Discharge Capacity of Natural Fibre Strip Drains using a New Drain Tester

G. Venkatappa Rao* and K. Balan†

Introduction

The evolution of the drainage system to accelerate the consolidation process of soft clay dates back to mid 1920's with the use of sand drains (Hansbo, 1993). It ultimately led to prefabricated strip drains of cardboard and geotextiles. Currently these drains are widely regarded as one of the most economical technique for the improvement of soft clays.

The primary function of the drains is to absorb the expelled water from the surrounding soil with a relatively low entry resistance and relatively large vertical discharge capacity. Hence the most important characteristics are the transverse and the longitudinal permeabilities, as well as the durability of these properties with time. These characteristics depend on the filter sleeve and the core components of the drain. Mechanical properties of drain are important for installation, and they may also play a role in performance.

This paper presents the details of a new drain tester developed for the determination of discharge capacity of pre-fabricated strip drains.

Literature Review

The water in the clay subjected to excess pore pressure under surcharge should permeate into the vertical drain and discharge as fast as possible to achieve the desired degree of consolidation. Both axial and filter permeabilities are important in this regard. The geotextile filter requires

* Professor and Head, Civil Engineering Department, Indian Institute of Technology, Delhi - 110016, India.

† Lecturer in Civil Engineering, Govt. Engineering College, Trichur, Kerala, India.

that the pore be sufficiently small to retain erodible soil particles and also has adequate permeability to allow the dissipation of pore water pressure from the surrounding clay. Adequate discharge capacity should be provided in a vertical drain for conveying the water along the drain. If the flow is obstructed, head drop caused by well resistance within the drain would retard the consolidation process. In this respect, the maintenance of discharge capacity when the drain is subjected to kinking due to settlement of soft layers between stiff layers in the soil profile, is important.

The effect of lateral pressure on the discharge capacity depends on several mechanical properties of the filter sleeve and core. In the short term, the extensibility under confining pressure of the filter primarily controls performance. If the filter is relatively extensible it can be squeezed in to the channels and thereby reduce the discharge capacity of the core. Therefore, any measurement of discharge capacity should be performed with the drain embedded in soil having permeability and stiffness characteristics similar to the soil at the site in question (Holtz et al., 1991).

As per Akagi (1994), quoting Kamon et al. (1994), the cros-sectional area of pre-fabricated drains when confined at a cell pressure of 320 kPa could reduce to 55 to 90% of that measured at a cell pressure of 5 kPa. It is also reported that the discharge capacity increases as specimen length increases under confining pressure of 5 kPa and 250 kPa with the hydraulic gradient, 'i' increasing from 0.5 to 2.5. On the other hand, the discharge capacity decreases upto a confining pressure of 300 kPa., as length increases, as reported by Broms et al. (1994).

TABLE 1 : Discharge Capacity Specifications for Strip Drains

Author / Agency	Specifications
Rathmayer and Komulainen (1992)	$10 \times 10^{-6}\ m^3/s$ at 100 and 200 mm water head
ASTM D-4716	$60 \times 10^{-6}\ m^3/s$; i = 0.5 and 360 kPa for straight
	$40 \times 10^{-6}\ m^3/s$ for folded
Kremer et al. (1983)	$\nless 25 \times 10^{-6}\ m^3/s$; i = 1 and 15 kPa
Za-chieh Moh et al. (1985)	$> 10^{-3}\ m/s$ in isolation 300 kPa
	$> 10^{-4}\ m/s$ in soil
Holtz (1987)	3 to $5 \times 10^{-6}\ m^3/s$ at 300-350 kPa

A general consensus on discharge capacity of pre-fabricated drains is not yet arrived at, as is evident from the literature. According to various schools of thought, the minimum required values of discharge capacity are as shown in Table 1.

Pre-fabricated Natural Fibre Drains

A flexible pre-fabricated "Fibre Drain" made out of jute fabric and coir ropes suitable for consolidating soft compressible soils, has been developed and field tested at Changi airport in Singapore and at other locations by Lee et al. (1989, 1994).

In view of the success of "Fibre Drain", new types of strip drains with natural fibres were developed and their discharge capacity was calculated.

Material Used

Woven jute, HDPE woven sacking, non-woven needle punched coir fabric (with and without scrim), jute ropes and coir ropes are used to fabricate strip drains of the following varieties :

Drain Type	Core	Filter sleeve
A	2 - layer needle punched coir fabric	One layer woven jute fabric
B	One layer needle punched coir fabric	One layer woven jute fabric
C	2 - layer needle punched coir fabric with scrim	
D	One layer needle punched coir fabric with scrim	2 - layers HDPE sacking
E	Four jute ropes	2 - layer woven jute fabric
F	Four brown coir ropes	2 - layer woven jute fabric

The drains Type A to D are the newly developed ones, Type E was developed by Indian Jute Industries Research Association, Calcutta and supplied to IIT, Delhi and Type F is fabricated in line with that of Lee et al. (1989). The detailed cross-sections of the drains are shown in Figs. 1 and 2.

