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LABORATORY MEASUREMENT OF THE DISCHARGE CAPACITY OF PREFABRICATED BAND SHAPED DRAINS

LABORMESSUNGEN DES ENTWÄSSERUNGSVERMÖGENS VON VORGEFERTIGTEN FLACHEN DRAINS

MESURE EN LABORATOIRE DE LA CAPACITE DE DECHARGE DE DRAINS PLATS PREFABRIQUES

This article deals with the apparatus developed in France by the Laboratoires des Ponts et Chaussées for the laboratory measurement of the discharge capacity of band-shaped drains. This equipment can be used to investigate the effect of confinement on discharge capacity; the drain may be placed either in a waterproof membrane or in a soil sample subjected to several radial consolidation increments. A simple device allows for the application of a vertical strain to the drain during the test. A further advantage of this apparatus is that it can be used as is to determine the transmissivity of a geotextile.

INTRODUCTION

In the last few years, vertical drain projects in France have made increasingly systematic use of prefabricated drains. In view of the large number of products available, the Laboratoires des Ponts et Chaussées judged it necessary to undertake a programme of research aimed at the establishment, in the future, of criteria for the acceptance or rejection of these materials.

The approach adopted in this research was two-fold:

- examination in the laboratory of the intrinsic characteristics of band-shaped drains;
- comparative analysis of the results obtained at instrumented sites.

This article deals with the determination in the laboratory of the intrinsic characteristics of these drains, in particular of discharge capacity q_w, which until 1983 was regarded as the preponderant factor in their effectiveness in the field.

It will be seen that the experimental method developed for this work also has useful applications in the field of geotextiles, since the testing apparatus may be used to determine their transmissivity (axial permeability times thickness).

1. LABORATORY MEASUREMENT OF THE HYDRAULIC CHARACTERISTICS OF BAND-SHAPED DRAINS

1.1. General remarks on the laboratory tests

The laboratory investigation of the hydraulic properties of prefabricated band-shaped drains has so far been based on three families of tests:

- evaluation of the "equivalent" diameter d_e of the drain, to be used in standard design methods;
- "overall" evaluation of the effectiveness of the drain;
- relative measurement of the hydraulic characteristics of the drain, namely:
  - its discharge capacity q_w in its horizontal direction;
  - its coefficient of lateral permeability (clogging problems may or may not be taken into account).

Tests of the first family in fact evaluate the performance of the prefabricated drains by comparison with sand drains, through the determination of an "equivalent diameter" d_e. The tests of the second family follow the evolution in time of radial consolidation around the drain, through continuous measurement of the quantity of water it evacuates. Interpreting the measurements yielded by tests of these two types is generally tricky: many factors, both theoretical and experimental, may distort the conclusions if they are not properly taken into account.

The tests of the third family, the selective measurement of the hydraulic characteristics of prefabricated drains, have been aimed at the determination:

- Either of their lateral permeability. In many cases, this measurement amounts to a measurement of the permeability of a filter surrounding the core of the drain, often with clogging phenomena taken into account.
- Or of their discharge capacity q_w. The discharge capacity q_w of a drain is the product of its coefficient of longitudinal permeability, k_w, in m/s, by its cross-sectional area, A_w, in m2: $q_w = k_w A_w$.

The influence of the discharge capacity of a drain on its effectiveness in dissipating a pore pressure field has been demonstrated theoretically by Hansbo [1] and Yoshikuni and Nakanodo [2].

The many tests developed to determine this parameter bear witness to the interest in it (Den Hoegt [3]; Kremer et al. [4], [5]; Hansbo [1], [6], [7], [8]; Oostveen [9], etc.), but the consensus stops there, and the procedures for measuring q_w remain highly diversified. In particular, there is a divergence of views between the partisans of tests of isolated specimens of drains and those of tests carried out on specimens of drain embedded in a soil.

1.2. Approaches chosen

To ensure the fullest possible understanding of the problems in connection with the analysis of the q_w factor, it was decided that the apparatus to be developed would have to be versatile enough for measurements both on "free" drains (in fact, drains isolated in a watertight membrane that must if possible transmit the pressure of the confinement fluid without distortion) and on drains embedded in soil specimens.

