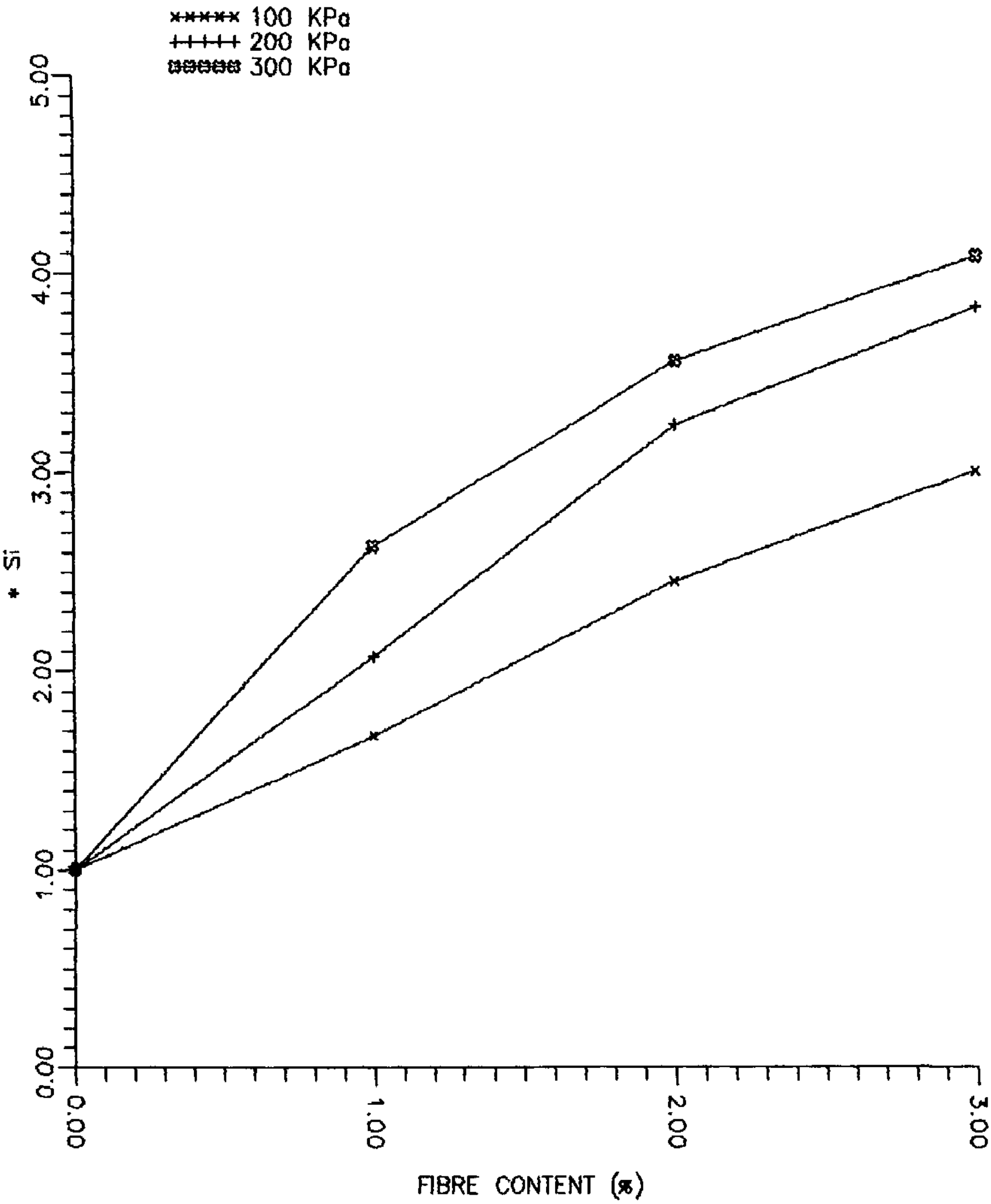
TABLE-11

VARIATION OF SHEAR STRENGTH PARAMETERS WITH FIBRE CONTENT

FIBRE CONTENT (%)	COHESION (KPa)	ANGLE OF INTERNAL FRICTION (^{0})
0	9	36.05
1	9	46.5
2	9	51.33
3	9	52.33

The values show that with the increase in fibre content the cohesion remains constant whereas the angle of internal friction goes on increasing. With the increase in fibre content from 0% to 1%, 2% and 3% the percentage increase in angle of internal friction is 29%, 42.4% and 45.2% respectively. The values show that the increase in angle of internal friction in significant up to 2% of fibre content and then the increase is not so appreciable.

Fig.-21 shows the variation of shear strength with fibre content and confining pressure.Here shear strength has been calculated by Mohr-Coloumb eqn. as $\tau_f = c + \sigma \tan \phi$ and is tabulated in Table-12 and plotted in Fig.21. Shear strength is taken as a nondimentional parameter as a ratio of shear strength of reinforced soil and shear strength of unreinforced soil and rlotted on the Y-axis and on the X-axis fibre content is taken and curves are drawn for confining pressure 100 KPa,200KPa and 300KPa.The values of shear strength are also tabulated in Table 17.From these values,curves were plotted.The curve shows that for



VARIATION OF SHEAR STRENGTH OF SOIL WITH FIBRE CONTENT AND CONFINING PRESSURE

Fig.21

$$* \; Si = \frac{\text{shear strength of reinforced soil}}{\text{shear strength of unreinforced soil}}$$

100KPa and 200KPa confining pressures,the shear strength increase is almost constant up to 2% fibre content and then the rate of increase in shear strength starts decreasing.For 300KPa the increase in shear strength is more rapid up to only 1% fibre content and then it starts decreasing.Further,the increase in shear strength at constant fibre content is more as the confining pressure increases.