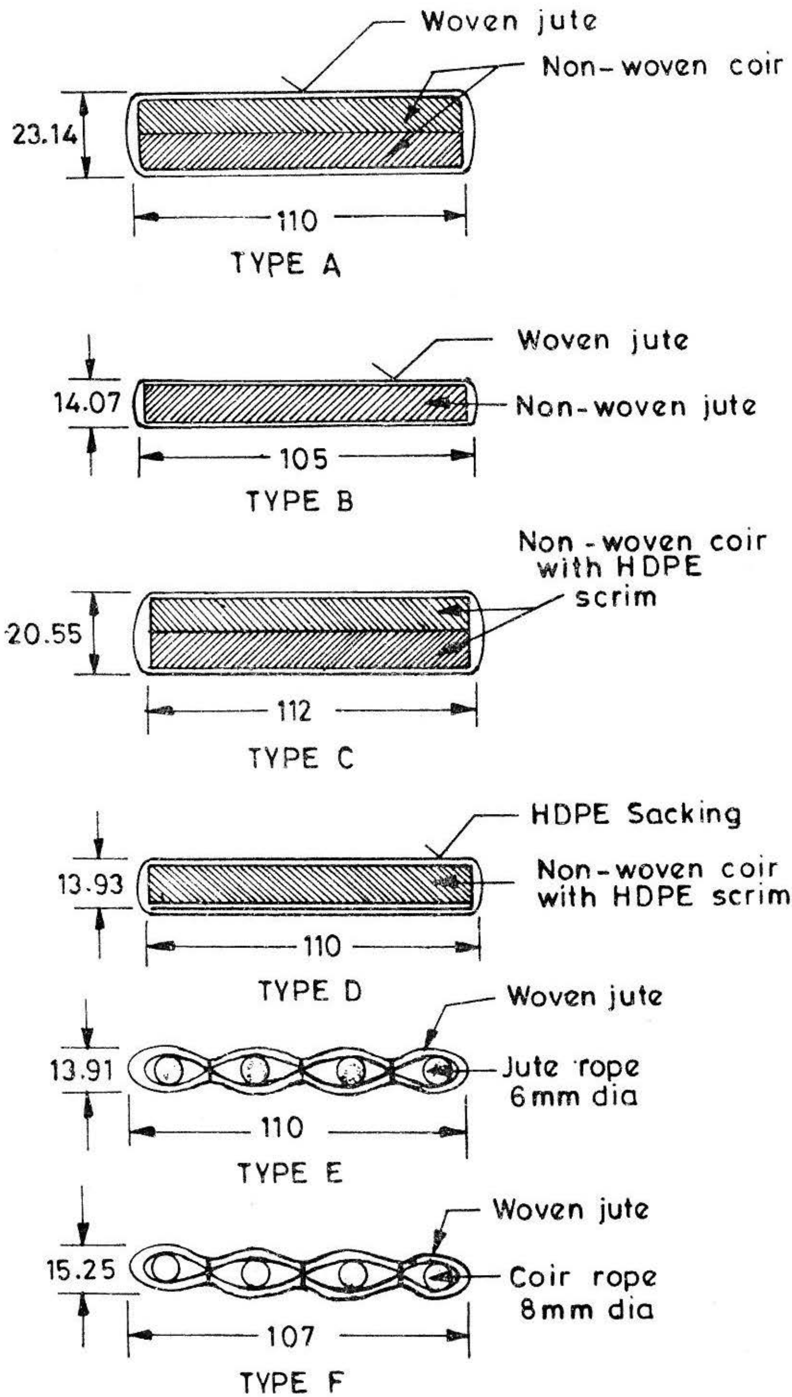

FIGURE 1 : Line Diagram of Cross-Sections of Strip Drains Developed with Natural Fibres