The design of the testing apparatus also had to meet other specifications:

. The possibility of conducting tests both on drain specimens 5 cm wide (conventional half drains), for routine tests, and on drain specimens 10 cm wide (full drains), for special tests.

. The possibility of varying the confinement pressure around the specimen from 0 to 1,000 kPa, with the pressures being either isotropic or anisotropic so as to represent the behaviour of the soil more accurately.

. Control of longitudinal deformations of the drain. This option makes it possible to impose a controlled deformation on the drain and measure its effect on the hydraulic properties of the drain.

. Monitoring of the consolidation of the soil for tests on embedded drains.

. Check of the seal between the measurement and pressurization systems before every test, so as not to perturb the measurements. The inside diameters of the piping of the measurement circuit (which contains deaerated, deionized water) must be large enough not to induce a significant loss of head.

Thought was also given to specifying a "standard" soil, and the procedure for its preparation, to ensure the perfect reproducibility of "embedded drain" tests.

2. THE L.P.C. TESTING APPARATUS

2.1. Description of the apparatus

The foregoing considerations led to a design based on the use of a large triaxial cell (large enough to hold specimens 150 mm in diameter), modified to allow water to circulate longitudinally through the drain, with no significant loss of head resulting from the apparatus itself.

Figure 1 shows the version of this cell used for the testing of half-drains (specimens of band-shaped drain 5 cm wide). A full drain (10 cm wide) can be tested using a suitable base and cap. Following calculation of the loss of head in each of the circuits, 10 mm was set as the minimum inside diameter of the discharge capacity measurement circuits. Allowance has been made for the fitting of pressure sensors on either side of the specimen tested, in the case of large drains or large gradients.

The most complex part of the development work was on the connecting system between the drain and the discharge capacity measurement circuit: the seal between this measurement circuit and the confinement pressures applied to the drain must be perfect.

This connection must also meet the following two contradictory requirements:

. It must be flexible laterally so as not to crush the drain (of which the outside dimensions are variable) and so introduce an undesirable loss of head.

. It must be rigid axially to allow for the application of forces parallel to the drain centreline (for tests with anisotropic stresses) or to induce large deformations.

The solution chosen is based on the use of two half shells that can be adapted to the type of test to be made. These half shells have recesses containing a rubberized sealing compound. The drain itself is cut in such a way that it can transmit the whole of any axial force.

This system makes it possible:

- in the case of a test on a free drain, to imposed a controlled deformation on the specimen;

- in the case of a test on an embedded drain, either to impose the same deformation on the drain and on the soil or to leave the deformation free.

As for the application of the hydraulic gradient to the ends of the specimens of drain or geotextile, the current system consists of tanks sliding on graduated rules and makes it possible to apply gradients ranging from 0 to 3 with the lengths of specimen possible with this enclosure. For larger gradient values, pneumatic pressurization of the water flowing in the drain is planned.

In all cases, the imposed direction of flow is upward.

2.2. Capabilities of the apparatus

The L.P.C. cell may be used with soil specimens, with embedded drains, up to 150 mm in diameter and 300 mm high. So far, the initial tests have been conducted with soil specimens 76.2 mm in diameter and 152 mm high, containing drain specimens 50 mm wide (standard half drain). The use of a triaxial cell also makes it possible to conduct a great variety of tests, especially on "embedded drains":

- confinement pressure ranging from 0 to 1,000 kPa, with the possibility of isotropic or anisotropic consolidation of the soil around the drain according to the problem posed;