TABLE-12

VARIATION OF SHEAR STRENGTH WITH FIBRE CONTENT

CONFINING PRESSURE	100 KPa		200 KPa		300 KPa	
FIBRE CONTENT (%)	τ_f	S_i	τ_f	S_i	τ_f	S_i
0	386.04	1.000	594.21	1.000	836.60	1.000
1	645.48	1.672	1231.38	2.072	1893.16	2.263
2	947.52	2.454	1924.78	3.239	2978.27	3.560
3	1161.91	3.010	2275.96	3.830	3417.21	4.085

where,

τ_f = c + σ tan ϕ =shear strength of the soil

$$S_i = \frac{\text{shear strength of reinforced soil}}{\text{shear strength of unreinforced soil}}$$

4.4 PLATE LOAD TEST :

The plate load test was done to evaluate the modulus of subgrade reaction (i.e. K-value) and the bearing strength. This K-value is used for both the design of flexible pavements as well as the rigid pavements. The sub grade strength, in case of rigid pavements, is expressed in terms of modulus of sub grade reaction, which is defined as pressure per unit deflection as determined by the plate load test.As the limiting design deflection for concrete pavement is recommended as 1.25 mm,he K-value is determined from the pressure sustained at this deflection. In order to determine the K-value and the bearing strength of the sub grade soil,plate load tests were performed on both unreinforced as well as reinforced soil sub grades. The sub grade was prepared in the pavement testing hall in transportation engg. section. In case of reinforced soil sub grades the reinforcement was varied a 0.5%, 1% and 2%. In this case the fibre content was varied only up to 2% as at 2% fibre content itself the mixing was very difficult. Thus an additional test was done with 0.5% fibre reinforcement to get the actual trend of change of strength properties of the sub grade soil due to fibre reinforcements. The fibres were taken 30 mm long so as to get an aspect ratio of 100. The aspect ratio was taken 100 as by Charan[13] (1994),the optimum value of fibre content is between 90 to 120. The test was performed on O.M.C and maximum dry density but due to longer duration of the preparation and larger amount of soil the actual moisture content and density varied from the optimum values. The actual values were measured by Troxler moisture and density gauge up to 300 mm depth at on interval of 50 mm and are tabulated in Table -13,14,15 and 16 for 0%,0.5% 1.0% and 2.0% respectively.

TABLE-13

DENSITY AND MOISTURE CONTENT FOR UNREINFORCED SOIL SUBGRADE

DEPTH (mm)	DRY DENSITY (KN/m^3)	BULK DENSITY (KN/m^3)	MOISTURE CONTENT (%)
300	17.04	18.75	10.0
250	17.09	18.81	10.5
200	17.14	18.84	9.90
150	17.14	18.84	9.90
100	-	-	-
AVERAGE	17.10	18.81	10.1

TABLE-14

DENSITY AND MOISTURE CONTENT FOR REINFORCED SOIL SUBGRADE WITH 0.5% FIBRE CONTENT

DEPTH (mm)	DRY DENSITY (KN/m^3)	BULK DENSITY (KN/m^3)	MOISTURE CONTENT (%)
300	17.30	18.98	9.75
250	17.16	18.94	10.35
200	17.40	18.85	10.45
150	16.97	18.70	10.18
100	16.98	18.70	10.10
AVERAGE	17.16	18.84	10.17

TABLE-15

DENSITY AND MOISTURE CONTENT FOR REINFORCED SOIL SUBGRADE WITH 1% FIBRE CONTENT

DEPTH (mm)	DRY DENSITY (KN/m^3)	BULK DENSITY (KN/m^3)	MOISTURE CONTENT (%)
300	17.27	19.21	11.6
250	17.08	19.05	11.5
200	16.90	18.92	12.4
150	16.94	18.85	11.4
100	16.72	18.73	12.0
AVERAGE	16.98	18.95	11.78

TABLE-16

DENSITY AND MOISTURE CONTENT FOR REINFORCED SOIL SUBGRADE WITH 2% FIBRE CONTENT

DEPTH (mm)	DRY DENSITY (KN/m^3)	BULK DENSITY (KN/m^3)	MOISTURE CONTENT (%)
300	16.77	19.19	11.5
250	16.58	19.05	11.9
200	16.60	19.02	11.6
150	16.29	18.69	11.7
100	16.27	18.57	11.1
AVERAGE	16.50	18.90	11.56

The extent of the subgrade area prepared was 750 mm * 750mm * 450 mm. The soil was compacted in three layers of 150 mm each by hand ramming.

Fig.22 shows the load penetration curve for unreinforced soil sub grade. This shows that in the beginning the sub grade took a heavier load at lesser penetration but as the load increased the value of penetration increased more rapidly as compared to the load. The values of the load taken by the plate and the deformation measured by the three dial gauges are shown Table 17.

TABLE-17

PLATE LOAD TEST RESULTS ON UNREINFORCED SOIL SUBGRADE

LOAD (kg)	DIAL-GUAGE 1	DIAL-GUAGE 2	DIAL-GUAGE 3	AVERAGE SETTLEMENT (mm)
341	52	30	32	0.38
651	100	69	70	0.80
1194	200	149	162	1.70
1907	301	240	269	2.70
2542	407	334	380	3.74
3038	502	418	468	4.63
3534	618	525	583	5.75
3999	709	605	675	6.63
4387	819	708	802	7.76
4697	929	818	950	8.99
4805	1023	920	1070	10.04

The value of load corresponding to 1.25 mm penetration unreinforced soil = 9250 N

Stress corresponding to 1.25 mm penetration for 300 dia plate on unreinforced soil