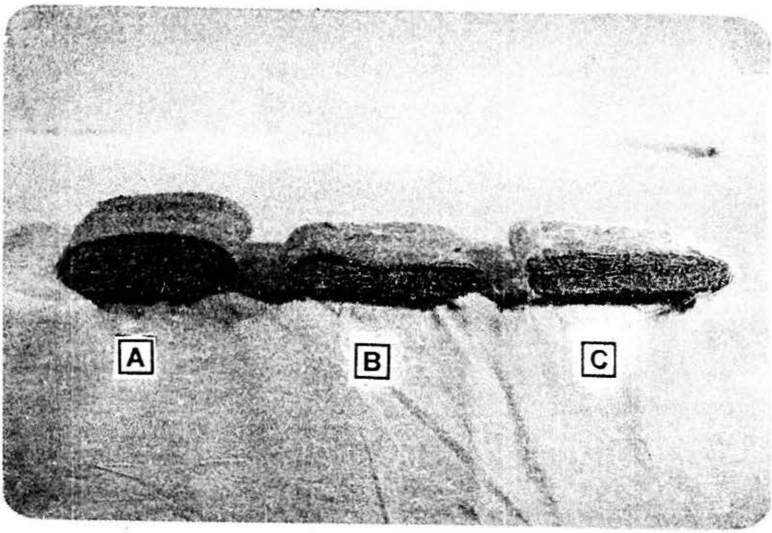

FIGURE 2(a) : View of Prefabricated Strip Drains with Natural Fibres. From Left to Right – Type A, Type B, Type C

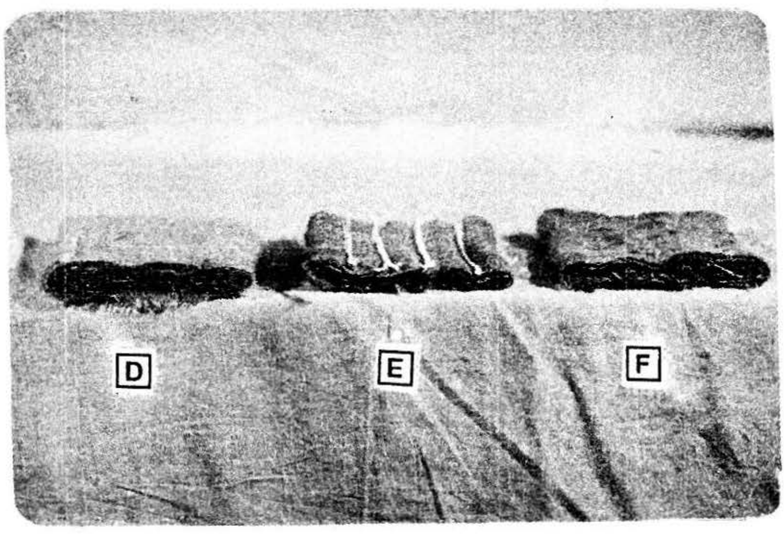

FIGURE 2(b) : View of Prefabricated Strip Drains with Natural Fibres. From Left to Right – Type D, Type E, Type F

The physical properties of these drains are presented in Table 2.

Soil used in the drain tester was Kaolinite clay. The physical properties of the clay are presented in Table 3.

Discharge Capacity Measurement

The in-soil discharge capacity of the drains was obtained in an apparatus developed in line with that of Broms et al. (1994). An assembly diagram of the apparatus is shown in Fig. 3a, and the various parts of the system are shown in Figs. 3b to 3d. A view of the components is presented in Fig. 4. The discharge capacity of the drains was measured under normal pressures upto 350 kPa.

TABLE 2 : Physical Properties of Strip Drains Used

Drain Type	Material		Mass per unit surface area (g/m^2)	Width (mm)	Thickness at 2 kPa (mm)	Mass per unit length (g / m)
	Core	Filter				
Type A	Two layer needle punched coir fabric	One layer woven jute fabric	2830	110	23.14	311
Type B	One layer needle punched coir fabric	One layer woven jute fabric	2450	105	14.07	257
Type C	Two layer needle punched coir fabric with scrim		2720	112	20.55	304
Type D	One layer needle punched coir fabric with scrim	Two layer HDPE scrim	1570	110	13.93	173
Type E	Four Jute ropes	Two layer woven jute fabric	3600	110	13.91	396
Type F	Four Coir ropes	Two layer woven jute fabric	4000	107	15.25	428

TABLE 3 : Properties of Kaolinite Clay

Liquid limit (%)	62
Plastic limit (%)	21
Plasticity index (%)	41
% Clay fraction	85
% Silt fraction	12
% Fine Sand fraction	3
Specific gravity	2.65

