Behaviour of bent prefabricated vertical drains

Le comportement des drains verticaux préfabriqués pliés

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SYNOPSIS: Large scale laboratory tests were conducted to evaluate the discharge capacity of prefabricated drains. The drains were tested in both the straight and bent conditions, and the influence of shape and applied horizontal stress on discharge capacity was determined. The related problem of long term durability is also examined. Finally, practical implications of bent vs. straight drains and durability on the design of vertical drain systems are discussed.

1 INTRODUCTION

In recent years, prefabricated vertical drains, sometimes called "wick" drains, have almost entirely replaced conventional sand drains as the preferred method to accelerate the consolidation of soft cohesive soils under preload embankments. The performance of prefabricated drains is markedly influenced by their transverse and longitudinal permeability as well as their durability with time, properties which are controlled by the filter sleeve and core components of the drain. Mechanical properties are important for installation, and they may also play a role in long term performance. Design of the filter (typically a geotextile) so that the desired filtration qualities are maintained throughout the design life of the drain is discussed in detail by Holtz, et al. (1987).

Once water from the foundation soil has entered the drain, it is still possible for the flow in the drain to be reduced (termed "well resistance"). The design problem is to estimate the drain discharge capacity, q_w, which is dependent on such factors as (1) the volume of the core available for flow, (2) the effect of lateral earth pressure on that volume, (3) possible folding, bending, and crimping of the drain due to large settlements, (4) infiltration of fine soil particles through the filter which could cause a reduction of flow capacity of the drain ("siltation"), and (5) the biological and chemical durability of the drain system. It is this third factor, reduction of the discharge capacity because of folding, bending, and crimping of the drain due to large settlements, that is the primary subject of this paper.

Although some investigations of bent drains both in the laboratory and in the field have been made, the results so far are inconclusive. After this work is summarized, data will be presented from large scale laboratory tests which were conducted on straight and initially bent prefabricated drains, as well as some which had undergone settlements up to 20%. Results of related field tests will also be mentioned. Finally, practical implications for design and long term performance of vertical drainage systems will be discussed.

2 PREVIOUS WORK ON DRAIN BENDING

Drain bending, folding, kinking, or wrinkling due to large settlements may possibly decrease the discharge capacity, but the evidence is mixed as to its effect and occurrence in the field (Kremer, 1983; Hansbo, 1983; and Oostveen, 1984). Laboratory testing of drains in large cylinders of compressible clay has indicated quite significant reductions in flow rate after settlements of 15 to 35% have occurred (see Cortlever, 1983; van de Griend, 1984; and Fellenius & Castonguay, 1985). Tests on drains purposely bent or crimped by Suits, Gemme, and Masi (1986) and Lawrence & Koerner (1988) showed that in no case was flow completely cut off, although in some cases the reduction was significant. Furthermore, it was impossible to predict bent performance based on the physical appearance of the core or filter.

3 SHORT AND LONG TERM PERFORMANCE REQUIREMENTS

Based on analytical considerations and a study of short term in-soil tests, Holtz, et al. (1987) concluded that, as long as the drain discharge capacity q_w is greater than 100 to 150 m^3/yr, a decrease in flow capacity of the drain has no significant influence on the consolidation rates of prefabricated drain installations, even for long (> 50 m) drains.

To be assured that this discharge capacity will be maintained over the long term is another matter, and all the factors enumerated in the introduction can affect long term system performance. Some factors such as siltation in the drain and clogging of the filter can be prevented by proper design of the geotextile filter, as described by Holtz, et al. (1987). Filter extensibility and creep of both the core and filter under lateral soil stresses, biological or chemical degradation, and drain bending or folding because of large settlements all tend to decrease the drain discharge capacity. Unfortunately, very few long term tests have been carried out, especially with drains confined in soil.

4 EXPERIMENTAL PROGRAM AND TEST RESULTS

Three series of tests were conducted on specimens of drains confined in soil: (1) drains initially straight, (2) drains initially bent, and (3) drains after 20% vertical deformation.