$$= \frac{9250}{\pi(150)^2} = 0.131 \ N/mm^2$$

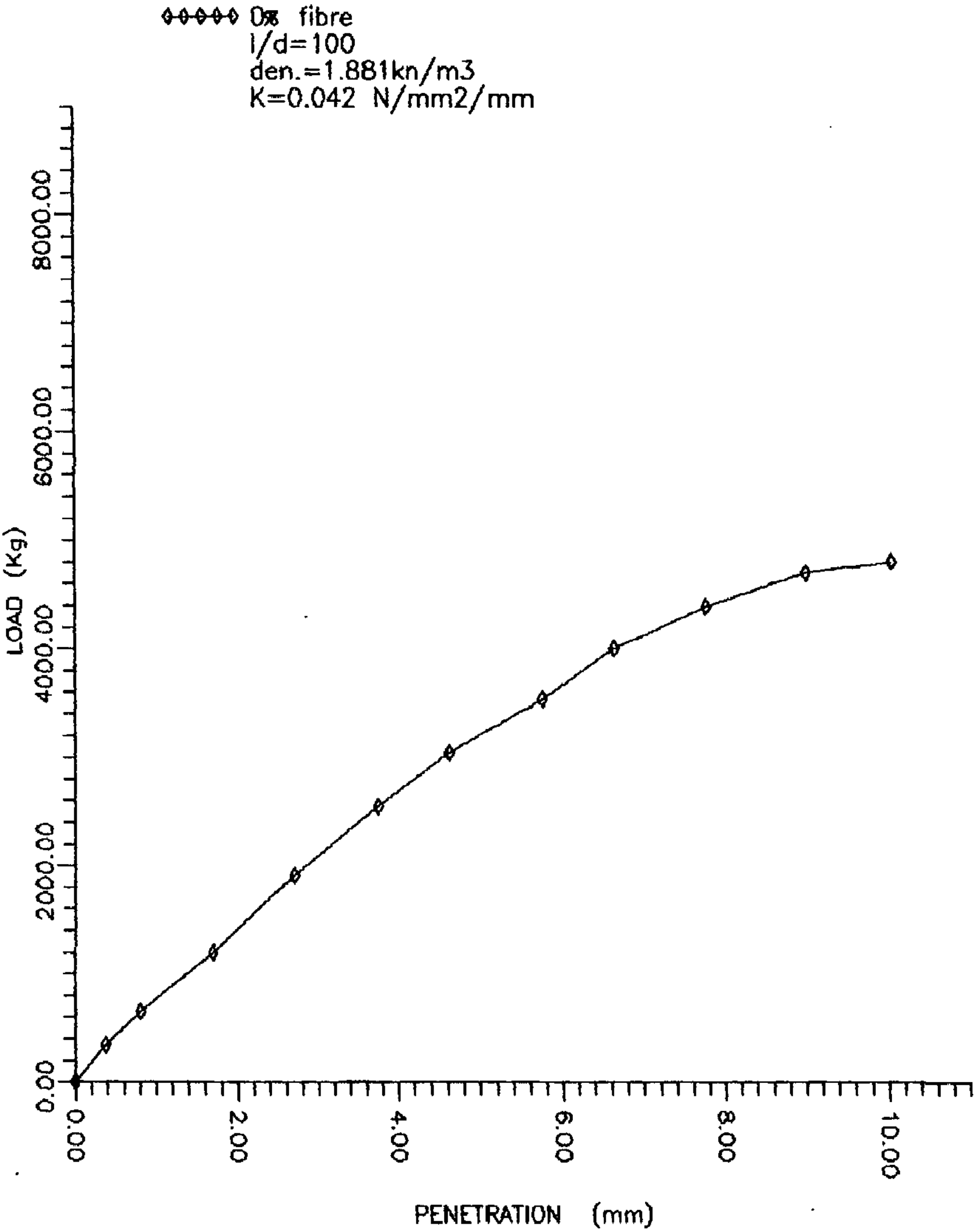
K-value corresponding to 300 mm plate $= \frac{0.131}{1.25} = 0.105 \ N/mm^2/mm$

K-value corresponding to 750 mm plate $= \frac{0.105 \times 300}{750} = 0.042 \ N/mm^2/m$

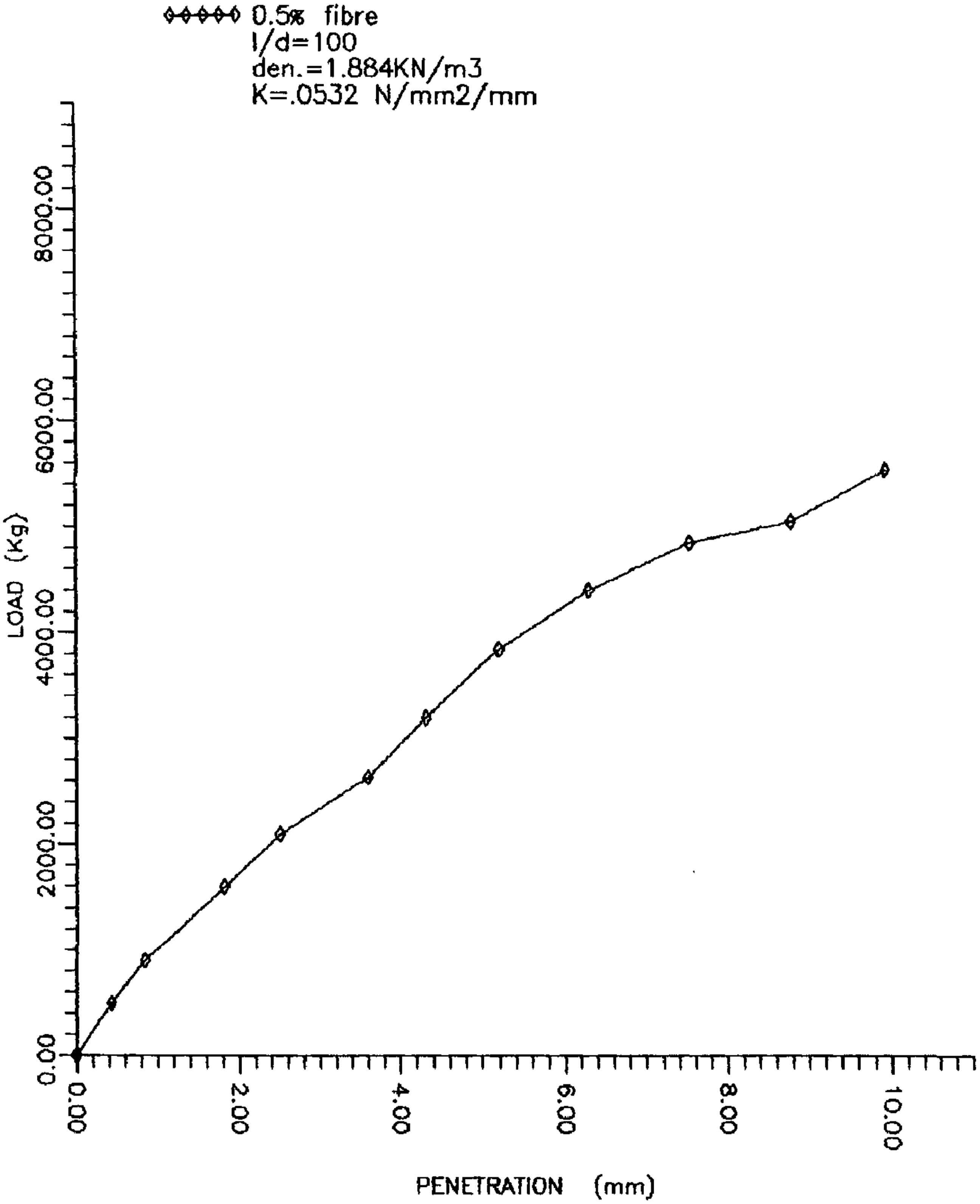
The bearing capacity of the unreinforced sand

$$= \frac{48000}{\pi \ (150)^2} = 0.679 \ N/mm^2$$

For reinforced soil with 0.5% fibre content the load and penetration values are tabulated in Table-18 and from these values load penetration curve was plotted as shown in Fig. 23. The curve is almost similar to that of the curve for unreinforced soil.