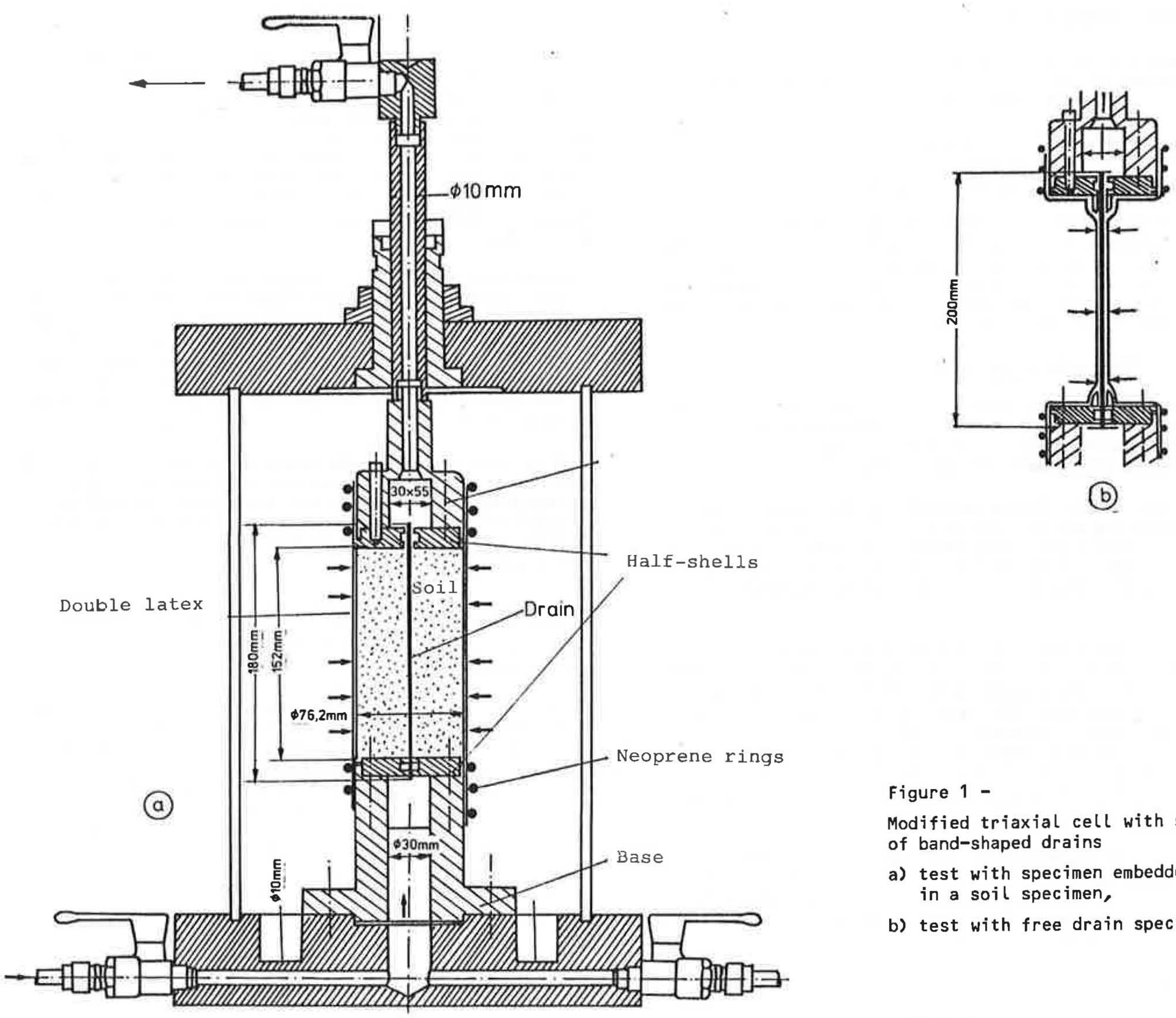

Figure 1 -
Modified triaxial cell with specimens of band-shaped drains
a) test with specimen embedded in a soil specimen,
b) test with free drain specimen.

- test with reconstituted soil or with natural soil taken in situ;
- and, generally, all the possibilities normally offered by triaxial cells (particular stress path, settlement without deviator, etc.), which may be used for the following:

  . comparison of the discharge capacity values of a free drain and the same drain embedded in a given soil;

  . measurement of the discharge capacity versus the confinement pressure or the deformation imposed on the drain;

  . comparison of the discharge capacity values of different types of drain, free or embedded in a natural or reconstituted soil;

  . measurement of the overall effectiveness of a drain in a soil by monitoring of the consolidation under different stress conditions;

  . measurement of the equivalent diameter of a band-shaped drain with reference to a cylindrical sand drain in a reconstituted soil;

  . determining the effect of the time factor on the performance of a drain by inserting, say, a variable waiting time, at each consolidation stage, between the end of primary consolidation and the actual measurement of the discharge capacity.