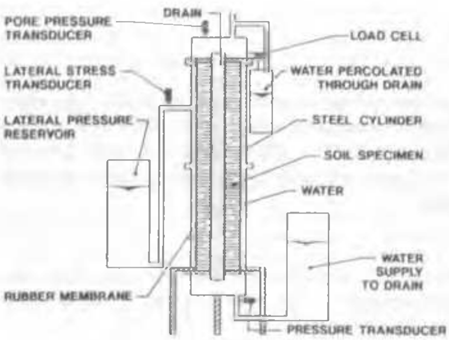

Figure 1. ENEL—CRIS apparatus for testing prefabricated drains.

In the first test series a large in—soil device (Figure 1) was developed at the ENEL—CRIS laboratories in Milan, Italy. The drain specimens were placed in a soil sample 300 mm in diameter and 500 to 3000 mm high. The lateral pressure capacity of the apparatus is about 600 kPa (≈40 to 50 m depth under average conditions). Flow tests under a hydraulic gradient of one were conducted as described by Holtz, et al. (1987), and the results are summarized in Figure 2. With only a few exceptions, the discharge capacity of the drains is of the order of several hundred m^3/year, which is sufficient for all but the most extreme situations (very long drains; very sandy—silty soils).

As shown in Figure 2, even drains by the same manufacturer can have a wide range of discharge capacities, almost an order of magnitude, depending on the type of core and filter used. Also, there is some variation in results even within the same drain type; the deviation from the mean is ±10 to 15%. Duplicate tests on other drains had approximately the same variation. Therefore, it is important to specify drains on the basis of material and test values required for the project, rather than on brand name and model number.

All the tests in Figure 2 were conducted using a hydraulic gradient of 1.0. Tests at lower hydraulic gradients under a wide range of confining pressures showed that drain discharge capacity is not significantly influenced by hydraulic gradient (Holtz, et al., 1987).

In the second series, tests were conducted on three prefabricated drains initially bent as shown in Figure 3. The results (Figure 4) indicated that the stiffness and geometry of the

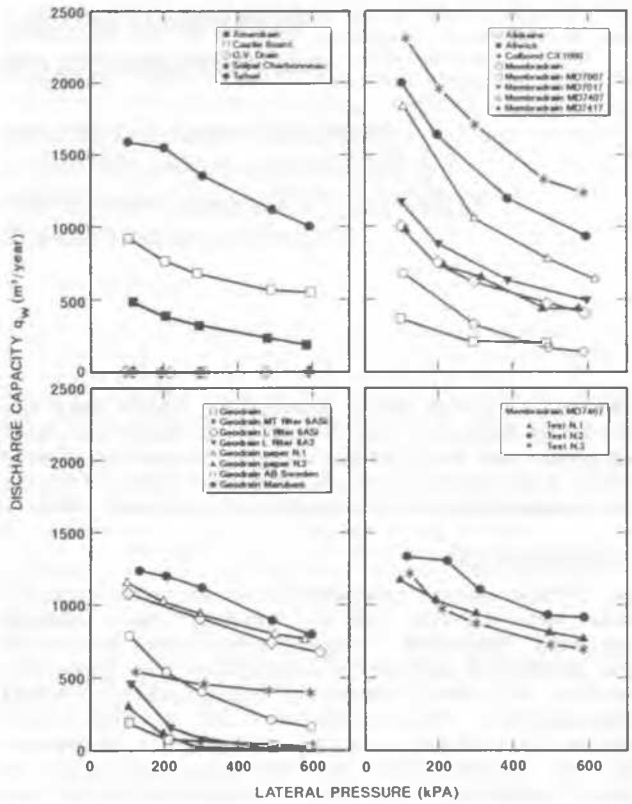

Figure 2. Discharge capacity of several prefabricated drains at i=1 performed by ENEL—CRIS.

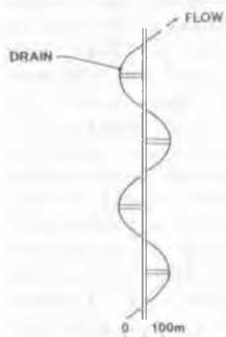

Figure 3. Configuration of initially bent drain.