LOAD-DEFORMATION CURVE ON
UNREINFORCED SOIL SUBGRADE
Fig-22



LOAD-DEFORMATION CURVE ON
REINFORCED SOIL SUBGRADE
Fig-23

TABLE-18

PLATE LOAD TEST RESULTS ON REINFORCED SOIL SUBGRADE WITH 0.5% FIBRE CONTENT

LOAD (kg)	DIAL-GUAGE 1	DIAL-GUAGE 2	DIAL-GUAGE 3	AVERAGE SETTLEMENT (mm)
496	58	32	39	0.43
899	108	72	75	0.85
1597	203	158	185	1.82
2093	275	248	233	2.52
2635	385	359	331	3.59
3193	455	435	406	4.32
3844	540	520	503	5.21
4402	650	635	602	6.29
4852	800	740	719	7.53
5053	900	884	850	8.78
5549	1020	997	962	9.93

The load corresponding to 1.25 mm penetration for reinforced soil with 0.5% fibre content = 11600 N

stress corresponding to 1.25 mm penetration for reinforced soil with 0.5% fibre content

$$= \frac{11600}{\pi\ (150)^2} = 0.164\ N/mm^2$$

K-value corresponding to 300 mm plate size for reinforced soil with 0.5% fibre content

$$= \frac{0.164}{1.25} = 0.133 \text{ N/mm}^2\text{/mm}$$

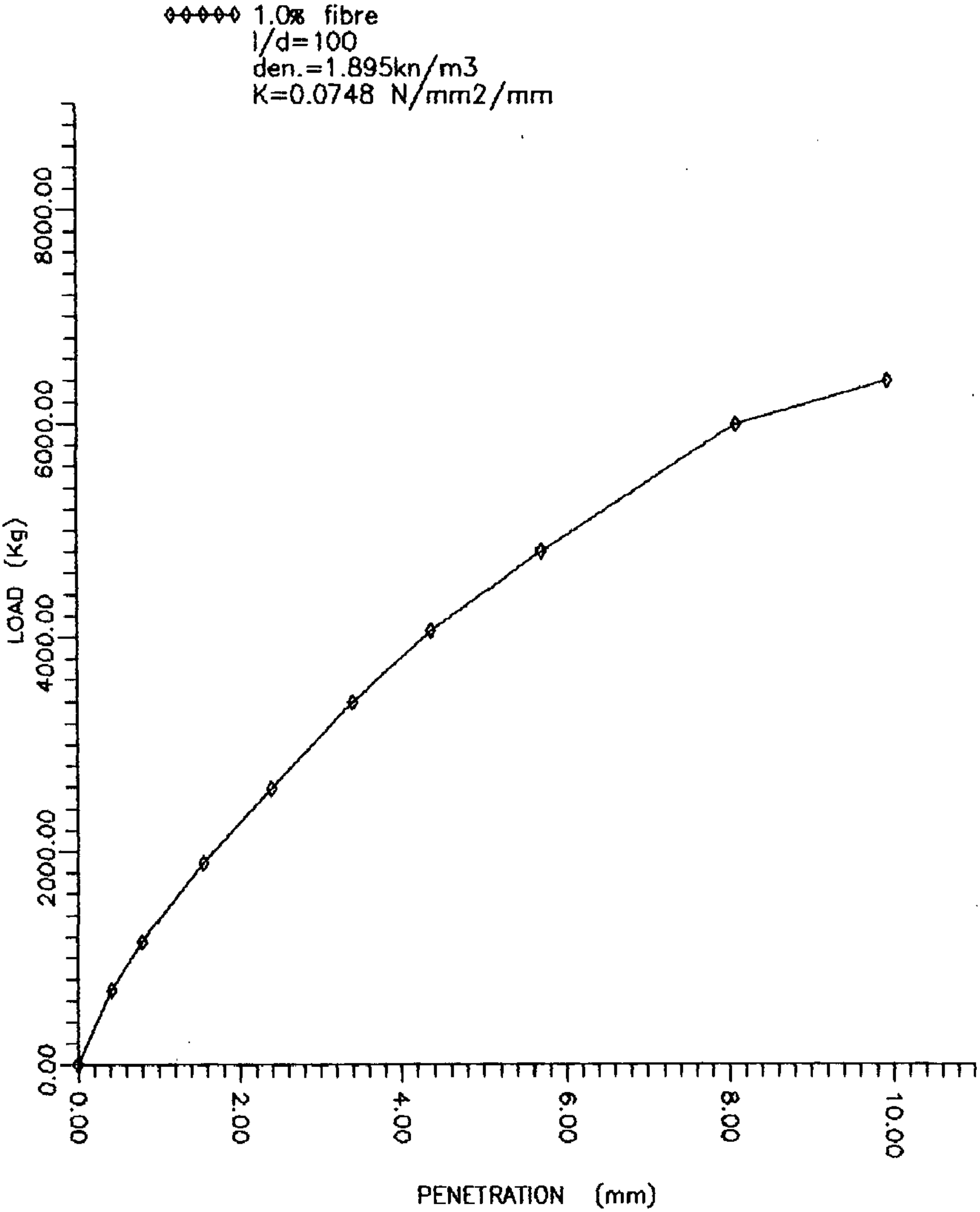
K-value corresponding to 750 mm plate size for reinforced soil with 0.5% fibre content

$$= \frac{0.133 \times 300}{750} = 0.532 \text{ N/mm}^2\text{/mm}$$

bearing capacity of the reinforced soil subgrade with 0.5% fibre content

$$= \frac{55500}{\pi\ (150)^2} = 0.79 \text{ N/mm}^2$$

Reinforced soil sulgrade with 1% fibre content was tested under plate load test and the results of load and penetration values are tabulated in Table-19. From these values,a load penetration curve was plotted as shown in the Fig. 24. The curve has the similiar nature as that of the unreinforced subgrade except the fact that it takes more load for same value of penetration.



