Geosynthetics Asia'97, 26–29 November, Bangalore, India

CHARACTERISTICS OF THE BRECODRAIN FOR SOFT SOIL CONSOLIDATION

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ABSTRACT

The production process as well as some critical properties of a new PVD, namely BRECODRAIN (patent applied for), are reported here in some detail. In order to view this development in proper perspective, comparisons are made with another drain made of natural fibres- namely FIBREDRAIN - and two commercial synthetic drains. The study puts the BRECODRAIN in a more favourable light vis-a-vis the FIBREDRAIN. However both these products compare poorly with synthetic PVDs barring probably in the ecological aspect and in sensitivity to deformation.

INTRODUCTION

Consolidation of soft soil involves subjecting the soil mass to a compressive load with a view to effect a reduction in intergranular space. An application of surface load results in a consequent increase in pore pressure in the saturated soil (1). This can be brought down quickly by draining out water under pressure from the pore spaces, thereby transferring the compressive stress to the soil grains. The traditionally economical method of accelerating the consolidation process has been the use of vertical sand filled cylindrical holes known as sand drains. Such drains are however liable to clog during the course of consolidation as well as undergo shear deformation during settlement, affecting the overall function. Moreover the drains might under circumstances may act as columns preventing complete vertical settlement.

The Prefabricated Vertical Drains (PVDs), starting with Kjellman's cardboard drains in 1937 and subsequently produced from diverse synthetic materials in various geometrical shapes in cross-section, have become increasingly popular in view of their consistent qualities, ease of transport and installation, non-clogging potential, high discharge capacity and low smear effect (2). In principle such PVDs exhibit a filtering sheath of very fine spunbonded material encasing a core made from diverse synthetic materials and having forms and shapes varying from one manufacturer to another. Detailed studies pertaining to properties and performance of such drains have been carried out during the past fifteen years (3-11). Rathmayer et. al.(12) have compiled the quality requirements as well as the test methods for such drains. Consequently, during the past fifteen years, PVDs have almost completely replaced sand drains in pre-consolidation of soft soil and over the past decade about 250 million metres of synthetic drains have been installed (13).

The performance of synthetic PVDs is however expected to be adversely affected through kinking of their relatively rigid cores (14) caused by settlement of soil. However, the possible deleterious effect of long term presence of synthetic hydrocarbon materials on the health of soil is also a matter of concern. However, the highly flexible and ecofriendly FIBREDRAIN (15) does not suffer from such drawbacks. But the process of production of this drain, involving cutting of long strips of jute fabrics, placing of coir yarns at intervals on a double layer of such strips, folding back the fabric strips on the coir yarns and sewing them together by three longitudinal stitches, is multistaged and laborious. The rate of production in expected to be low and controlled variation of quality such as of discharge capacity or of permittivity must be quite difficult. Overcoming these deficiencies of FIBREDRAIN has been the motivation behind the development BRECODRAIN.

THE CONSTRUCTION OF BRECODRAIN

The BRECODRAIN sports a triaxially braided sheath of jute yarns encasing a large number of coir yarns. The braiding jute yarns are wound in required numbers on a flanged bobbin (Fig. 1) which are then mounted on the spindles of the Braiding machine (Fig. 2). The spindles move in predetermined serpentine tracks of the machine thus creating an ordered entanglement resulting in the body of the sheath. Owing to the orientation of yarns, this sheath is incapable of withstanding the axial force during installation without deforming appreciably. Hence a set of axial yarns are also fed to the Braiding machine from suitable packages. These yarns would not take part in the braiding process but would only get trapped in the sheath thus remaining perfectly aligned along the direction of force to be exerted on the drain during installation. It is clear from the above that count and quality ratio of braiding jute yarns can be selected with cost as the primary goal parameter, as the force exerted on the braiding yarns during the production process is very low (less than 20 N) and once in the sheath, they do not have to bear any load. The count, quality ratio and number of axial yarns have however to be so chosen that the strength requirement of the product can be satisfied. Obviously there is a great flexibility in regard to this aspect as well.

In addition to the jute yarns listed above, the braiding machine is also supplied with the required number of coir yarns at the braiding point. The sheath of jute forms continuously around this sheet of coir yarns and the whole assembly is pressed flat and wound continuously on a Batching roller. The winding process is so designed that on achieving the desired length, the roll may be doffed without stopping the machine. The heart of the Braiding machine is situated at the braiding point and here the width of the drain can also be adjusted to any desired value and maintained absolutely trouble-free. Similarly the permeability of the sheath can also be controlled to any required value by suitably choosing the number of braiding yarns in a strand (Fig. 3) and the braid angle, the latter being in turn dictated by the rate of take-up and tension in the braiding yarns. The discharge capacity of the drain can obviously be adjusted by controlling the thickness and number of coir yarns in the core. While varying all these factors one has to keep in mind that the final thickness of the product would be approximately equal to the sum of the thickness of individual coir yarns and six times the thickness of braiding jute yarns. Hence depending on the constraints of the installing rig, the thickness of the drain can also be adjusted to the required value. It is clear from the construction process of BRECODRAIN described in the foregoing that

- the dimensional properties such as width, thickness and weight in g/linear meter of the drain can be varied at will, and
- the strength, permeability and discharge capacity can also be varied easily as per requirement.

A very important consideration for designing the sheath is the opening size of the pores. The pore of a braided construction is shaped like a parallelogram (Fig. 4) and its exact dimensions would exhibit a distribution depending on the C.V.% of the thickness of braiding jute yarns. The mean pore size can be controlled by regulating the extent of packing of yarns. However, jute yarns exhibit considerable swelling when in contact with water and 75% of the pore volume of the fabric sheath exhibited in Fig. 5, would get modified to those of Fig. 6 after one hour of immersion in water. This reduction in pore size would be accompanied by an increase in thickness and reduction in permeability. Thus the effective values of permeability and opening size distribution of the jute sheath after installation in soil would also depend on the swelling potential of the braiding jute yarns. The

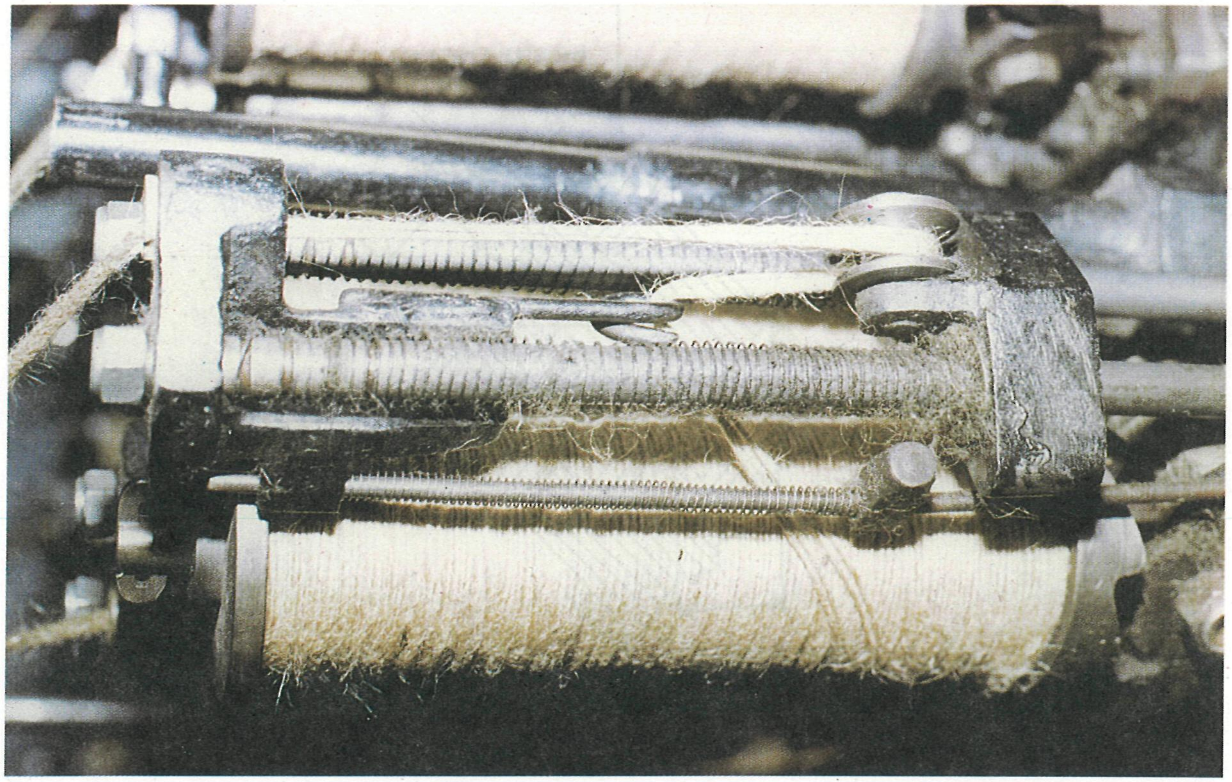


Fig. 1: View of flanged bobbin of the braiding machine.

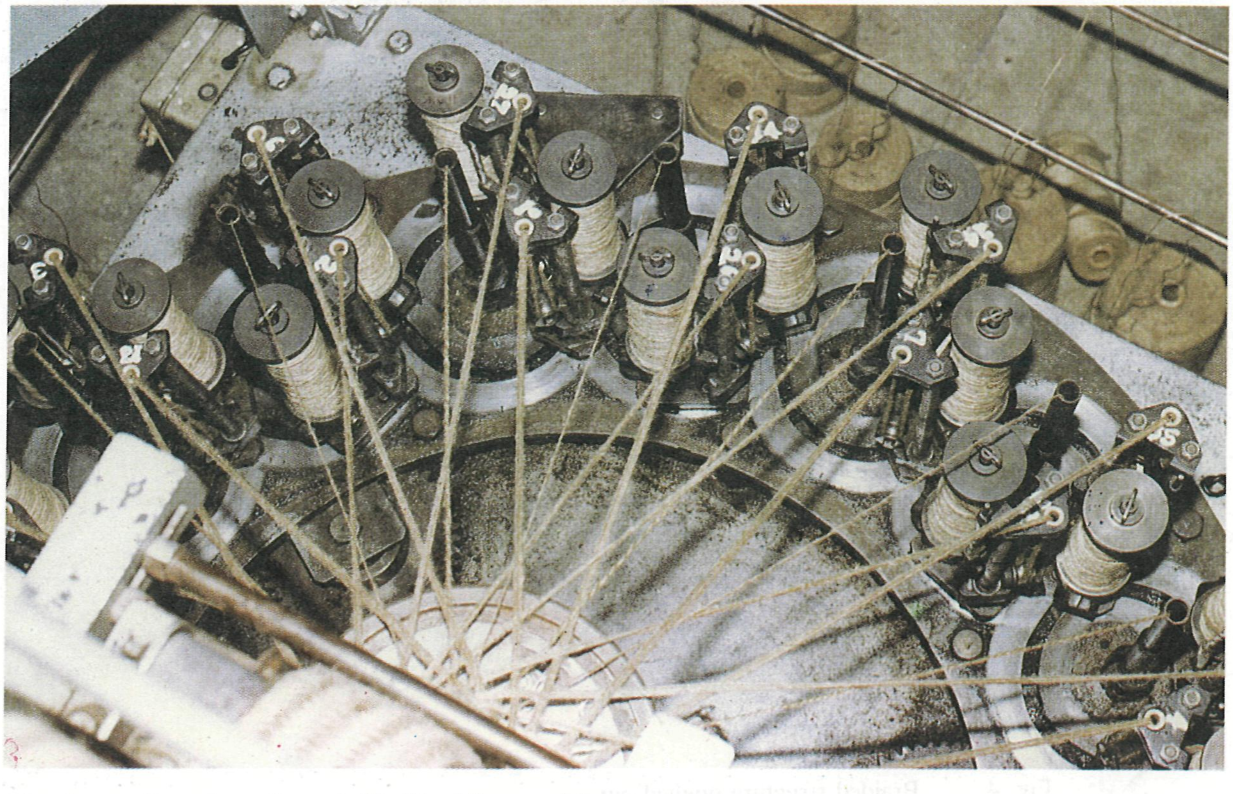


Fig. 2: Top view of one half of braiding machine.

