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Quality Standards for Vertical Drains

Demandes de qualité pour drains verticaux

An ever increasing number of various types of prefabricated drains are being marketed to replace the traditional sand drain.
On the basis of the primary function of a vertical drain quality standards for drains should state:
a. those qualities of drains which should be determined;
b. the way in which drain properties should be established.
Quality standards and testing methods should be related to the various situations in building practice and to installation procedures. Quality standards should state that a drain can only be accepted for a job if a test report is available from a recognized laboratory in combination with a classification on the basis of requirements caused by subsoil, design and construction.

L'offre des divers types des drains préfabriqué; pour remplacer les drains sables, augmente de plus en plus.
En émanent des functions primaires du drain vertical, il faudra être fixé:
a. quelles qualités d'un drain doivent être déterminés;
b. comment les propriétés du drain doivent être établites.
Les demandes et méthodes d'inspecter les drains, doivent être en relation aux situations pratiques, qui changent constamment et doivent être en relation aux procédures d'installation des drains, lesquelles on doive suivre.
En vertu des demandes dequlité, on peut seulement admettre des drains préfabriqués à l'usage d'un projet de drainage vertical, s'ils sont guidés par un rapport d'inspection d'un laboratoire reconnu.
L'inspection catégorique doive être arriver en vertu des demandes par rapport à la souterraine, la construction et l'exécution du projet.

1. INTRODUCTION

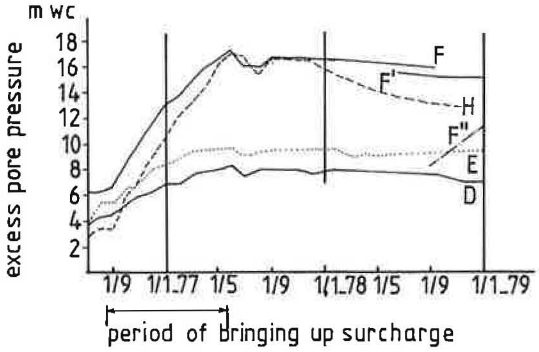
1.1. To shorten the consolidation process initiated by earthworks, vertical drains are used in many cases. In the past mostly sand drains or "sand piles" have been employed. In the seventies a large number of band-shaped prefabricated drains have been marketed, in continuation of the development of the cardboard drain by Kjellmann. Claims are made that they function as well as or even better than sand drains. Quality control of the latter has to be concentrated primarily on the way of installation and the precaution on the job site.
For prefab drains, however, it is necessary as well as effective, to put quality requirements on the drain itself. The necessity for standards is becoming more important since there is a tendency to decrease the available time of consolidation in which through the application of a dense pattern of prefab drains good and interesting possibilities are offered.
In the formulation of quality standards for drains, consideration has to be given to the application in building practice, and the function drains have to perform in the subsoil.
The objective of vertical drainage is: "to bring about a more rapid progress in the settlement process and a more rapid increase in shear resistance in highly impermeable subsoil."
The primary function of the drains is: "to absorb the expelled groundwater from the surrounding soil, with a relatively low entry resistance and to discharge it vertically."

1.2. Until 1974 sand drains were used almost exclusively for this purpose in the Netherlands. Many years of experience in application, supported by theoretical considerations, have resulted in a number of empirical rules with respect to the installation of such drains and the design of the drainage scheme for a project.
The introduction of the prefabricated drains has stimulated the rethinking of the theoretical and practical aspects of vertical drainage considerably.
The users are confronted with a strip, small in size compared to sand drains, which is composed of one or more elements. These elements, which are manufactured out of materials that are foreign to soil machanics engineers, are used as a filter medium and a discharge medium. It is understandable that doubts concerning the working and the durability of these types of drains may arise.
The most currently applied prefab band-shaped drains can be divided into the following types:
- one piece non-woven fabric drains;
- composite drains, having a profiled core with surrounding filter sleeve.

The most current sizes are 100 mm x 3 to 4 mm.