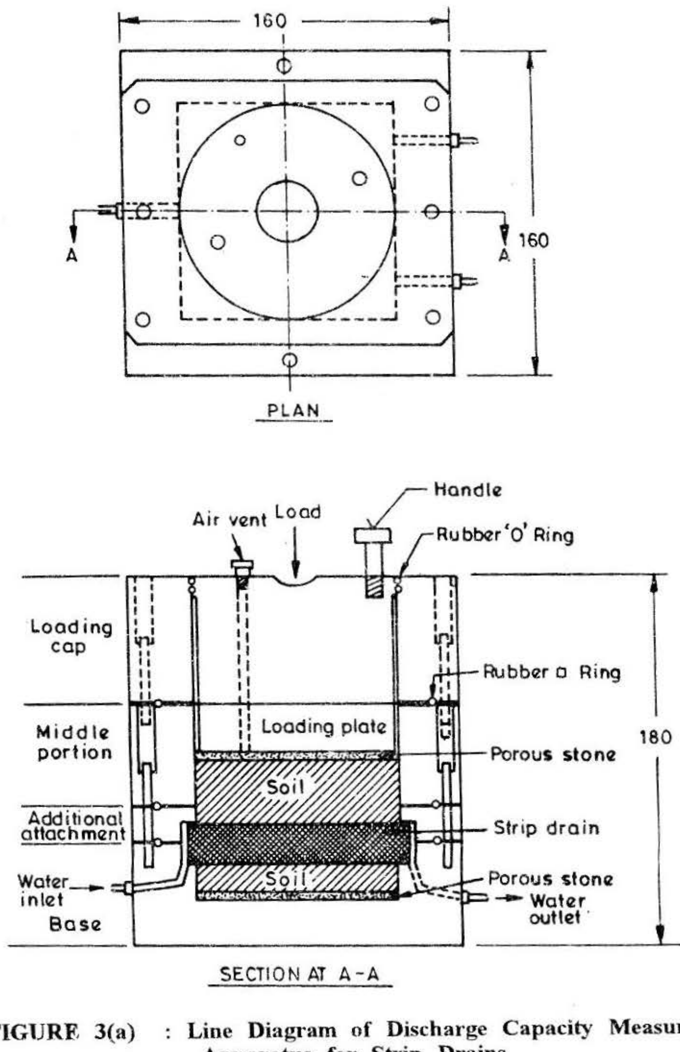

FIGURE 3(a) : Line Diagram of Discharge Capacity Measuring Apparatus for Strip Drains

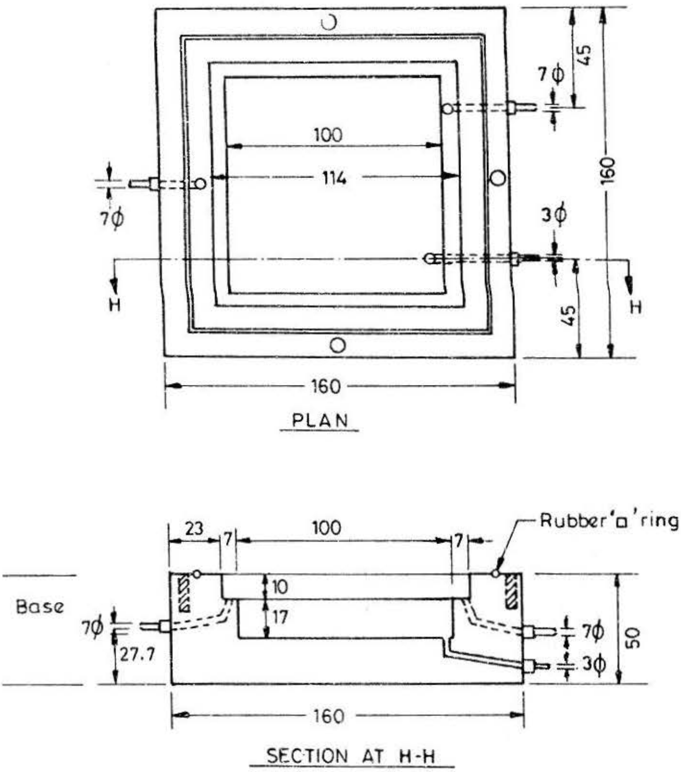

FIGURE 3(b) : Detailed Drawing of Base of the Drain Discharge Capacity Measuring Apparatus

The apparatus consists of the following components :

1. The base (Fig. 3b) is of square shape with outer dimensions 160 mm × 160 mm and a height of 50 mm with inner dimension of 100 mm × 100 mm × 7 mm. It has a 7 mm wide × 10 mm deep seating groove on the top to hold the drains of 114 mm length in horizontal position. Drainage holes of 7 mm diameter are provided on the base of the groove, on opposite sides for inflow and outflow of the water through drain. A drainage hole of 3 mm diameter is also provided at the bottom to enable consolidation of the clay at the bottom of the drain.