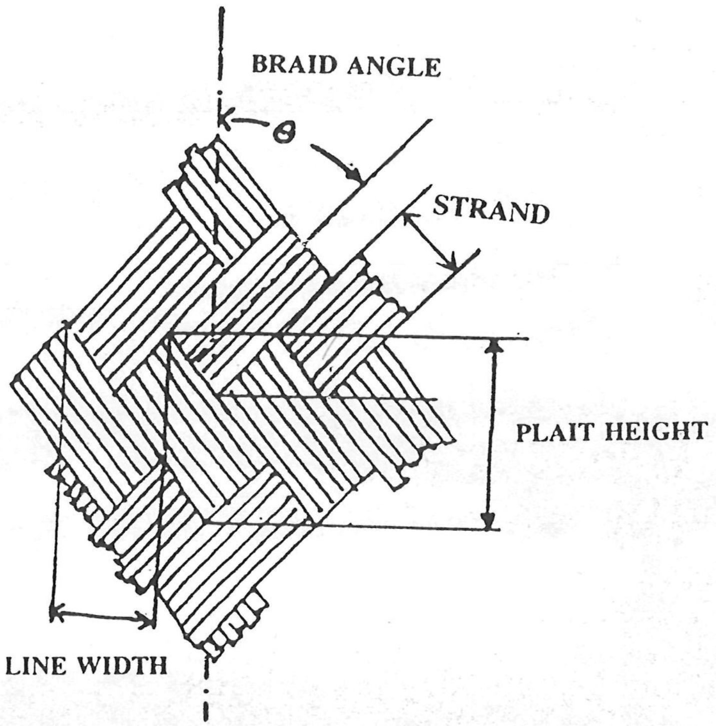


Fig. 3: Plan of braided structure (regular braid).

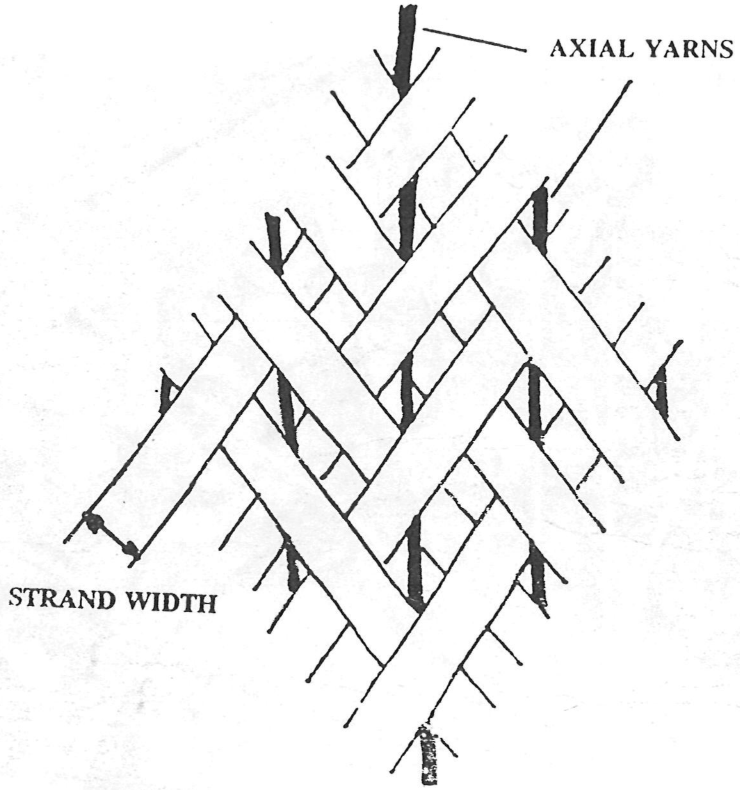


Fig. 4: Braided structure opened out.

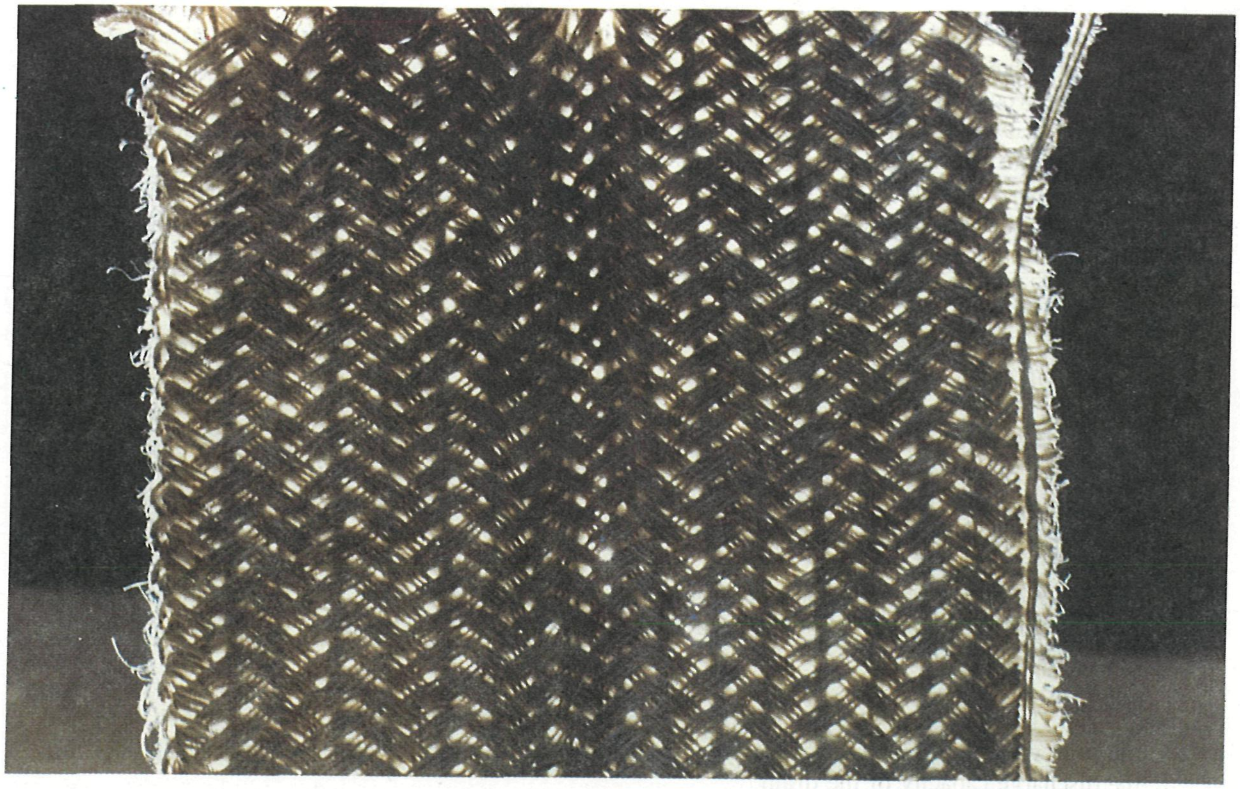


Fig. 5: Braided sheath in dry condition.

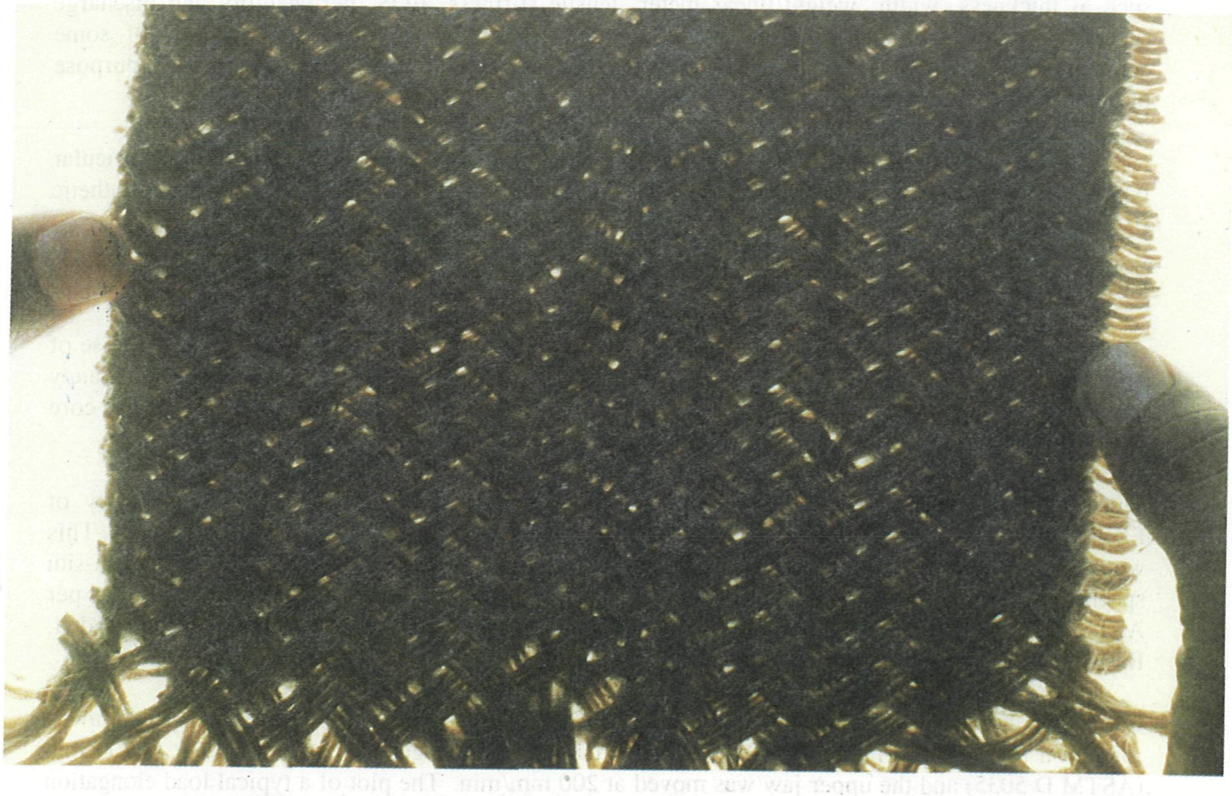


Fig. 6 : Braided sheath in wet condition.

increase in thickness on swelling would however be nullified to a large extent by the lateral pressure on the sheath exerted by the surrounding solid mass, causing a flattening of the yarns. This additional flattening would in turn result in a further reduction of permeability and opening size. Thus it is apparent that while adjusting packing of the jute braiding yarns on the machine, sufficient margin has to be left for the subsequent dimensional changes in the jute yarn in saturated state so that the resultant permeability and pore openings of the sheath do not fall below critical values, dictated by the nature of the soil in which the drain is going to be encapsulated.