LOAD-DEFORMATION CURVE ON
REINFORCED SOIL SUBGRADE
Fig-24

TABLE-19

PLATE LOAD TEST RESULTS ON REINFORCED SOIL SUBGRADE

WITH 1% FIBRE CONTENT

LOAD (kg)	DIAL-GUAGE 1	DIAL-GUAGE 2	DIAL-GUAGE 3	AVERAGE SETTLEMENT (mm)
698	52	40	33	0.42
1147	103	63	73	0.80
1891	201	128	136	1.55
2589	304	193	222	2.39
3394	410	260	351	3.40
4061	516	348	447	4.37
4805	612	463	634	5.70
5999	832	742	858	8.10
6401	1072	920	993	9.95

The value of load corresponding to 1.25 mm penetration for 1.0% reinforcement = 16500 N

Stress corresponding to 1.25 mm penetration for 300 mm plate on reinforced soil with 1.0% fibre content

$$= \frac{16500}{\pi\ (150)^2} = 0.233\ N/mm^2$$

K-value for 300 mm plate size for reinforced soil with 1.0% fibre content

$$= \frac{0.233}{1.25} = 0.184\ N/mm^2/mm$$

K-value for 750 mm plate size for reinforced soil with 1.0% fibre content

$$= \frac{0.184 \times 300}{750} = 0.0746\ N/mm^2/mm$$

The bearing capacity of the reinforced soil with 1.0% fibre content

$$= \frac{64000}{\pi\ (150)^2} = 0.91\ N/mm^2$$

Reinforced soil subgrade with 2% fibre content was prepared and tested under plate load test and the results of the load penetration values are tabulated in Table-20.

TABLE-20

PLATE LOAD TEST RESULTS ON REINFORCED SOIL SUBGRADE

WITH 2% FIBRE CONTENT

LOAD (kg)	DIAL-GUAGE 1	DIAL-GUAGE 2	DIAL-GUAGE 3	AVERAGE SETTLEMENT (mm)
1147	56	37	42	0.45
1752	106	55	83	0.81
2046	150	78	104	1.11
2496	208	112	139	1.53
3271	306	166	185	2.19
4588	411	200	195	3.7
5797	614	459	495	5.23
6898	822	678	733	7.44
7354	1034	762	775	8.50
7502	1218	967	950	9.70

From these values, a load penetration curve was plotted as shown in Fig. 25. The curve has the similar nature as that of load penetration curve for unreinforced soil subgrade and reinforced soil subgrade with 0.5% and 1% fibre content except the fact that it takes much more load than the previous one. From the curve the load corresponding to 1.25 mm penetration was measured to calculate the K-value of the subrade.

The load corresponding to 1.25 mm penetration for reinforced soil with 2% fibre content =22000 N

Stress corresponding to 1.25 mm penetration for reinforced soil with 2% fibre content

$$= \frac{22000}{Z\ (150)^2} = 0.311\ N/mm^2$$

K-value corresponding to 300 mm plate size for reinforced soil subgrade with 2% fibre content

$$= \frac{0.311}{1.25} = 0.2489\ N/mm^2/mm$$

K-value corresponding to 750 mm plate size for reinforced soil subgrade with 2% fibre content

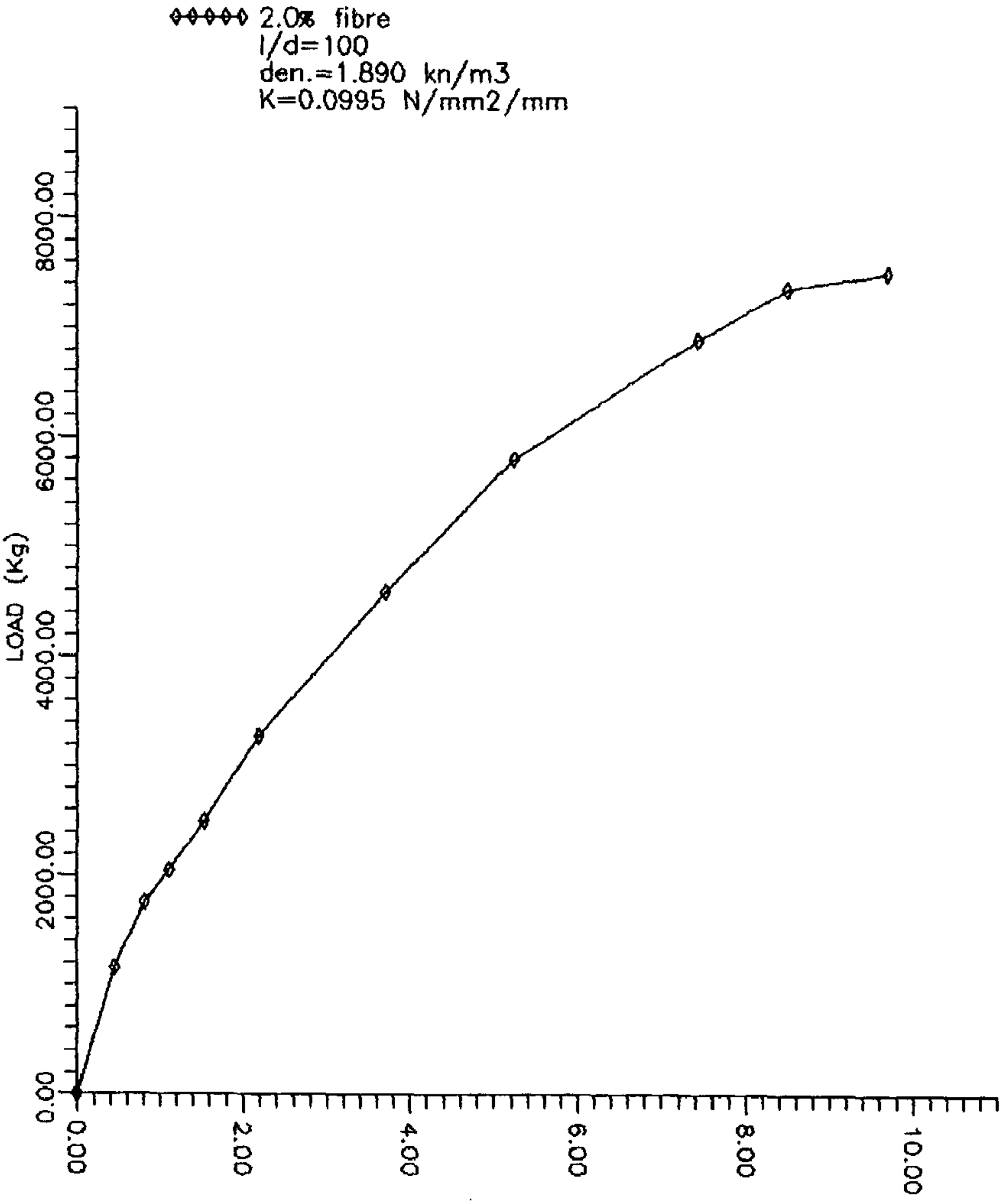
$$= \frac{0.2489 \times 300}{750} = 0.0995 N/mm^2/mm$$