The L.P.C. cell also offers an extensive range of possibilities in the evaluation of the transmissivity of geotextiles, especially as regards taking into account the influence of the type of soil on the evolution of the hydraulic properties of the drain material.

3. TWO EXAMPLES OF APPLICATIONS

The apparatus described above has been used on specimens of two types, a band-shaped drain (DESOL) and a geotextile (BIDIM U 64).

3.1. Tests on DESOL drain

3.1.1. Description of the DESOL

This drain takes the form of an extruded band of polyolefine, 2 mm thick and 95 mm wide. Its internal structure is a succession of parallel channels, of which the wall in contact with the soil can be perforated on request with orifices in sizes from 10 to 40 m.

3.1.2. Testing programme

The programme carried out included "free drain" tests and tests of the drain embedded in a reconstituted soil. In both cases, the specimens used were 50 mm wide.

The free drain tests served to determine the drainage capacity, without soil, versus: the applied isotropic confinement stress (from 10 to 500 kPa); time (up to 360 hours); and the axial deformation of the specimen (kinking test).

The following procedure was used for the embedded drain tests: The cylindrical specimen of reconstituted soil was cut to the dimensions of the drain and the drain placed in it. The soil and drain together were then subjected to isotropic consolidation and the discharge capacity was measured at the end of consolidation, at different loadings (50 to 500 kPa), and as a function of time.

The reconstituted soil used (kaolin corrected with a little sand: D85 = 50 µm; D50 = 2 µm; D35 = 1 µm) has a particle size distribution within the range of French fine soils in which drains are likely to be used.

3.1.3. Test results

Figures 2, 3, and 4 show the most characteristic results yielded by the tests performed.
Figure 2 shows the discharge capacity q_w versus the lateral pressure applied directly to the drain ("free drain" test) or to a cylindrical specimen of reconstituted soil. The figure also shows the particle size distribution of the soil used. The curves obtained reveal two distinct types of behaviour by this band-shaped drain in both types of test:

- When the lateral pressure on the drain or the soil specimen is less than 200 kPa, discharge capacity q_w varies little with pressure, and depends primarily on the applied gradient. The behaviour of the drain is substantially the same in the free and embedded tests (figure 3): the values of q_w differ by less than 10 %.
- When the lateral pressure exceeds 200 kPa, the discharge capacity drops off sharply, and depends not only on the hydraulic gradient applied to the ends of the drain specimen but also on the confinement pressure in the cell (figure 4).

It will be noted that the values for the free drain tests are not corrected for possible damping of the applied stresses by the double latex membrane.

It would therefore seem that, when the confinement pressure in the cell is less than 200 kPa, the rigidity of the drain itself prevents its deformation, and discharge capacity q_w is then independent of the lateral pressure and is between q_w = 2.1 and 2.3 l/mm for the drain 95 mm wide; the results are substantially the same whether the drain is free or embedded in soil. This corresponds to a longitudinal permeability of the drain of:

$$k_w = 2.10^{-1} \text{ m/s.}$$

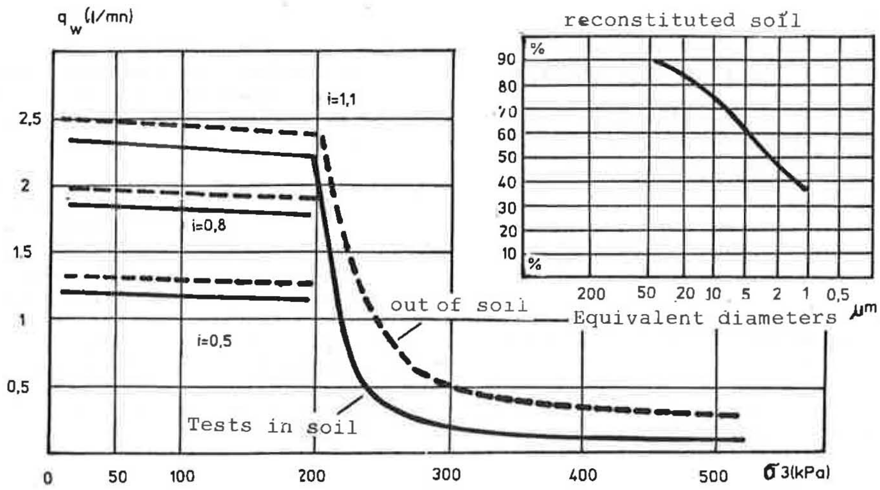

Figure 2 - Discharge capacity q_w versus pressure σ_3

Above the 200-kPa threshold, as soon as the drain is substantially deformed, there is a large difference between the free and embedded test results: the measured values of q_w may then differ by more than 100 %.