2. The middle portion (Fig. 3c) is of square shape with outer dimensions of 160 mm × 50 mm high and the inner dimensions of 100 mm × 100 mm × 50 mm high. This ensures that the drains having thickness upto 10 mm are held down in the base with the help of the rubber 'O' ring and the vertical bolts. When the thickness of the drain is more, an additional square attatchment of 160 mm × 160 mm outer

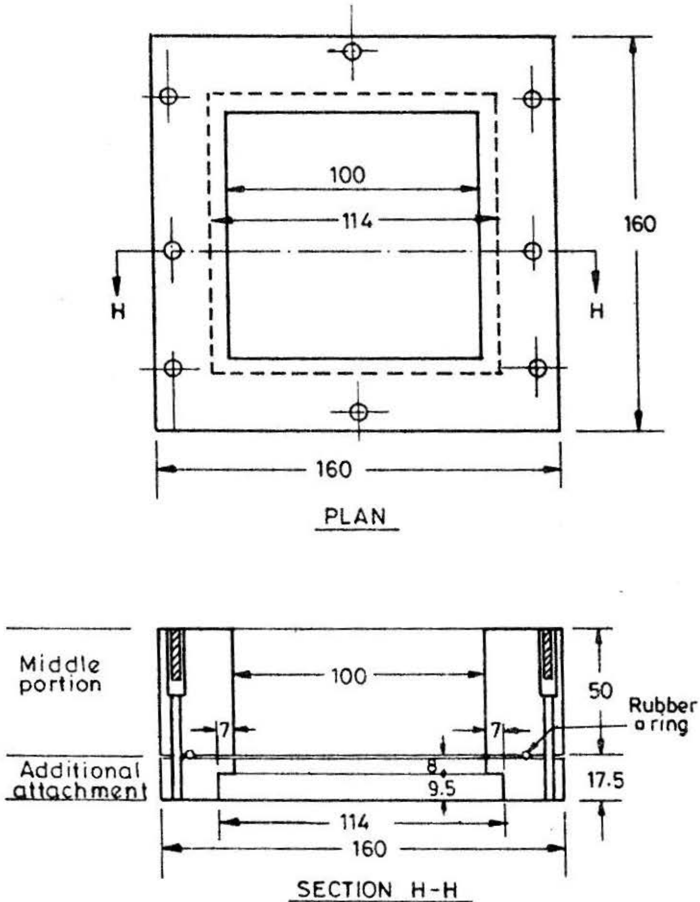

FIGURE 3(c) : Detailed Drawing of Middle and Additional Attachment of the Drain Discharge Capacity Measuring Apparatus

dimensions and 100 mm × 17.5 mm deep inner dimension, including a groove of 7 mm wide × 9.5 mm deep at the bottom is provided to give a proper seating to the drain.

3. A loading cap with guide system and air bleeder is provided at the top of the upper plate (Fig. 3d).

The detailed procedure adopted for discharge capacity was as follows :

i) De-air all the valves in the bottom half by circulating water.

ii) Place the porous plate and above this, a filter paper in the bottom portion.

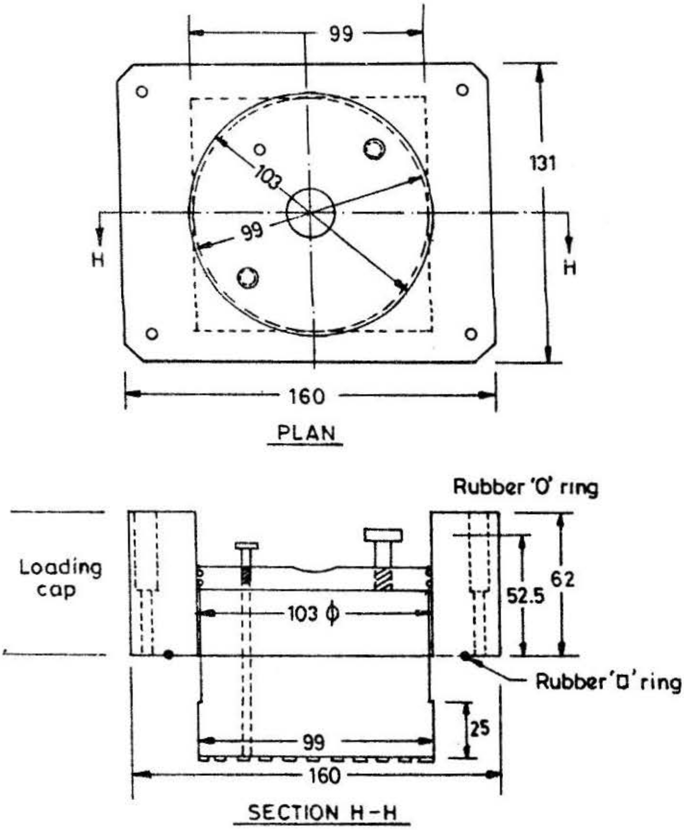

FIGURE 3(d) : Detailed Drawing of Top Portion with Loading Cap of Drain Discharge Capacity Measuring Apparatus

iii) The clay, mixed slightly above its liquid limit, is carefully hand remoulded in, without any air bubbles. Level the top of the clay layer along the bottom level of the groove provided for the drain.

iv) Place the drain, of 114 mm length and saturate for 24 hours on the top of the clay layer.

v) Cover the edges and side gaps (if any) of the drain with filter paper strips.

vi) Place the upper plate in position and tighten after placing a rubber □ - ring in between to prevent any leakage. De-air the drain by letting in the water through the inlet valve to fill up the top half. Allow the water to drain out through the outlet valve. Press the drain repeatedly, if necessary, to push out any entrapped air in the drain.