CHARACTERISATION OF BRECODRAIN

A doctoral programme is currently under progress aiming to relate structural variables of the BRECODRAIN with its functions.

The structure of a braided material is characterised by braid angle, strand width, plait height and line width (Fig. 3). Assuming homogeneity of the material and circular cross solution of the constituent yarns it is possible to relate weight/linear meter, thickness, tensile stiffness and pore radius of the braided sheath with its structural variables (16,17).

A 2/2 twill (regular braid) was chosen to construct the sheath, since this interlacement allows lot of mobility to the yarns for lateral deformation (swelling and flattening) as well as results in a thick filtering layer.

The function of coir yarns within the sheath being to generate fine capillaries for channelising the pore water, the selection of the type and number of coir yarns plays a crucial role, influencing the discharge capacity of the drain.

Consequently a series of BRECODRAIN samples have been generated in the laboratory of IIT Delhi varying the structure of the sheath as well as coir yarns of the core and various properties such as thickness, width, weight/linear meter, tensile stiffness, EOS, permeability and discharge capacity are being evaluated. Concurrently, properties of FIBREDRAIN as well as of some commercial synthetic drains are also being evaluated under similar conditions of test for the purpose of comparative evaluation.

This paper is limited to discussing results of laboratory tests carried out with one particular type of BRECODRAIN and comparing the same with those of FIBREDRAIN and some synthetic PVDs.

TEST RESULTS OF THE BRECODRAIN (4-16)

An assembly of four (4) jute yarns each of 30 lb was wound on Flanged bobbins for the purpose of braiding. Nine single strands and nine double strand yarns, each of 30 lb were arranged alternately and fed to the braiding zone as axial yarns. Sixteen (16) coir yarns each of 270 mpk were fed as core yarn. The dimensional specifications of the ensuing drain in dry state are listed in Table - I.

The pressure dependent thickness profile of sheath as well as of the sheath core assembly of FIBREDRAIN as well as of BRECODRAIN (4-16) were studied in dry as well as in wet states. This would help in establishing correlation between the dry state specifications and the effective in-situ specifications. The pressure was varied stepwise between 0 - 10 kPa and thickness measured as per ASTM D1777. Subsequently, pressure was released in steps and recovered thickness values recorded. Results of these tests are plotted in Fig.7 to Fig.14.

For testing the tensile stiffness value of the BRECODRAINS on Instron Tensile Tester, special jaws - based on roller grip principles (18) - had to be fabricated. The gauge length was kept at 200 mm (ASTM D 5035) and the upper jaw was moved at 200 mm/min. The plot of a typical load elongation profile is shown in Fig. 15.

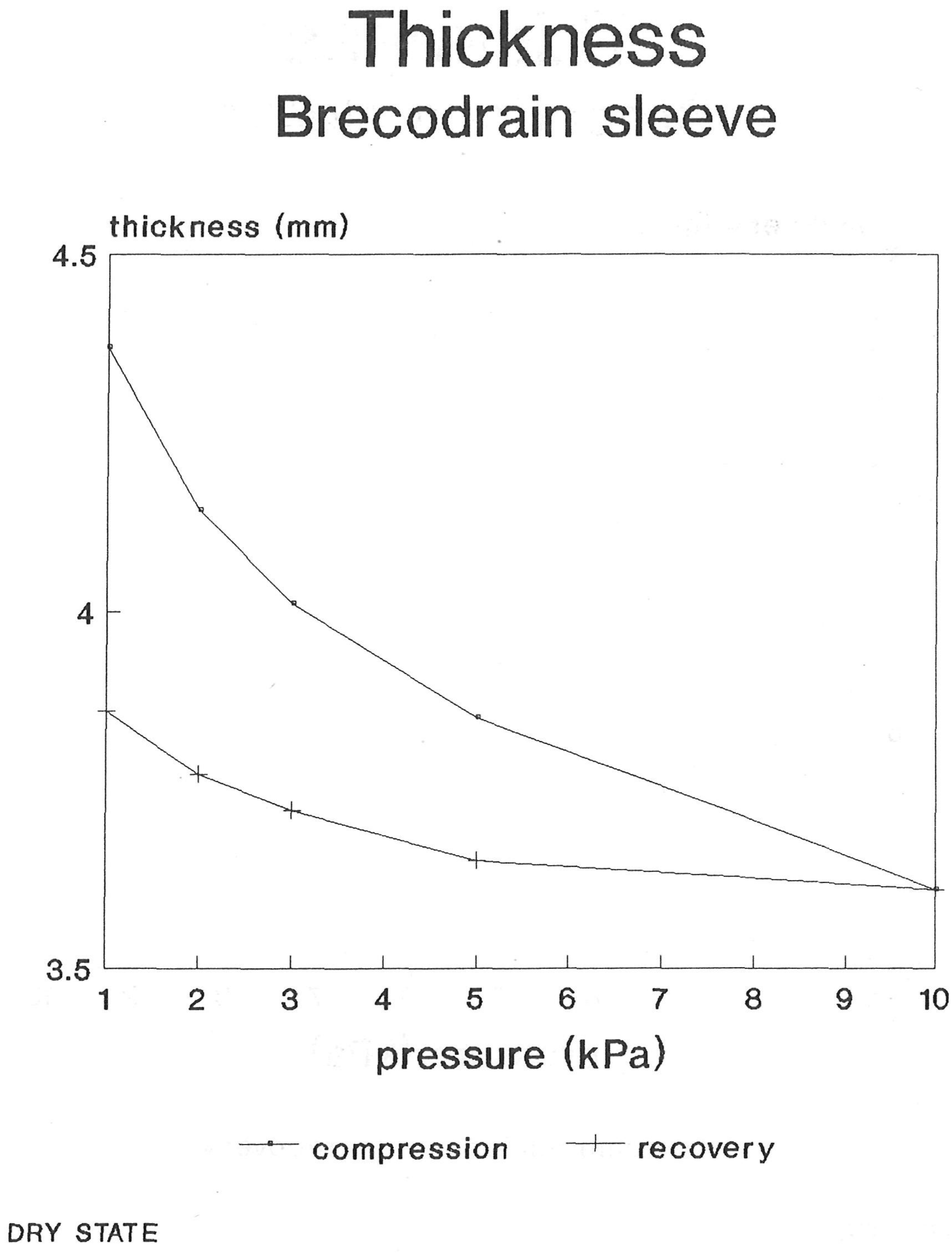


Fig. 7 : Effect of pressure on thickness of braided sheath in dry state.