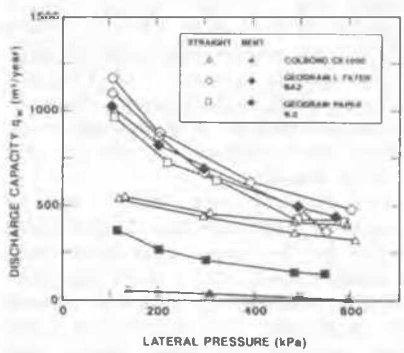

Figure 4. Discharge capacity of straight vs initially bent drains.

filter core system have a great influence on the resistance of the drain to bending.

The third series of tests were on drains which had experienced 20% vertical deformation. The device used in these tests is shown in Figure 5.

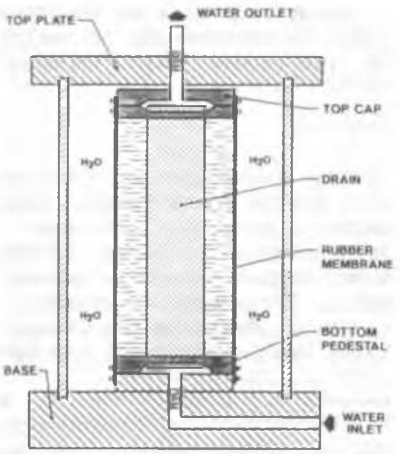

Figure 5. ENEL–CRIS apparatus for testing prefabricated drains after 20% of vertical deformation.

The drain was first placed vertically in a metal tube, 140 mm in diameter and connected to a bottom plate. The cylinder was then filled with a slurry of clay and water to a height of 530 mm. During the filling operation care was taken to minimize entrapment of air. Then the drain was connected to the top plate and the apparatus loaded by a piston to a maximum vertical stress of 100 kPa. After the specimen consolidated to 420 mm (or 20% strain), the vertical load was removed. Next, the specimen was extruded from the cylinder and placed in the apparatus shown in Figure 1. The drain was connected to the bottom pedestal and a rubber membrane with an internal diameter of 204 mm and supported by a perforated plate former was placed around the specimen. The 32 mm annular space between the specimen and the membrane was filled with the clay–water slurry, the top of the specimen closed by the top cap, and the rubber membrane sealed at both the top and bottom by O rings (see Figure 5). The top plate was then installed on the cylinder and the cell filled with water so that a hydrostatic pressure could be applied to the specimen. The discharge capacity test was performed as previously described by Holtz, et al. (1987) for straight prefabricated drains (Series 1 tests).

Typical results for this series of tests are shown in Figure 6. As before, the discharge capacity is given versus the lateral pressure for straight drains as well as drains which have experienced 20% vertical strain. The results indicate that the discharge capacity of some drains is markedly decreased after 20% vertical compression, even at modest confining stresses. For example, the discharge capacity of the Colbond (CX1000), which had a q_w of 400 to 500

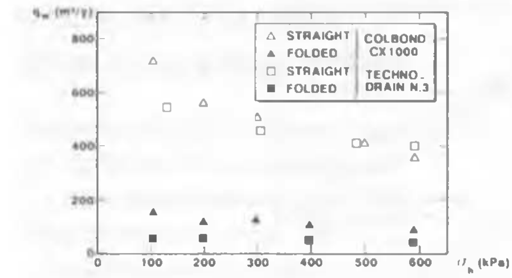

Figure 6. Discharge capacity of drains before and after 20% vertical compression.

m^3/year when straight (Figure 2), was reduced to about 50 m^3/year after 20% vertical compression. The q_w of the Technodrain No.3 reduced to 20 or 25% of its straight flow capacity after a similar vertical compression. Other drains were less susceptible to a significant decrease in flow capacity after large settlement.