bearing capacity of reinforced soil subgrade with 2% fibre content

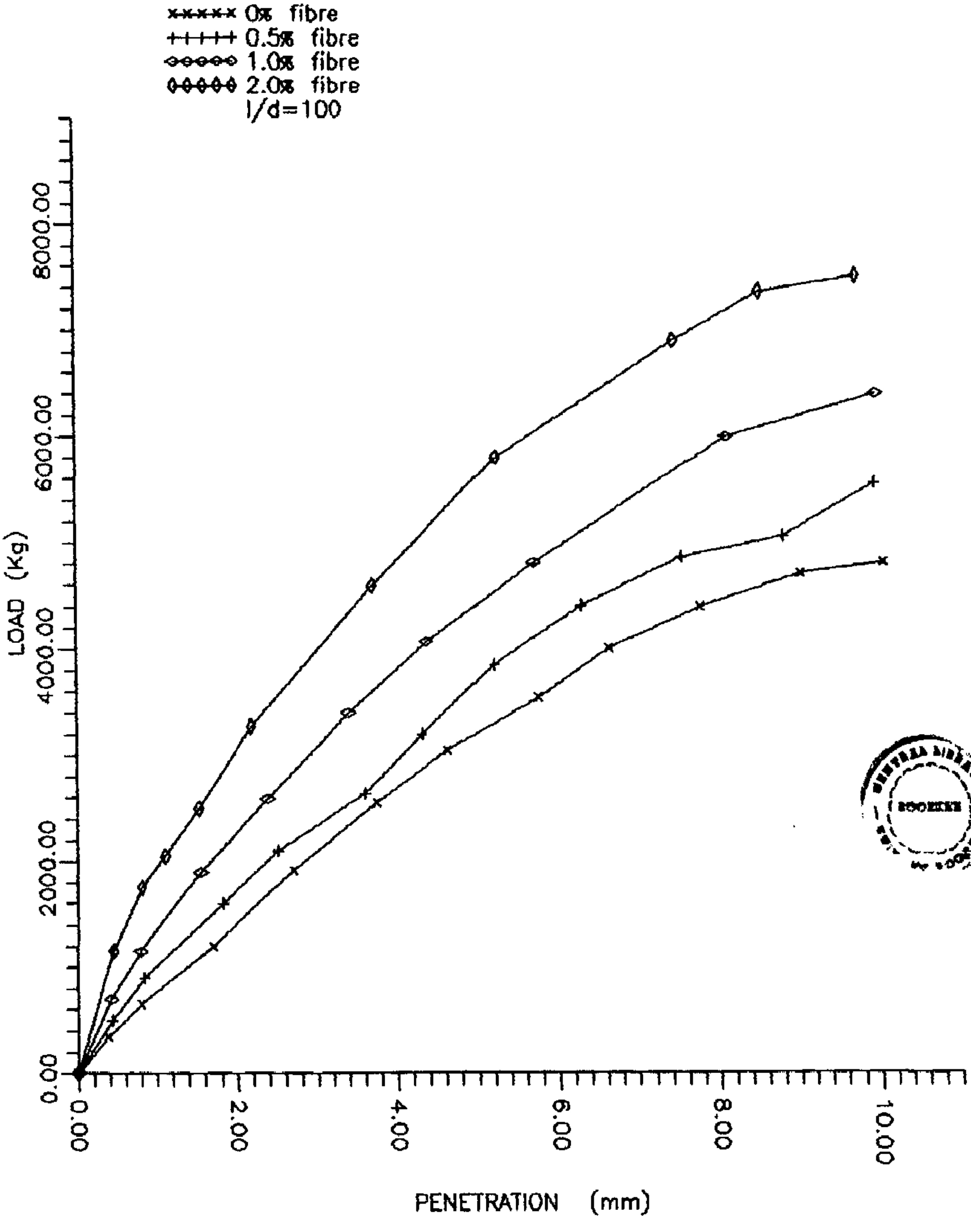
$$= \frac{75500}{\pi\ (150)^2} = 1.070\ N/mm^2$$

Fig.-26 show the load penetration curve for both unreinforced soil subgrade as well as reinforced soil subgrade with 0.5%, 1% and 2% fibre content. The curve shows that as the fibre content increases from 0% to 2%,the value of load taken by the subgrade for same penetration level increases and the increase is higher for lesser penetration as compared to higher penetration level.

Table -21 shows the K-values for the unreinforced as well as



LOAD-DEFORMATION CURVE ON
REINFORCED SOIL SUBGRADE
Fig-25



LOAD-DEFORMATION CURVE ON
REINFORCED SOIL SUBGRADE
Fig-26

reinforced soil subgrade with 0.5%, 1% and 2% fibre content. It also shows the percentage increase in K-value with the increase in fibre content. The values indicate that the percentage increase in K-value with 0.5%, 1% and 2% fibre content is 26.67%, 78.1% and 136.9% respectively. This shows that the rate of increase is high up to 1% fibre content and then after 1% the rate of increase of K-value decreases.

TABLE-21

K-VALUES FOR REINFORCED AND UNREINFORCED SOIL SUBGRADE

FIBRE-CONTENT	K-VALUES (N/mm^3)	(%) INCREASE IN K-VALUES
0.0	0.0420	-
0.5	0.0532	26.67
1.0	0.0746	78.01
2.0	0.0995	136.90

CHAPTER-5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS :

The present investigation has been carried out to study the strength characteristics of randomly distributed fibre reinforced soil subgrades with respect to their load carrying capacity, modulus of subgrade reaction, shear strength, and California bearing ratio values. The investigation was carried out in the lab and semi full scale field tests, have shown that the randomly distributed fibre reinforced sand subgrades,even though slightly higher in cost as compared to unreinforced soil subgrade,exhibit superior perforcemence as compared to conventional unreinforced soil subgrades.