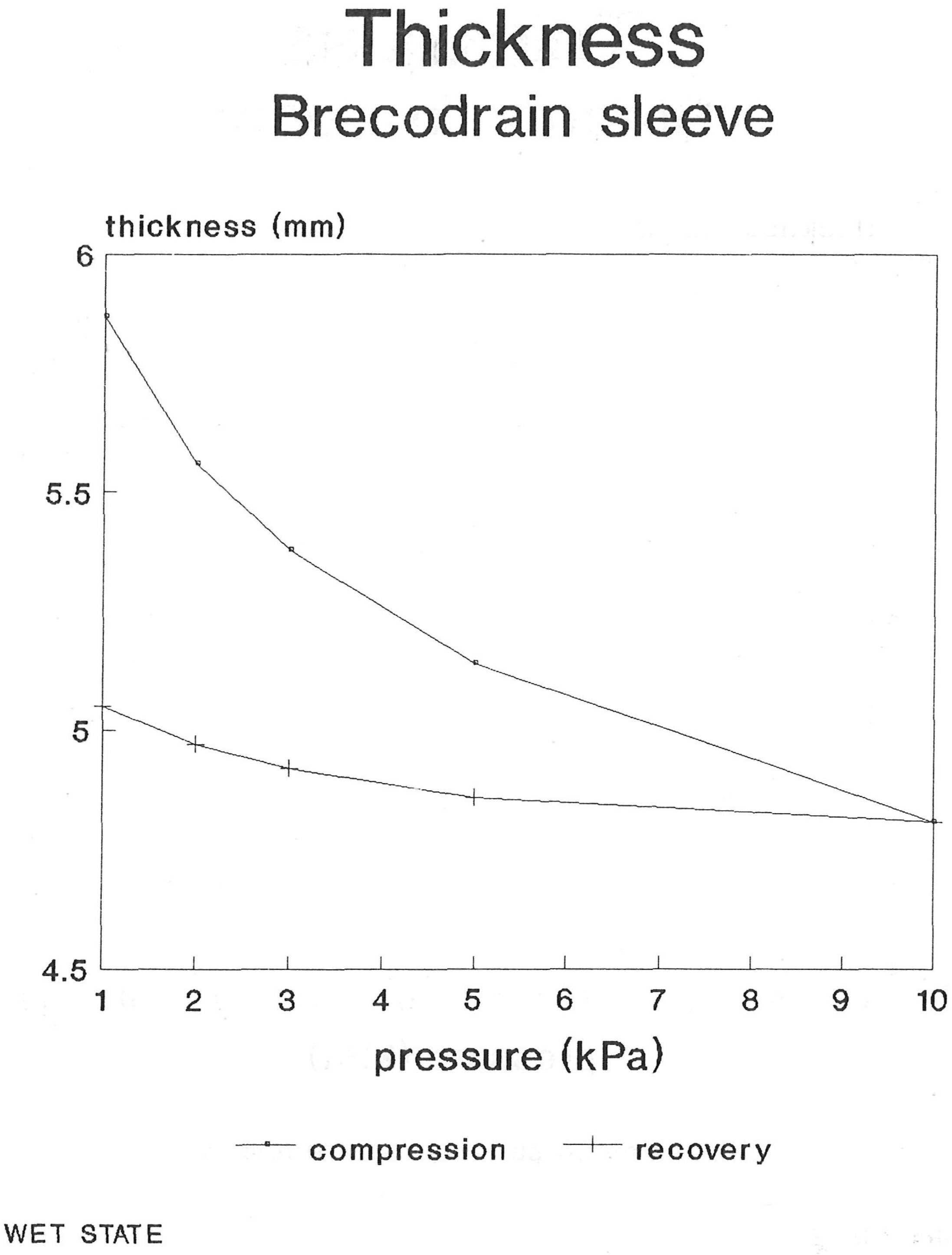
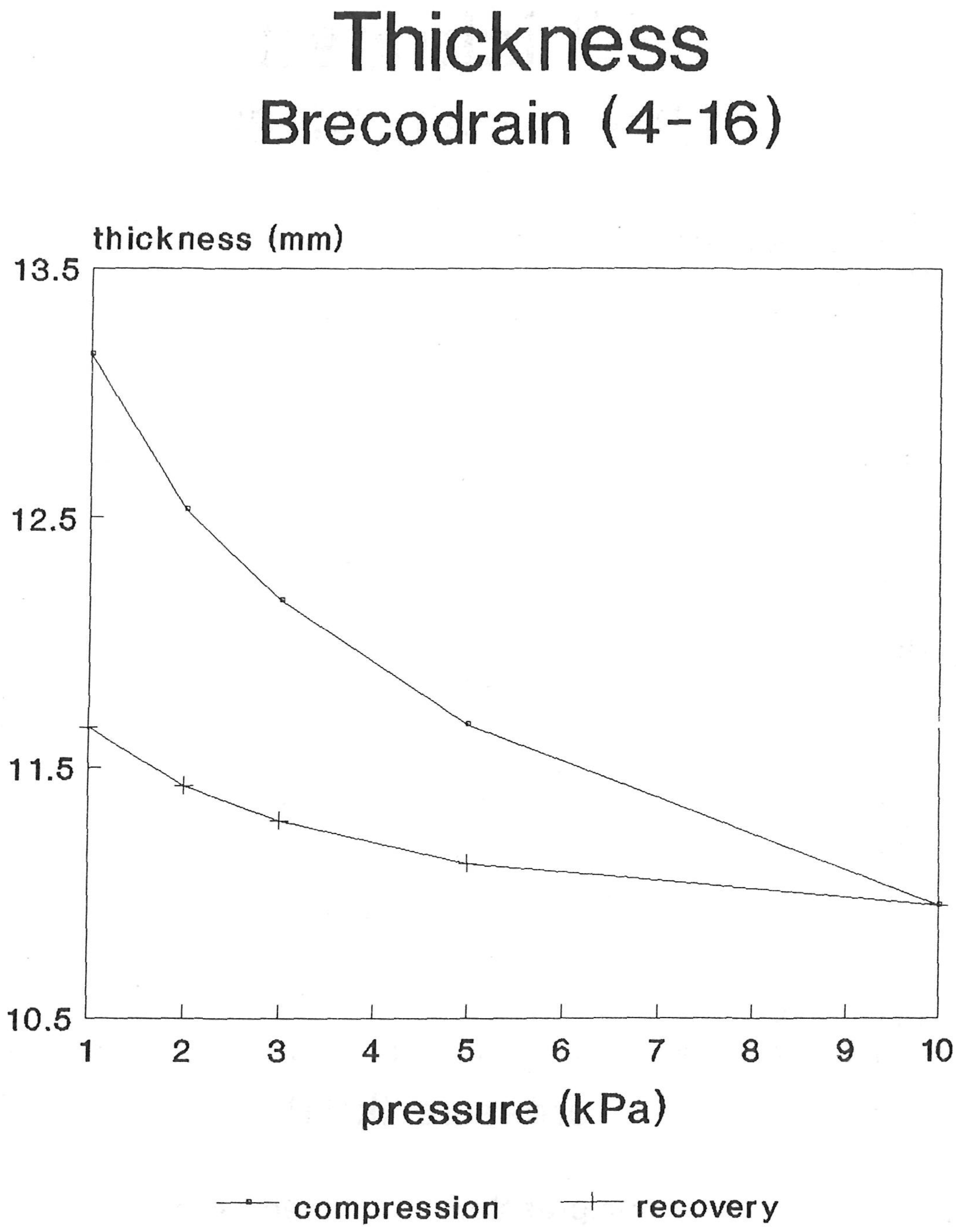
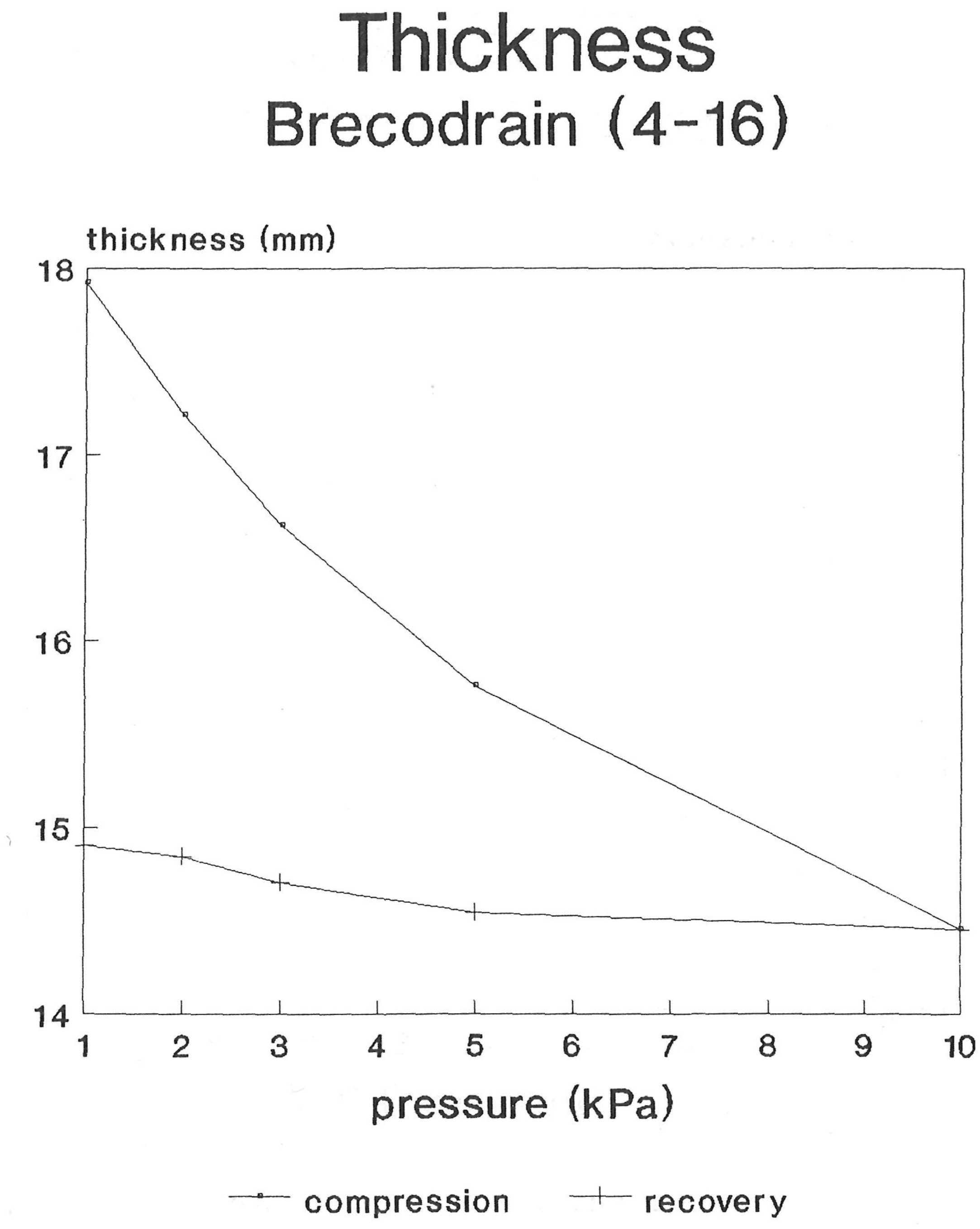


Fig. 8 : Effect of pressure on thickness of braided sheath in wet state.



DRY STATE

Fig. 9 : Effect of pressure on thickness of BRECODRAIN in dry state.



WET STATE

Fig. 10 : Effect of pressure on thickness of BRECODRAIN in wet state.