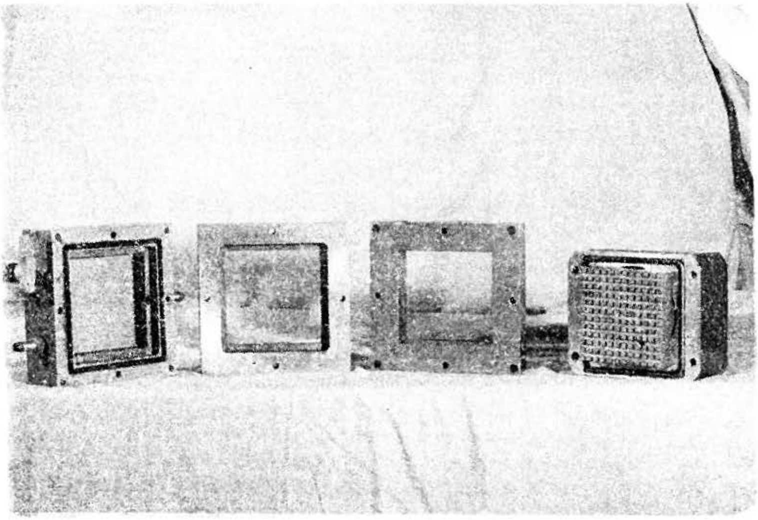

FIGURE 4 : View of the Drain Components of Discharge Capacity Measuring Apparatus

vii) With a thin layer of water above the drain, fill the clay in the upper half ensuring that there is no entrapped air, upto a height of 250 mm.

viii) Place filter paper followed by porous plate over the clay layers.

ix) Fix the loading cap with the guide assembly, keeping the air bleeds open, above the upper half with a □ - ring in between.

x) Place the entire set up in loading frame.

xi) Allow the set up to saturate by closing the outlet valves and opening the air bleeder.

xii) De-air the system. Close the air bleeder and allow drainage to take place through the drain for four hours.

xiii) Measure the quantity of discharge through the drain at different gradients without any loading.

xiv) Apply the first increment of load (50 kPa) on the drain set up and allow the clay to consolidate under the load for about one hour.

xv) Repeat steps (xiii) and (xiv) till the load reaches 350 kPa.

Results and Discussion

The discharge capacity of the drain at hydraulic gradients of 0.5 and 1.0 are shown in Figs. 5 and 6 at different normal pressures upto 350 kPa. The discharge capacity decreases with increasing normal pressure in an exponential manner upto 200 kPa, caused by the reduction in thickness of the drain. Table 4 presents a summary of discharge capacity measurements for drain Type A. Figures 7 and 8 show the variation in discharge capacity with hydraulic gradient at a normal pressures of 100 kPa and 350 kPa respectively. The variation of discharge capacity with hydraulic gradient is almost linear. The discharge capacity of the drain at 100 kPa for various hydraulic gradients is presented in Table 5.

It is observed that Type D drain has a higher discharge capacity followed by Types A, B, C, F and E drains. The low discharge capacity of the drain Type E may be due to the presence of jute rope as core which absorbs more water rather than assisting in carrying out the water. the discharge capacity obbtained from the new test set up has been compared with the specifications available in literature (Table 1) and are tabulated in Table 6. The model studies conducted using these drains (Balan, 1995) revealed poor performance by drain Type E confirming the results from the new drain tester.