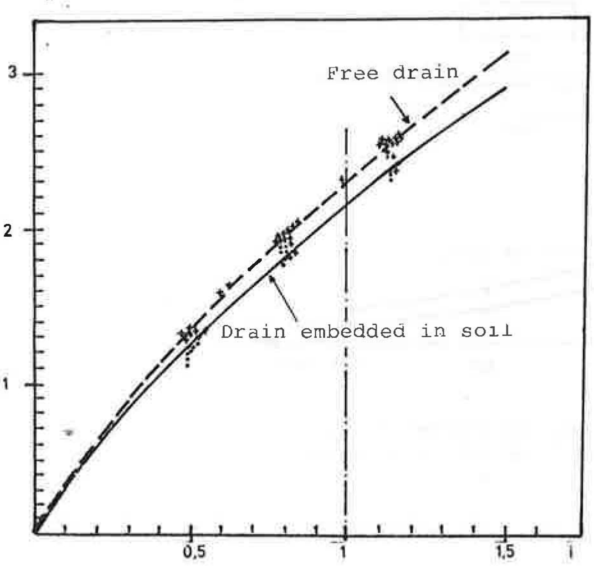

Figure 3 - Discharge capacity q_w versus hydraulic gradient i, with σ_3 < 200 kPa

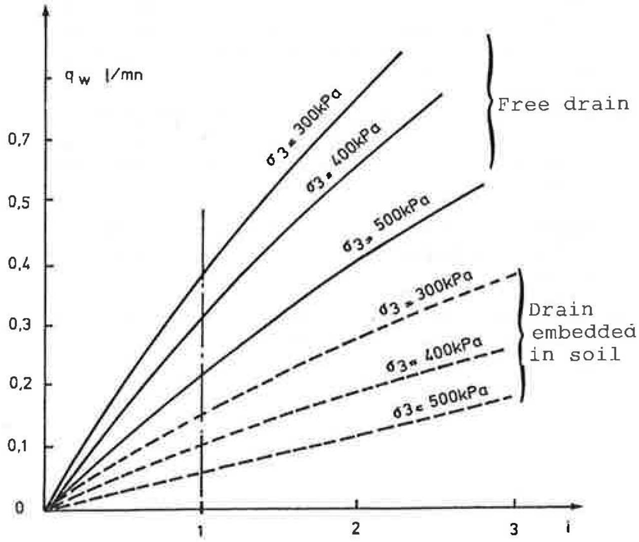

Figure 4 - Discharge capacity q_w versus hydraulic gradient i, with σ_3 > 200 kPa

3.2. Tests on BIDIM U 64 geotextile

3.2.1. Description of the BIDIM U 64

The U 64 geotextile is a nonwoven made of continuous polyester filaments, produced by tufting. It is 4.2 mm thick and has a weight of 550 g/m^2.

3.2.2. Testing programme carried out

The tests were performed on specimens of geotextile 5 cm wide and 20 cm long. The programme was the same as for the DESOL band-shaped drain, i.e., tests with the geotextile embedded in a cylindrical soil specimen (76 mm in diameter) and tests with the free geotextile surrounded by a latex membrane.

3.2.3. Test results

The results obtained (figure 5) show that the behaviours of the geotextile and band-shaped drain tested are different. The geotextile is deformed from the first loads, unlike the band-shaped drain, and the measured discharge capacity varies with this deformation, with no plateau at low lateral pressure values. And, here, the measurement results for the free and embedded geotextile specimens are different at all lateral pressures. Table I indicates these differences between the measured values of q_w, which are substantially constant, ranging from roughly 40 to 60 %.