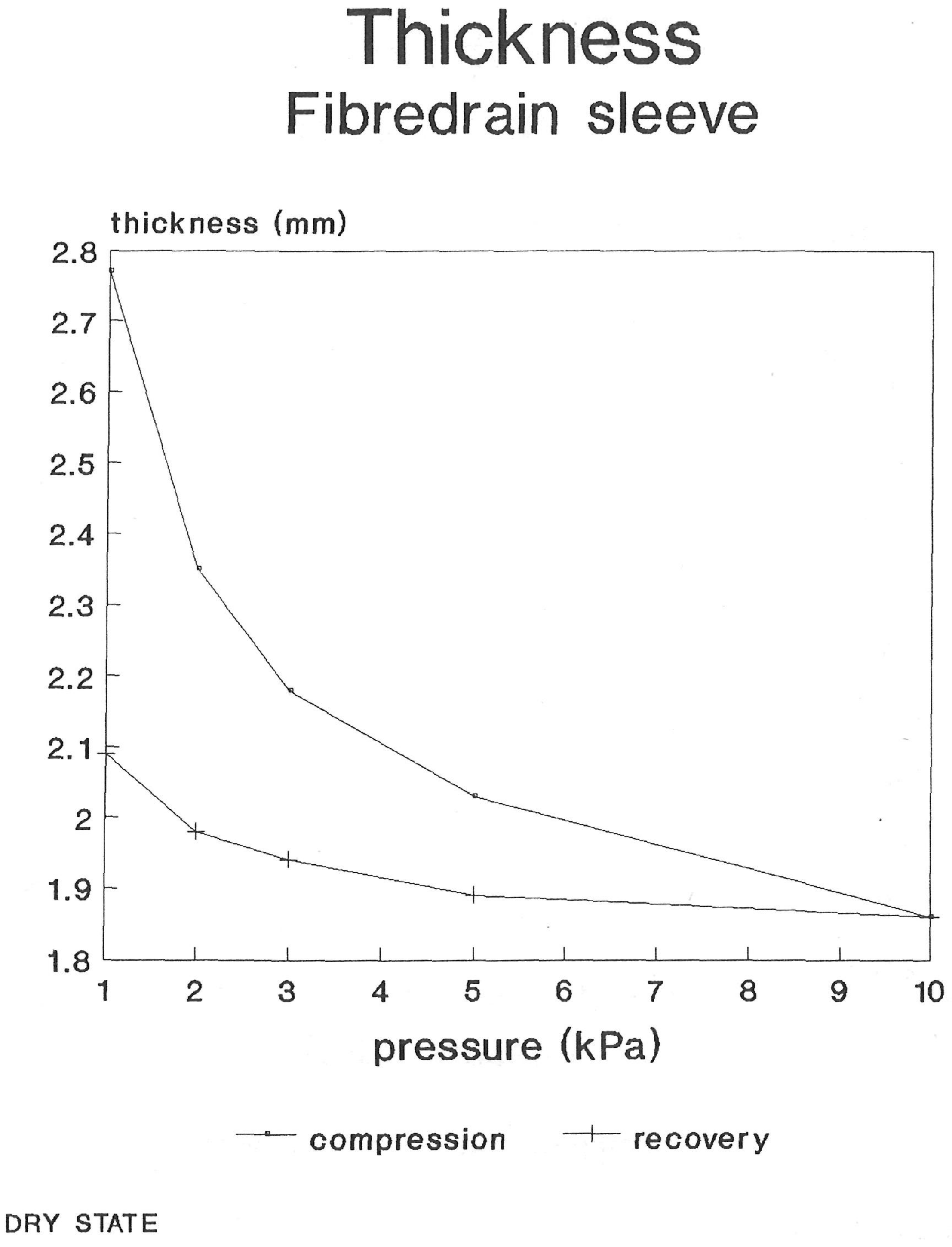


Fig. 11 : Effect of pressure on thickness of filter sleeve of FIBREDRAIN in dry state.

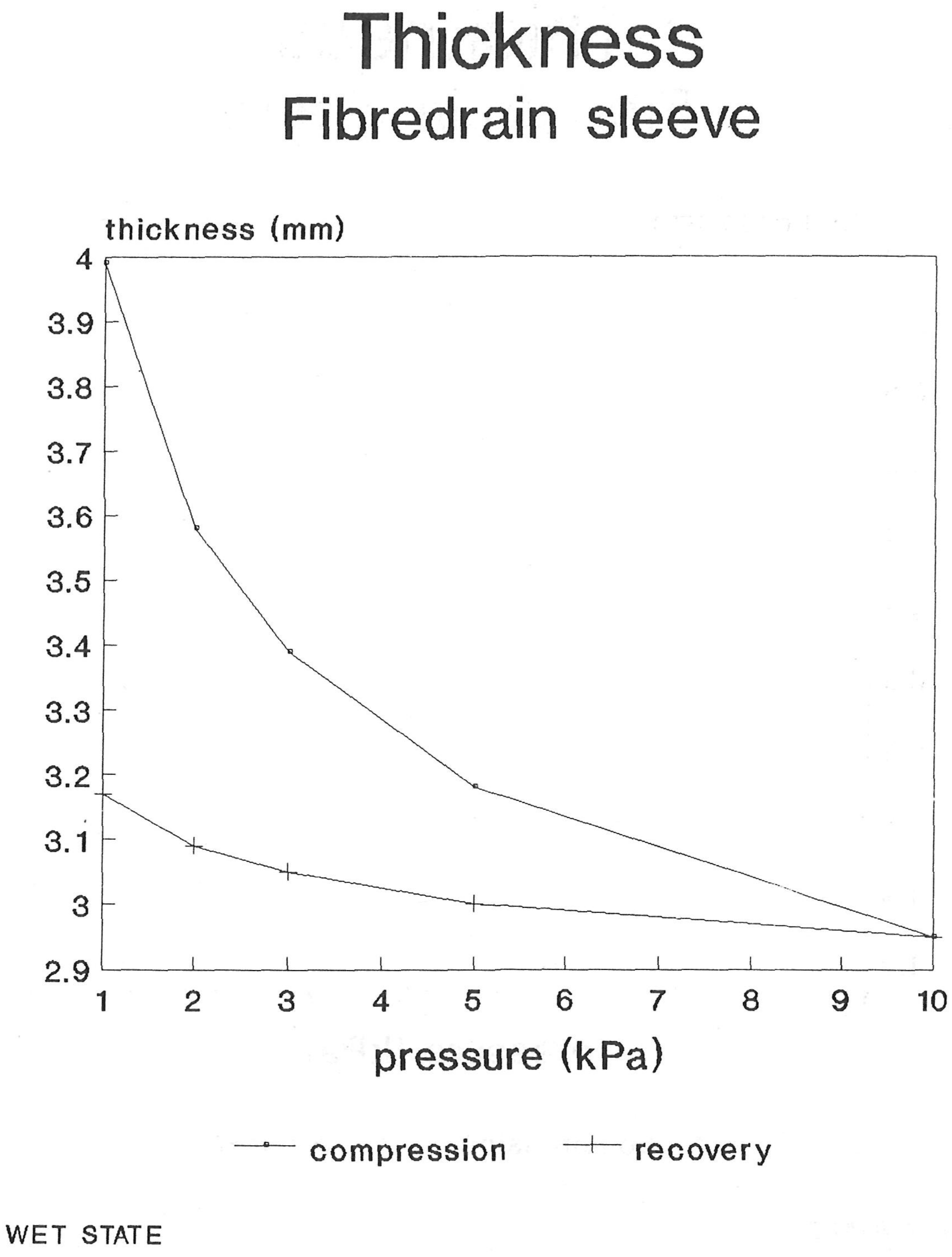


Fig. 12 : Effect of pressure on thickness of filter sleeve of FIBREDRAIN in wet state.

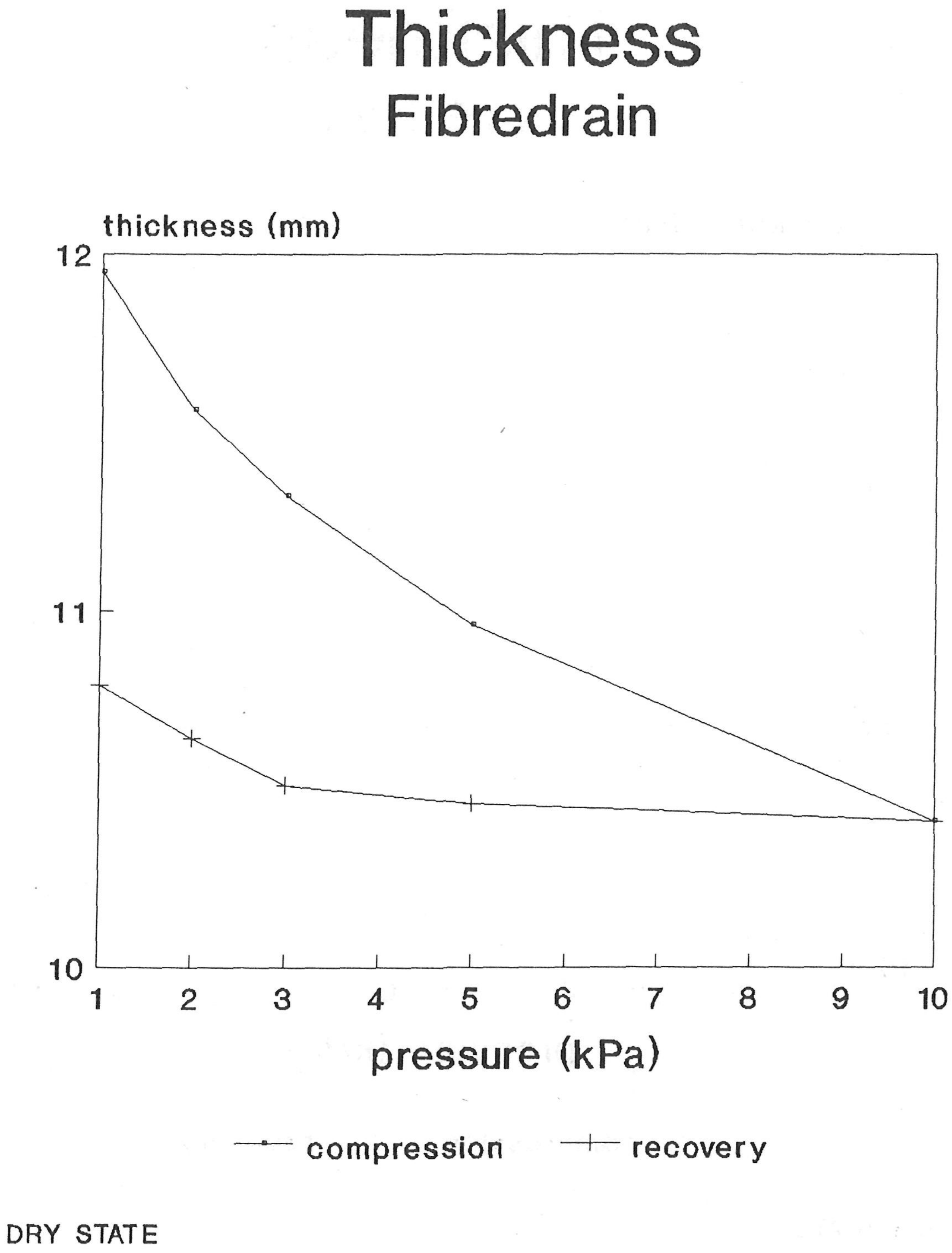


Fig. 13 : Effect of pressure on thickness of FIBREDRAIN in dry state.