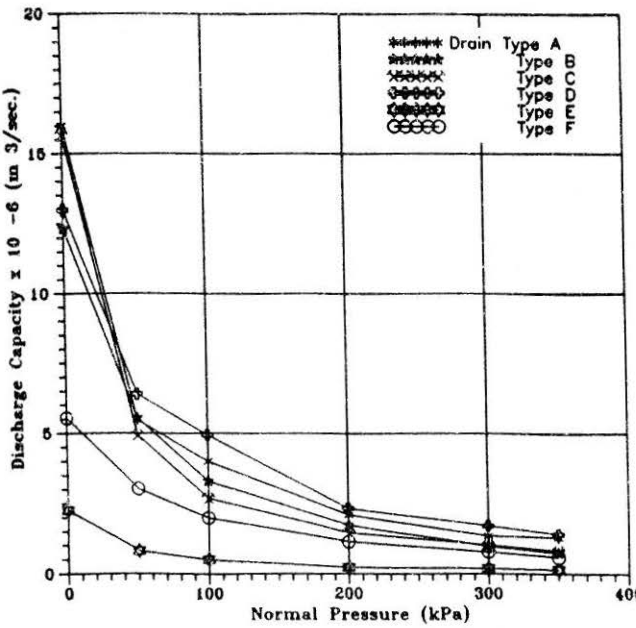

FIGURE 5 : Variation of Discharge Capacity of Drains with Normal Pressure Under a Hydraulic Gradient of 0.5

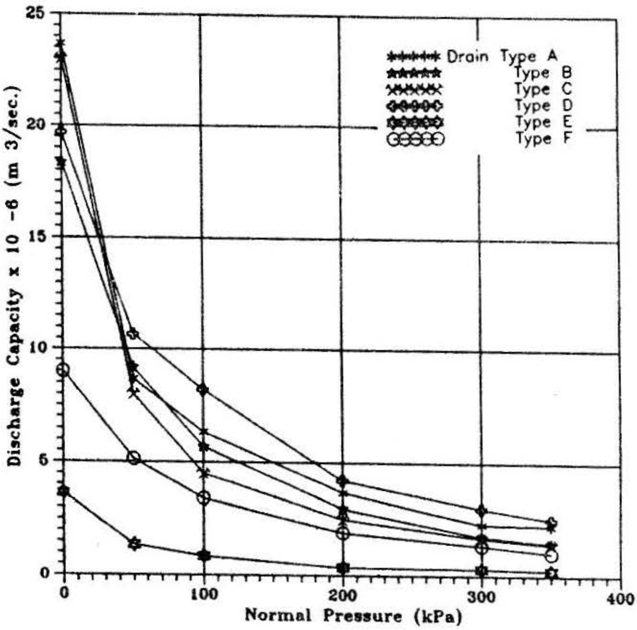

FIGURE 6 : Variation of Discharge Capacity of Drains with Normal Pressure Under a Hydraulic Gradient of 1.0

TABLE 4 : Summary of Discharge Capacities for Drain A under Hydraulic Gradients of 0.5 and 1.0

Load (kN/m^2)	Hydraulic Gradient i = 0.5		Hydraulic Gradient i = 1.0	
	Measured Discharge (cm^3 / min)	Discharge Capacity ($\times 10^{-6}$ m^3 / sec)	Measured Discharge (cm^3 / min)	Discharge Capacity ($\times 10^{-6}$ m^3 / sec)
0	940	15.67	1380	23.0
50	296	4.93	480	8.0
100	162	2.70	272	4.5
200	88	1.46	150	2.5
300	60	1.00	100	1.7
350	48	0.80	84	1.4

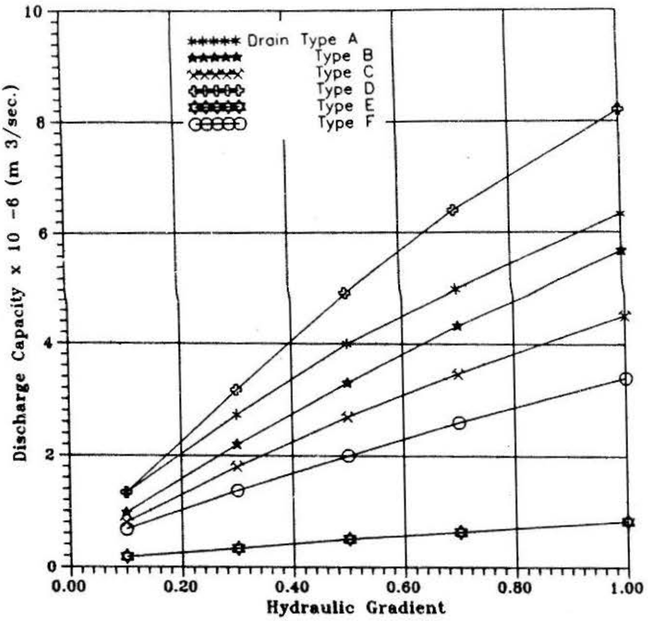

FIGURE 7 : Variation of Discharge Capacity with Hydraulic Gradient for All the Drains at a Normal Pressure of 100 kPa