As a result of the experimental investigations tests and semi-full scale pavement testing,on sand reinforced with polypropylene fibres,the following conclusions are drawn :

1. CBR value increases with increase in fibre content for soaked and unsoaked conditions. But the rate of increase is higher up to 1% fibre content and there after the rate of increase is not so appreciable.

FIBRE CONTENT	% increase in CBR value	
	soaked	unsoaked
1	246.16	194.62
2	276.42	238.79
3	306.75	267.58

The table above indicates that at 2% fibre content the increase in CBR value is only 30.26% for soaked condition and 44.17%.

2. CBR value corresponding to 5 mm penetration is always greater than CBR value corresponding to 2.5 mm penetration at all strain levels.

3. CBR values for unsoaked conditions is always greater than CBR values for soaked conditions for constant value of fibre content.

4. The value of cohesion remains constant with the increase in fibre content but the angle of internal friction increases with the increase in fibre content and the net effect is increase in shear strength as shown below:

fibre content	% increase in cohesion	% increase in angle of internal friction	% increase in shear strength		
			confining pressure(kpa)		
			100	200	300
1	0	29	67.2	107.2	126.3
2	0	42.4	145.4	223.9	256
3	0	45.2	201	283	308

5. Shear strength increases linearly with increase in fibre content up to 2% fibre content by weight, beyond which the rate of increase is not appreciable.

6. Deviatorial stress and axial strain curves for constant confining pressure for unreinforced sand attains a peak stress at 14% axial strain, which remains constant up to 20% axial strain. However, reinforced sand sample do not exhibit any peak stress and show increasing trend even at 20% axial strain.

7. The value of major principal stress at failure increases with increase in fibre content at constant value of confining pressure. It also increases with increase in confining pressure at constant value of fibre content.

8. The K-value of the soil subgrades increase with increase in fibre content and the rate of increase of K-value is higher up to 1% fibre content and thereafter the rate of increase of K-value decreases.

9. The load carrying capacity of the soil subgrades increases with the increase in fibre content.As the fibre content increases from 0% to 0.5%,1% and 2%,the load carrying capacity increases by 16.2,33.8 and 57.4% respectively.

10. For all practical purposes there is significant improvement in strength characteristics of fibre reinforced soil subgrades up to 1% fibre content and there after the rate of increase is not appreciable. Also, mixing of fibre at higher fibre content is very difficult. Therefore, for all

practical purposes 1% fibre content may be reccomended as the optimum fibre content to be used.

5.2 RECOMMENDATIONS FOR FURTHER STUDY :

Till recently not much work has been done on the fibre reinforced soil. So it is very important to have a lot of studies in this area. Specially no work has been done on the durability of the fibre reinforced structures. It is necessary to standerdise the shape and dimensions of the objects tested, the experimental conditions and precisely lay down the methods of the test. In a way one may hope for the results as little scattered as possible and have a good reproducibility.

Further studies must be done with all other types of soil using both natural and synthetic fibers. Special consideration should be done to locally available fibre in order to have a cheap construction practice.

In order to determine the effect of using a reinforced soil subgrades underneath the pavement a token test was done over WBM road layed over unreinforced and reinforced soil with fibre content 2% by weight. The results of the plate load test are shown on Table-22 and Table 23. From these values curves were drawn between load and penetration and are shown in Fig.-27 and fig. 28.