BIDIM U 64 type of test	q_w in m^3/yr lateral pressure σ_3 (kPa) 50	100	200	300	400
drain embedded in soil	26.3	12	5.3	3.4	2.1
drain out of soil	18.9	7.9	3.4	2.2	1.3
difference in %	39	52	56	55	61

TABLE 1. Comparison of discharge capacities measured by two types of test:

- geotextile embedded in soil;
- geotextile out of soil.

(for a 10-cm width of geotextile)

CONCLUSION

Apparatus has been developed that may be used to investigate the discharge capacity of prefabricated band-shaped drains or the transmissivity of geotextiles in various configurations.

The results of the tests conducted so far reveal that the behaviour of the drain material differs according to whether or not it is embedded in soil.

Analysis of this difference will require the development of a theoretical model of the distribution of pore pressures and stresses around the specimen. As things stand, the values measured seem to be in good agreement with those obtained elsewhere on comparable drains.

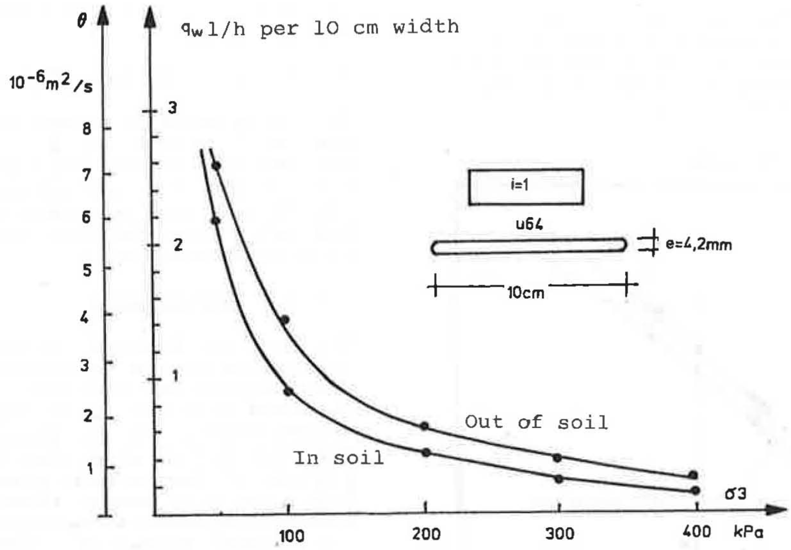

Figure 5 - Discharge capacity q_w and transmittivity Θ of geotextile tested versus lateral pressure

REFERENCES

[1] HANSBO S. Consolidation of clay by band-shaped prefabricated drains, Ground Engineering, vol. 12, no. 5, July 1979, pp. 16-25.

[2] YOSHIKUNI H., NAKANODO H. Consolidation of soils by vertical drain wells with finite permeability, Soils and Foundations, vol. 14, no. 2, 1974, pp. 35-46.

[3] DEN HOEGT G. Laboratory testing of vertical drains. Proc. 10th I.C.S.M.F.E., Stockholm, 1981, vol. 1, pp. 627-630.

[4] KREMER R., DE JAGER W., MAAGDENBERG A., MEY-VOGEL I., COSTUEE. Quality standard for vertical drains, Proc. 2nd Int. Conf. on Geotextiles, Las Vegas, 1982, vol. 2, pp. 319-324.

[5] KREMER R.H.J., OOSTVEEN J.P., Van WEELE A.F., DE JAGER W.F.J., MEYVOGEL I.J. The quality of vertical drainage, Proc. 8th Eur. Conf. S.M.F.E., Helsinki, 1983, vol. 2, pp. 721-726.

[6] HANSBO S. Consolidation of fine-grained soils by prefabricated drains. Proc. 10th I.C.S.M.F.E., Stockholm, 1981, vol. 3, pp. 677-682.

[7] HANSBO S. How to evaluate the properties of prefabricated drains, Proc. 8th Eur. Conf. S.M.F.E., Helsinki, 1983, vol. 2, pp. 621-626.

[8] HANSBO S. Discussions, Proc. 8th Eur. Conf. S.M.F.E., Helsinki, 1983, vol. 3, pp. 1148-1149.

[9] OOSTVEEN J.P. Discussions, Proc. 8th Eur. Conf. S.M.F.E., Helsinki, 1983, vol. 3, pp. 1152-1154.