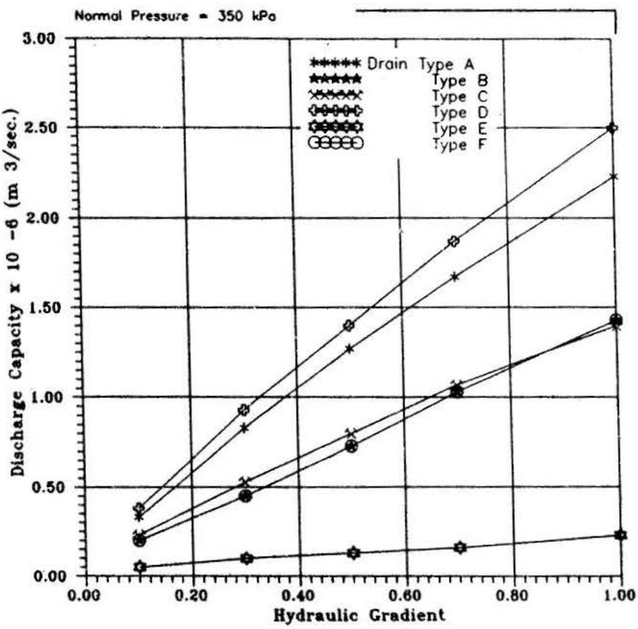

FIGURE 8 : Variation of Discharge Capacity with Hydraulic Gradient at a Normal Pressure of 350 kPa

TABLE 5 : Summary of Discharge Capacities of All the Drains at 100 kPa at different Hydraulic Gradients

Drain Type	Hydraulic Gradient i of									
	0.1		0.3		0.5		0.7		1.0	
	M	D	M	D	M	D	M	D	M	D
A	80	1.33	164	2.73	240	4.00	300	5.00	380	6.33
B	58	0.97	132	2.20	198	3.30	260	4.33	340	5.67
C	48	0.80	108	1.80	162	2.70	208	3.47	272	4.53
D	80	1.33	190	3.17	296	4.93	384	6.40	492	8.20
E	11	0.18	20	0.33	30	0.50	38	0.63	50	0.83
F	40	0.67	82	1.37	120	2.00	156	2.60	204	3.40

M – Measured Discharge (cm^3/min)

D – Discharge Capacity ($\times 10^{-6}$ m^3/sec)

TABLE 6 : Comparative Performance of Drains with the Existing Specifications

Drain Type	Rathmayer and Komulainen (1992)	ASTM D 4716	Kremer et al. (1983)	Za-chieh Moh et al. (1985)	Holtz (1987)
A	No	No	No	Yes	Yes
B	No	No	No	Yes	No
C	No	No	No	Yes	No
E	No	No	No	Yes	Yes
F	No	No	No	Yes	No
G	No	No	No	Yes	No

Conclusion

The test set up for measuring the discharge capacity of prefabricated drains attempts to give rational values for the drains tested under simulated field conditions. It will be of immense use in evaluating the relative efficacy of the drains.

Acknowledgement

The authors are grateful to Mr. M.D. Nair of M/s Associated Instruments Manufactureres (I) Ltd. for the assistance rendered in the fabrication of the set up. Thanks are also due to M/s Indian Jute Industries Research Association, Calcutta for making available the Type E drain.

References

AKAGI, T. (1994) : "Hydraulic applications of Geosynthetics to Filtration and Drainage Problems with Special Reference to Prefabricated Band-shaped Drains", *Proc. 5th Int. Conf. on Geotextiles,* Geomembranes and Related Products, Singapore, pp.99-119.

BALAN, K. (1995) : "Studies on Engineering Behaviour and Uses of Geotextiles with Natural Fibres", *Ph.D Thesis,* IIT Delhi.

BROMS, B.B., CHU, J. and CHOA, V (1994) : "Measuring the Discharge Capacity of Band Drains by a New Drain Tester", *Proc. 5th Int. Conf. on Geotextiles, Geomembranes and Related Products,* Singapore, Vol.2, pp.803-806.

HANSBO, S. (1993) : "Band Drains", *Ground Improvement,* M.P. Moseley (Ed.), Blackie Academic and Professional, Glasgow.

HOLTZ, R.D., JAMIOLKOWSKI, M.B., LANCELLOTTA, R. and PEDRONI, R. (1991) : "Prefabricated Vertical Drains : Design and Performance", *CIRIA Ground Engineering Report*, Butterworth - Heinemann Ltd., Oxford.

HOLTZ, R.D. (1987) : "Preloading with Prefabricated Vertical Strip Drains", *Geotextiles and Geomembranes*, Vol.6, pp.109-131.

KREMER, R.H.J., OOSTVEEN, J.P., WEELEVAR, A.F., DE JAGER, W.F.J. and MEYOOGEL, I.J. (1983) : "The Quality of Vertical Drainage", *Proc. 8th European Conference on S.M and F.E.*, Helsinki, Vol.2, pp.721-726.