5 FIELD EXPERIMENTS IN POLAND

Koda, Szymanski, and Wolski (1986 and 1988) reported on some very interesting long term discharge capacity tests on Geodrains. First, five 320–mm diameter and 6–m long perforated steel tubes were installed in peat and organic clay at a test site in the Notec River valley in Poland. Then Geodrains were inserted in the usual manner into each tube. Two Geodrains had nonwoven polyester geotextile filters while the other three had common paper filters. After about 250, 500, and 1000 days after installation of the drains, the tubes were extracted, and from them samples 150 mm in diameter and 300 mm long containing the drains were trimmed and mounted in a special triaxial type apparatus for discharge capacity testing. The specimens were reconsolidated to the estimated in situ state of stress, and the discharge capacity of the drains was measured under a hydraulic gradient of 1.0 as the cell pressure was increased incrementally to 250 kPa.

The results, shown in Figure 7 for peat, indicate that:

- On a short term (10 days) basis, the q_w decreases with increase of confining pressure remaining satisfactory for both types of filters.
- After 1000 days in the ground the results are less satisfactory, particularly for the paper filter for which q_w was reduced to less than 10% of its initial value. The discharge capacity of the drain with polyester was reduced by 50 to 70% and became more sensitive to the increase of confining stress.

A visual inspection of the filters indicated that after 1000 days the paper filters were almost completely deteriorated. On the other hand, the polyester filters seemed practically unaffected after the long burial time. The inspection of the dug–out drains showed no significant drain folding despite relative compression of the soil of about 20%.

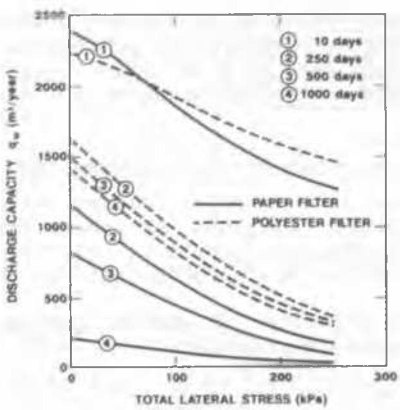

Figure 7. Influence of time on discharge capacity of Geodrains (Koda et al. 1988).

6 PRACTICAL IMPLICATIONS AND RECOMMENDATIONS

In some drains, especially at higher lateral pressures, there is a significant reduction in flow capacity in highly bent drains. In some cases this capacity is less than the desired minimum of 100 to 150 m^3/year. High lateral pressures are more likely to occur in very deep deposits of soft clays in which the drains are very long. Long drains are, of course, more susceptible to decreased discharge capacity which could in turn effect the rate of consolidation of foundation.

The simple appearance of the core of a vertical drain may be misleading as to its sensitivity to drain bending, as shown by Lawrence & Koerner (1988) as well as the present tests. For very long drains and for projects wherein the drains must function for a relatively long time, the specifications should not permit the use of drains that [e.g., by Suits, Gemme & Masi (1986), Lawrence & Koerner (1988), and the present tests] have indicated relatively poor performance. Thus, some type of prequalification testing during the design phase may be warranted. If a brand name type specification is used, periodic retesting will probably be necessary, as drain manufacturers are continually changing and improving their products.

A conservative approach for design is to keep the working lateral stresses well below the material creep limits. Since nothing can be done to reduce the in situ lateral stresses, the minimum allowable discharge requirements for the projects may be arbitrarily increased. A better approach would be to conduct long term in-plane permeameter tests on drain specimens confined under the estimated in situ lateral stresses.

7 CONCLUSIONS

Results of large scale laboratory tests conducted at ENEL-CRIS in Italy have indicated that some prefabricated drains are subject to a significant decrease in discharge capacity if they are significantly bent or folded. Bending or folding can occur if settlements at the site are signficant, say, greater than 15 or 20% vertical consolidation. In this case, a decrease in drain discharge capacity to less than the desired minimum of 100 to 150 m^3/year may result. Physical appearance of the core of the drain is not a certain indicator of whether the drain core is susceptible to significant decrease in discharge capacity due to bending.

Additional field testing such as that reported by Wolski et al. (1988) is recommended to verify the results of the laboratory test reported herein.

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