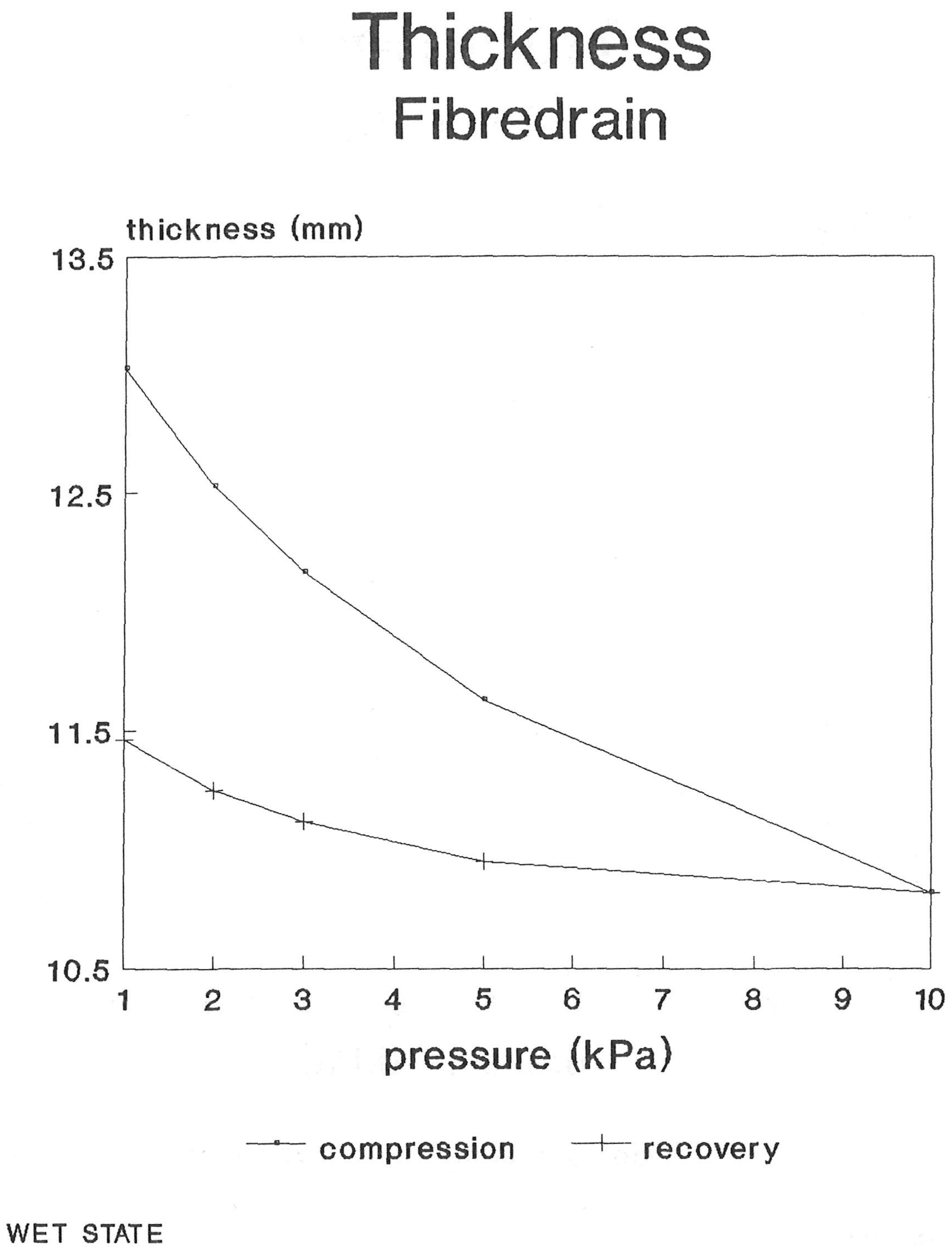


Fig. 14 : Effect of pressure on thickness of FIBREDRAIN in wet state.

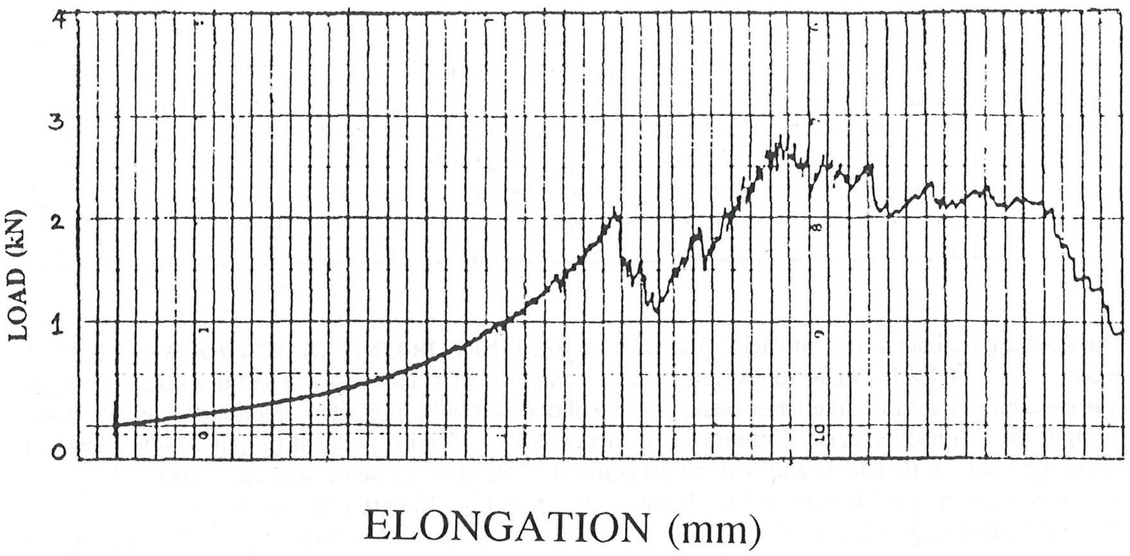


Fig. 15 : Load-elongation behaviour of BRECODRAIN (4-16).

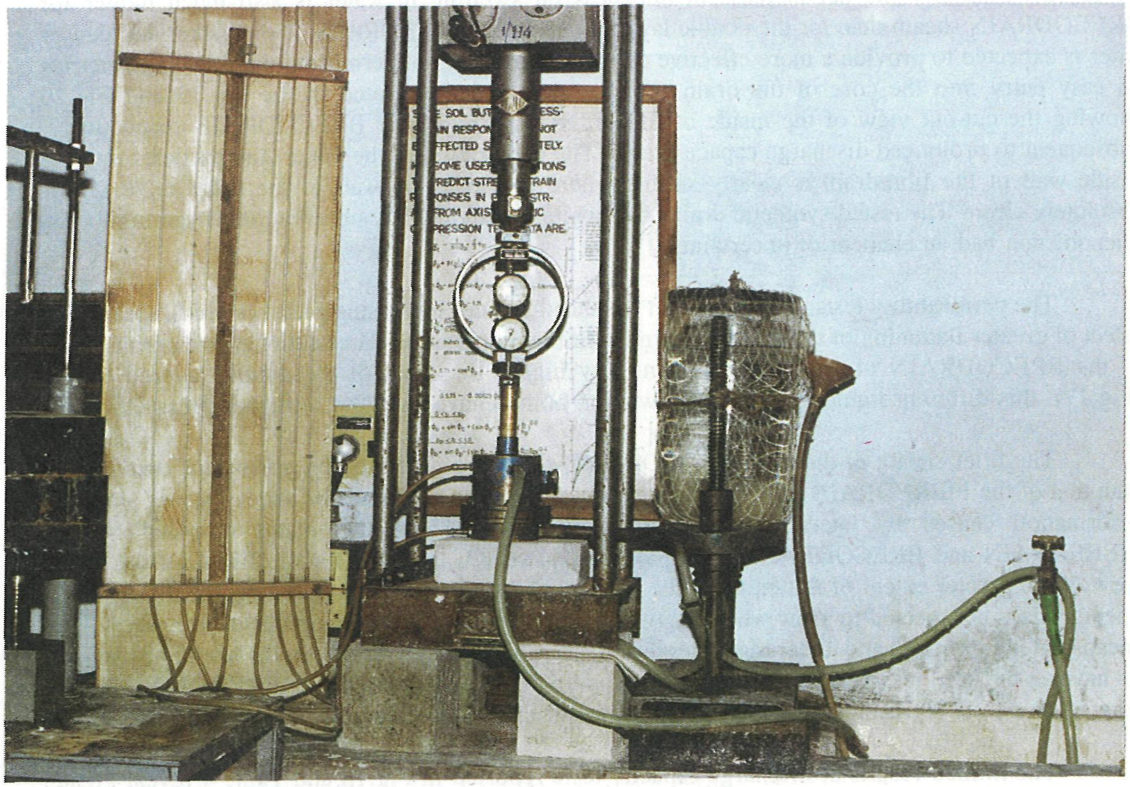


Fig. 16 : The permeameter.

The EOS values (O_{90} and O_{95}) of the braided sheath and of the double layer of Burlap of the BRECODRAIN (4-16) and of the FIBREDRAIN respectively were determined on a hydrodynamic sieving tester working on the principles outlined by Venkatappa Rao (19). A typical particle size distribution of sand used for the tests is given in Table 2. The sand was graded into groups of different sizes and a known grade was used in the tester at any instant. The EOS value of fabric corresponds to the size of that particle mass of sand, 95%, (or 90%) of whch is retained by the fabric under consideration after the completion of test. Results of the EOS tests are given in Table 3. The permeability tests of the sheaths of BRECODRAIN (4-16) and of the FIBREDRAIN were carried out as per ASTM D4491-35 on a Permeameter, shown in Fig. 16. Results of this test are plotted in Fig.17.

The discharge capacity tests of BRECODRAIN (4-16), FIBREDRAIN, COLBONDDRAIN CX-1000 and of TENAXDRAIN VDR-100 were carried out as per ASTM D4716-87. The fully saturated drain was encased in kaolinite, the latter being slightly above its liquid limit. The amount of water flowing through the drain over various durations of time (30 s to 15 min) under different combinations of hydraulic gradient (0.1 to 1) and vertical pressure (0 - 350 kPa) are being studied in detail. A typical discharge capacity profile for the four drains is shown in Fig. 18 pertaining to the collection time of 30s and hydraulic gradient of unity. In order to explore the capillary action of the coir yarns and of the jute sheaths of the two drains made of natural fibres, a series of tests, under conditions mentioned in the foregoing, were carried out with progressive reduction in number of coir yarns. Results of this test are depicted in Table - 4.

DISCUSSION OF RESULTS

From similar values of thickness in dry state (Fig. 9 and Fig. 13) BRECODRAIN (4-16) becomes much thicker in wet state (Fig.10 and Fig.14) than FIBREDRAIN. This is due to the opposite nature of sheath and core in these two drains. Thus the sheath of the BRECODRAIN (4-16) is much thicker than that of FIBREDRAIN both in dry as well as in wet states (Fig. 7 & 8 and Fig. 11 & 12). Similarly the net increase in thickness on swelling in water is also much higher for BRECODRAIN sheath than for the double layered burlap of FIBREDRAIN. This thicker and denser filter is expected to provide a more effective depth of filtration, not permitting the fine clay particles an easy entry into the core of the drain. This is clearly demonstrated in the Fig.19 and Fig.20 showing the cut-out view of the inside of FIBREDRAIN and of the BRECODRAIN respectively, subsequent to prolonged discharge capacity tests. The penetration of the white clay particles into the inside wall of the fibredrain is clearly visible where as the inside wall of the BRECODRAIN is absolutely clean. The tested synthetic drains had white sheath and any observation pertaining to this phenomenon had an element of uncertainty.

The permeability tests, carried out on the sheaths under increasing pressure reveal clearly the effect of greater flattening of the braiding yarns with rise in pressure. Thus although the permeability of the BRECODRAIN (4-16) sheath was initially higher than that of the doubie layered Burlap (Fig.17), this difference quickly narrows down and both behave similarly at higher pressure.