TABLE-22

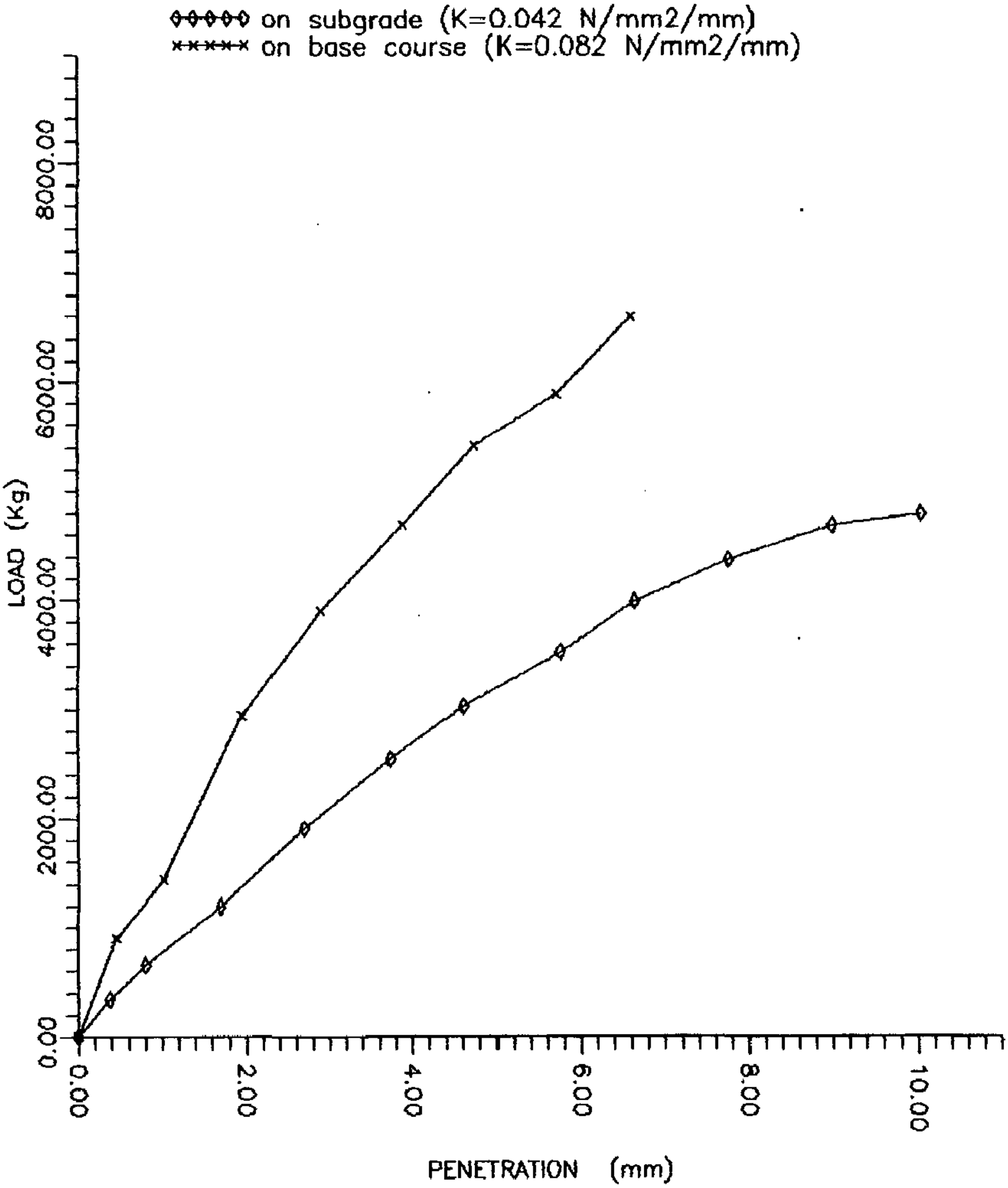
PLATE LOAD TEST RESULTS ON WBM OVER UNREINFORCED SOIL SUBGRAD

LOAD (kg)	DIAL-GUAGE 1	DIAL-GUAGE 2	DIAL-GUAGE 3	AVERAGE SETTLEMENT (mm)
899	48	48	42	0.46
1442	106	104	93	1.01
2945	212	195	180	1.96
3906	315	282	271	2.89
4696	429	370	369	3.89
5424	522	450	452	4.75
5890	629	540	544	5.71
6603	720	625	628	6.58

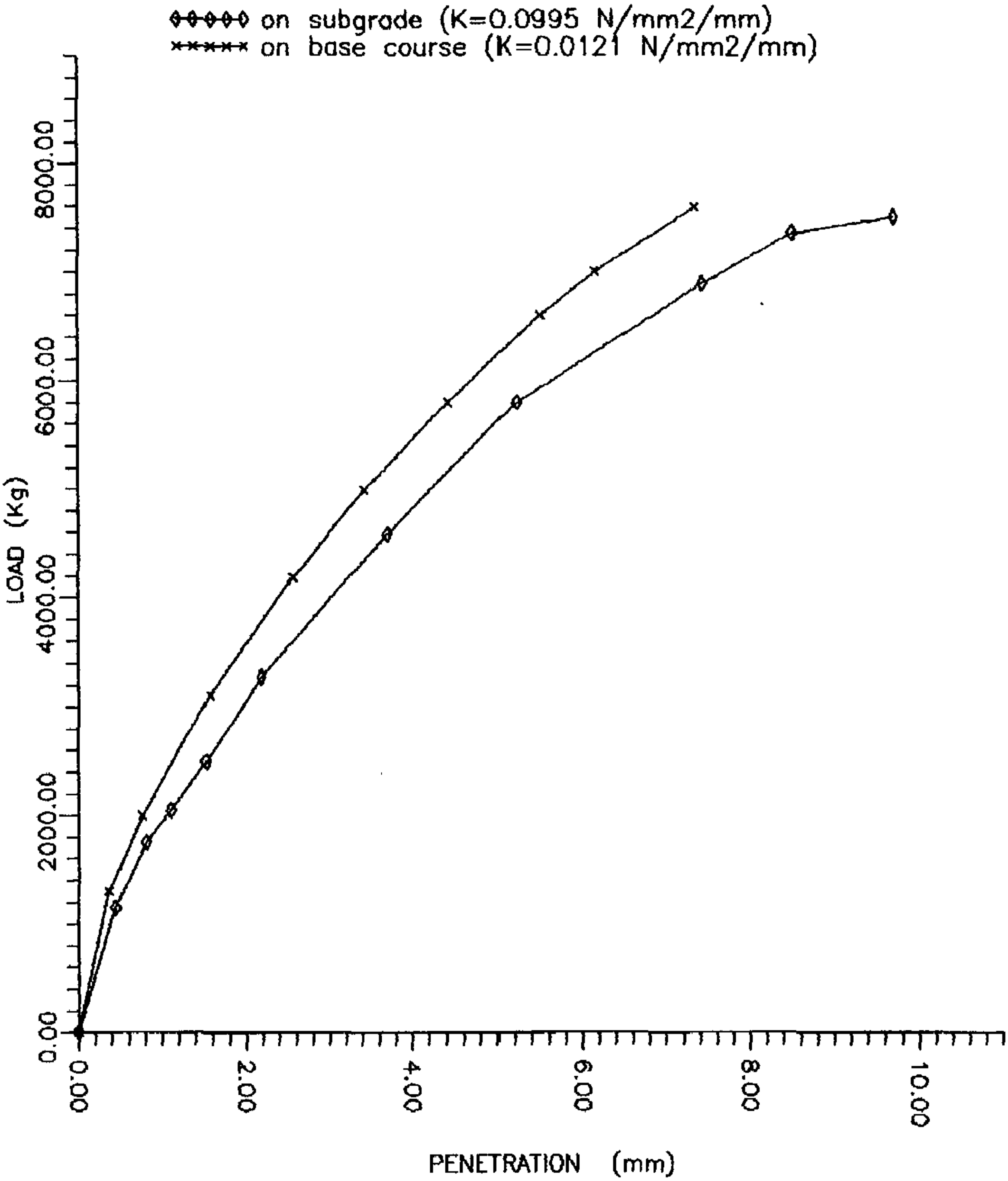
TABLE-23

PLATE LOAD TEST RESULTS ON WBM OVER REINFORCED SOIL SUBGRADE WITH 2% FIBRE CONTENT

LOAD (kg)	DIAL-GUAGE 1	DIAL-GUAGE 2	DIAL-GUAGE 3	AVERAGE SETTLEMENT (mm)
1302	58	27	25	0.37
2000	105	62	60	0.76
3100	204	129	139	1.57
4185	310	220	315	2.57
4991	408	302	429	3.42
5797	518	382	540	4.43
6603	635	477	617	5.51
7006	715	515	700	6.16
7595	808	682	711	7.34



LOAD-DEFORMATION CURVE ON REINFORCED SOIL SUBGRADE AND BASE COURSE
Fig-27



LOAD-DEFORMATION CURVE ON REINFORCED SOIL SUBGRADE AND WBM BASE COURSE ABOVE IT

Fig-28

The results show that the K-value of the WBM base course increase significantly when it is laid over a reinforced soil subgrades with 2% fibre content as compared to the unreinforced soil subgrades. It is recommended that studies must be taken up to evaluate the performance of the different types of pavement when laid over fibre reinforced soil subgrades.

Studies should also be done to evaluate the effect of weight fraction, aspect ratio, and soil granulometry on the characteristics of fibre reinforced soil using different types of soils and different types of natural as well as synthetic fibres.

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