The filter sheath of the wet BRECODRAIN (4-16) at high confining pressure is thus thicker than that of the FIBREDRAIN but equally permeable. Tests on opening size under varying stages of deformation caused by lateral pressure are planned ahead but the values recorded for the FIBREDRAIN and BRECODRAIN (Table 3) show lower O_{90} and O_{95} for the BRECODRAIN. In view of the greater extent of flattening of the braided sheath under rising pressure, the difference in opening sizes is expected to grow when the two drains are subjected to rising lateral pressures. Thus encapsulated in wet soil and under high lateral pressure, the BRECODRAIN (4-16) would be expected to have a thicker, less porous but an equally permeable sheath as the FIBREDRAIN. Similar comparative tests are being performed with sheaths of the synthetic drains.

The limited results of discharge capacity tests reported in Fig.18 and Table 4 reveal greater efficiency of BRECODRAIN (4-16) as compared to FIBREDRAIN. Both these forms of natural drains

TABLE 1 : Dimensional specifications of BRECODRAIN (4 - 16)

S.No.	Properties	Values
1.	Thickness in mm at 10 kPa pressure	11.0
2.	Width (mm)	Approx. 100
3.	Weight in g/linear meter	328
4.	Weight in g of braiding jute yarns/linear meter	233
5.	Weight in g of axial jute yarns/linear meter	27
6.	Weight in g of coir yarns/linear meter	68

TABLE 2 : The grain size distribution of Yamuna Sand

Particle size (μm)	Percentage finer
70	5
150	10
200	30
300	80
400	95
500	100

TABLE 3 : Comparison of functional properties of some selected PVDs

Variables	Unit	Desirable Minimum Values	COLBOND-DRAIN CX1000	FIBREDRAIN	BRECO-DRAIN (4-16)
1. Material composition Sheath Core	 - -	 - -	 PET Fibre PET Sheet	 Jute Fabric Coir Yarn	 Jute Yarn Coir Yarn
2. Width	mm	Nom ± 5%	91 - 96	92 - 93	approx. 100
3. Thickness at 20 kPa	mm	Nom ± 5%	4.5	9.0	10.2
4. Weight of material/ linear meter	g	-	80	136 + 96	260 + 68
5. Material strength at 1st break point a) Strength b) Extension	 kN %	 >1 <10	 1.74 - 1.89 24.6 - 28.7	 4.5 4 - 5	 2 - 2.4 5 - 6
6. EOS of Sheath i) O_{90} ii) O_{95}	 mm mm	Depending upon type of soil $O_{90} < d_{85}$ soil	 0.075 - 0.14 0.08 - 0.175	 0.425 - 0.6 0.6	 0.3 >0.3
7. Permeability at 50 mm water head and 2 kPa pressure	mm/s	$>50\ k_{soil}$ (0.1)	1.15 - 1.64	0.41	0.54
8. Discharge capacity at 50 kPa and hydraulic Gradient = 1	ml/s		46.2	13.1	22

TABLE 4 : Discharge capacity of different drains measured at unit hydraulic gradient

Pressure (kPa)	FIBREDRAIN					BRECODRAIN (4-16)				
	4 Coir	3 Coir	2 Coir	1 Coir	Only sleeve	16 Coir	12 Coir	8 Coir	4 Coir	Only sleeve
0	40	28.1	34.2	18.4	23.9	53.5	46.3	47.3	40.7	20.7
50	13.1	4.8	5.1	2.2	1.4	22.0	19.5	10.1	6.6	4.3
100	5.8	2.0	2.1	0.5	0.5	12.4	6.4	4.5	2.1	1.7
150	3.5	1.0	1.3	-	-	6.0	3.6	2.2	1.5	-
200	2.0	0.7	0.6	-	-	3.7	1.2	1.3	1.0	-
250	1.4	-	-	-	-	2.7	0.9	-	-	-
300	1.0	-	-	-	-	2.0	-	-	-	-
350	0.8	-	-	-	-	1.5	-	-	-	-

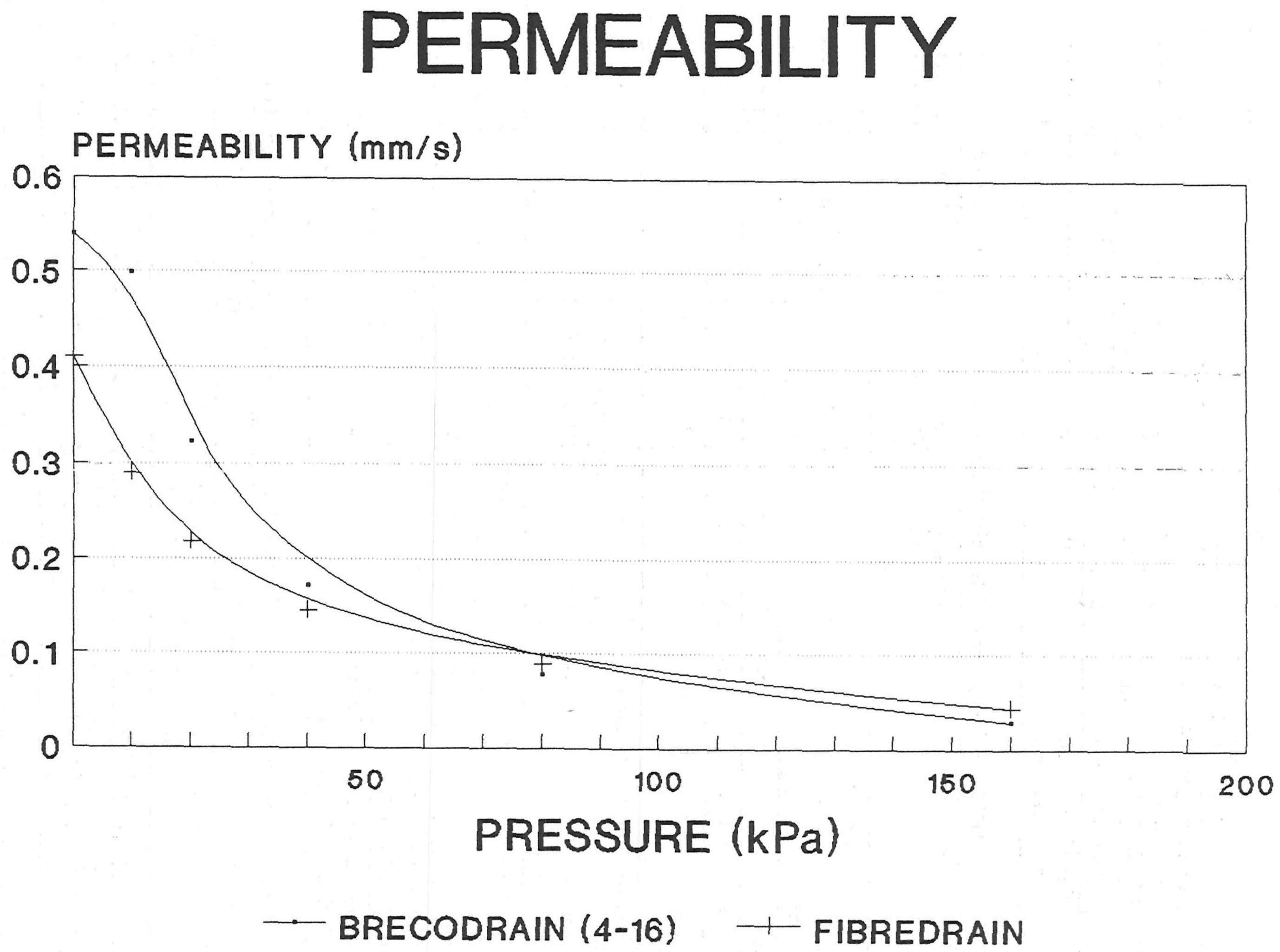


Fig. 17 : Permeability values of FIBREDRAIN and BRECODRAIN under different pressures.

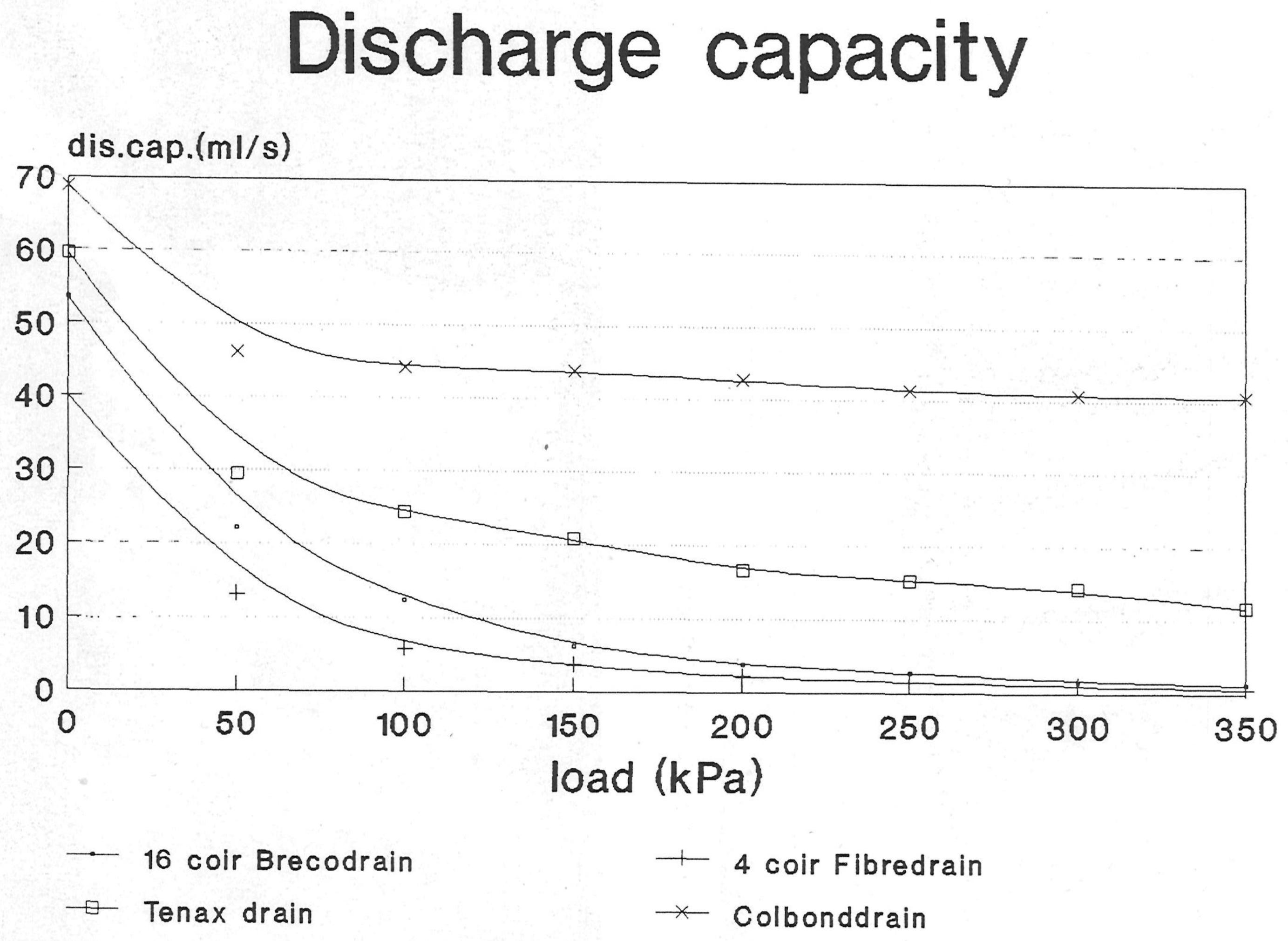


Fig. 18 : Discharge capacity values of natural drains (FIBREDRAIN and BRECODRAIN) as well as synthetic drains (TENAX and COLBONDRAIN) under varying loads.

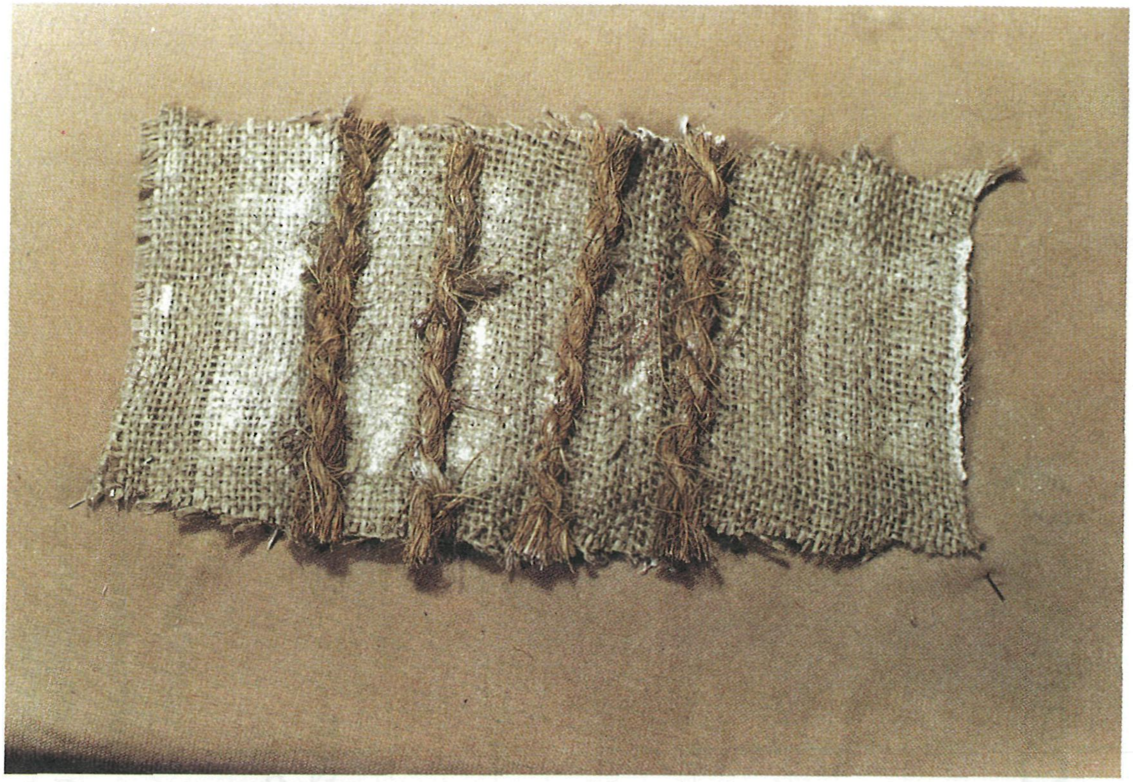


Fig. 19 : Cut-out view of FIBREDRAIN.

Fig. 20 : Cut-out view of BRECODRAIN.

are however quite inferior to the tested synthetic drains in terms of actual magnitude of discharge at any pressure as well as in respect of the reduction in discharge capacity with increasing lateral pressure. However, this superiority of synthetic drains in expected to be impaired through kinking caused by soil settlement. Tests in this regard are planned to be carried out in future. The data in Table 4 clearly demonstrate the role played by coir yarns in creating stable capillaries in the drain system. Thus though the sheaths by themselves can transmit some water along their plane, rising pressure quickly destroys capillaries of both braided sheaths as well as of the two layers of Burlap fabrics of FIBREDRAIN. The tougher fibres of coir yarns however resist these pressures to a much greater extent evidenced by the direct correspondence between discharge capacity at higher pressures and number of coir threads in the core. The thicker coir threads of FIBREDRAIN provide thick bundles of capillaries separated by zones of ineffective strips of drain caused by stitching of Burlap layers. On the other hand the much finer but more numerous coir threads in BRECODRAIN (4-16) provide thinner bundles of capillaries spread across the entire width of the drain. In fact 16 coir threads, each of approximately 4 mm diameter occupy about 64 mm lateral space in the drain core leaving a substantial space free. In these free spaces the inter yarn capillaries would be interrupted resulting in lowering of potential discharge capacity. One would infer from the foregoing that a complete packing of the core space with thin coir yarns would improve the discharge capacity of BRECODRAIN (4-16) further. Thick coir yarns would not only make the drain thicker and heavier but the dimension of inter yarn capillaries would also grow leading possibly to a difference in efficiency of capillary action. But this aspect needs to be probed systematically so as to arrive at the optimum combination of thickness and number of coir yarns in the core. In this respect the progressive flattening of the coir threads with increase in lateral pressure has also to be kept in view.

SUMMARY AND CONCLUSIONS

Results of a limited study on BRECODRAIN has been reported in this paper. While carrying out the investigations, control samples of a commercially used natural drain - namely FIBREDRAIN - and two types of synthetic drain - namely Colbondrain Cx1000 and Tenax VDR 100 - have been subjected to similar tests. As an outcome of this study the following important conclusions can be inferred:

1. The production process of BRECODRAIN ensures a very great flexibility in product design. One can easily change width, weight/ linear meter, permeability, strength, discharge capacity etc, of the drain by making alterations in the input material as well as in machine settings.

2. Behaviour of BRECODRAIN differs from that of FIBREDRAIN considerably owing to fundamental differences in nature of sheath and core. Properties of braided sheath undergo substantial changes under influence of moisture and pressure such that it becomes thicker and denser when encapsulated under pressure in wet soil. This improves in-situ filtration properties of BRECODRAIN. The flexible design of core permits optimisation of the discharge capacity of drain.

3. The continuity of the core of BRECODRAIN also compares favourably with that of four discreet capillary bundles in FIBREDRAIN.

4. The properties of synthetic drains are by far superior to those of drains made from natural fibres. However, the possible changes in their properties on kinking or the effect of their long term presence on ecology needs to be investigated to put the matter into proper perspective.

REFERENCES

1. Barron, R.A. (1948). Consolidation of fine-grained soil by drain wells. *Trans. ASCE. 2346*: 718 - 54.
2. Hansbo, S. (1979). Consolidation of clay by band shaped prefabricated drains. *Ground Engg.* 12(5): 16-25.

3. Akagi, T. (1994). Hydraulic applications of geosynthetics to filtration and drainage problems - with special reference to prefabricated band drains. Keynote lecture. *5th Int. Conf. on Geotextiles, Geomembranes and related Products*. Singapore. 3 : 99 - 119.
4. Bergado, D.T., Alfaro, M.C. and Balasubramaniam, A.S. (1993). Improvement of Soft Bangkok clay using vertical drains. *Geotextiles and Geomembranes*. 12 - 7 : 615 - 663.
5. Chen, R.H. and Chen, C.N. (1986). Permeability characteristics of Prefabricated vertical drains. *Proc. 3rd Int. Conf. on Geotextiles*. Vienna : 785 - 790.
6. deJager, W.F.J. and Oostveen, J.P. (1990). Systematic quality Control of Vertical drainage. *Proc. 4th Int. Conf. on Geotextiles, Geomembranes and related products*. Rotterdam : 321 - 326.
7. Hansbo, S. (1983). How to evaluate the properties of prefabricated drains. *Proc. 8th European Conf. on SMFE*. Helsinki : 621 - 626.
8. Holtz, R.D. (1987). Preloading with prefabricated vertical strip drains. *Geotextiles & Geomembranes*. 6 : 109 - 131.
9. Kremer, R.H.J., Oostveen, J.P., Van Weele, A.F., de Jager, W.F.J. and Meyvogel, I.J. (1983). The quality of vertical drainage. *Proc. 8th European conf. on SMFE*. Helsinki: 721-726.
10. Oostveen, J.P. and Troost, G.H. (1990). Discharge index tests on vertical drains. *Proc. 4th Int. Conf. on Geotextiles, Geomembranes and related products*. Rotterdam: 345 - 350.
11. Queyroi, D., Soyez, B. and Schmitt, P. (1986). Laboratory measurement of the discharge capacity of prefabricated band shaped drains. *Proc. 3rd Int. Conf. on Geotextiles*. Vienna: 1263 - 1268.
12. Rathmayer, H. and Heikki, K. (1992). Quality requirements of prefabricated string drains - Quality control and tests methods. Finn. road administration report. No. 22/92, Helsinki.
13. Rawes, B.C. (1997). Critical Parameters for Specification of prefabricated vertical drains. *Geosynthetics International*. 4(1) : 51-64.
14. Ramaswamy, S.D., Karunaratne, G.P. and Palit, S. (1993). Application of biodegradable jute geotextile filters. *Filters in Geotechnical & Hydraulic Engng*. Balkema Rotterdam : 285 - 291.
15. Lee, S.L. Karunaratne, G.P., Das Gupta, N.C., Ramaswamy, S.D. and Aziz, M.A. (1989). A vertical drain made of natural fibre for soil improvement projects. *Proc. Int. workshops on Geotextiles*. Bangalore : 271 - 276.
16. Brunnschweiler, D. (1953). Braids and braiding. *J. Text. Inst.* 44: p 666 - 692.
17. Brunnschweiler, D. (1954). The structure and tensile properties of braids. *J. Text. Inst.* 45: T55 - 76.
18. Myles, B. and Carswell, I.G. (1986). Tensile testing of Geotextiles. *3rd Int. Conf. on Geotextiles*. Vienna: 713 - 718.
19. Venkatappa Rao, G. (1996). Geosynthetics in the Indian environment. *Indian Geotechnical Journal*. 26 : 1 : 1 - 94.