1.3. The usual practice in the Netherlands up to now is to accept a specific brand and type of drain on a job only, after the functioning of that drain has been demonstrated by the producer or supplier by means of prolonged measurements from a field test site. Although this condition is understandable, it does not guarantee the proper functioning of the drain under all conditions. For prefab drains, as with sand drains, not only careful installation is important, but the material quality has to be consistent on any job site.
The circumstances in which the drains are to function can be of great influence, such as the nature of subsoil,

the existence of a horizontally layered soil structure, the type of earthwork, the size of the embankment resulting in high or low earth pressures, small or large vertical and horizontal deformations, etcetera.
It has become evident in several cases that in practice large differences with respect to design expectations can occur. An example of such a case has been reported (1). Fig. 1, taken from that report shows the high level of the excess pore pressures continuing for more than one year, although the same type prefab drain was very succesfully applied to a power plant construction project 400 m from the site.



gauge D: N.A.L. - 15,4 m F: N.A.L. - 21,6 m
E: N.A.L. - 16,8 m H: N.A.L. - 11,1 m

Fig. 1 Excess pore pressures under a surcharge with drains.

Measurements on several types of drains tested under comparable conditions, such as those which have been carried out south-east of Amsterdam, and which are reported in this conference (2) can be of greater value. However, a disadvantage of all in situ measurements is that the outcome is not explicitly related to the performance of the different components of the drain with respect to the surrounding soil. This is one of the major reasons why it is desirable to perform laboratory tests and to relate these results as fully as possible to in situ measurements. The conduction of laboratory tests is a much more suitable approach because the tests can be performed uniformly, they are reproducible and they are much less time and money consuming. As a result the development of new drains and the optimization of the existing types may be stimulated.

1.4. The lack of official quality standards together with the fact that some Dutch principals have good experience with one or two drain brands resulted in prescribing a specific drain brand in the specifications of a job.
However, in such cases also an equivalent product has to be accepted.
Without quality standards the determination of equivalence can be difficult and is usually relatively subjective in practice. This can be a potential cause of conflicts between principals and contractors, the potential being greater if the subsoil conditions and the nature of the earthworks do not allow the determination of the proper performance of the drainage system in a simple and objective way.
From the foregoing it may be concluded, that even though the development of prefabricated drains is an important step in accelerating consolidation, quality standards are necessary to prevent disappointments and conflicts.

2. THE NEED FOR DRAINSPECIFICATIONS

In spite of the fact that many aspects of vertical drainage are not well understood, it must be possible to set up quality standards that drains have to be subjected to, in accordance with our present knowledge, insight and experience.
The objectives for quality standards are as follows.
a. To ensure the effectiveness of vertical drainage in view of the nature of the earthwork and embankment stability during the construction period.
b. To prevent unsuitable drains -with respect to soil conditions and construction- from being applied.
By means of such standards it is hoped that the following will be achieved.
1. An objective laboratory testing procedure.
2. A documentation of in situ measurements demonstrating the effectiveness and reliability of drains classified in relation to subsoil, method of installation and type of earthwork.
3. A stimulation of appropriate further developments based on laboratory and in situ experience.
4. A classification system for drainage works.
The operation of vertical drains as influenced by the surrounding soil, the installation procedures and the interaction between earthwork and subsoil is very complicated. It is therefore almost impossible to set up a unique series of quality standards so that tested drains will function properly and reliably in all the various types of works. In many cases this would lead to an unnecessary rise in costs and would, moreover, reduce the possibilities of new developments to a minimum. It goes without saying that such a series of quality standards would take many years of research at high costs.
Therefore quality standards should be subdivided in relation to subsoil characteristics and types of earthworks. This will lead to standards related to different types of the latter.
The effectiveness and reliability of drains can be determined by measurements on the job site. By introducing a system of in situ measurements in connection with the specified levels of quality standards, properly documented practical experience with drains will become available.

3. ELEMENTS OF QUALITY CRITERIA FOR DRAINS

3.1. Apart from influences which are difficult to quantify, such as the interaction between the drain and the soil, the installation procedure of the drain and the care taken during the installation, the effectiveness of the drain depends on the properties of the materials forming the drain and the construction of the drain. Determination of the material properties lends itself to laboratory investigation. Influences that are dominated more or less by the care and manner of application in the field can hardly be determined in another way than by in situ measurements.

3.2. Firstly, the type of requirements that the drains will have to meet has to be determined and secondly the corresponding laboratory tests that will have to be performed, must be defined.
These requirements and testing procedures should be related to the variation in field circumstances.
Prefabricated drains will have to meet requirements for the following properties.
a. Mechanical properties
- tensile strength in connection with the installation procedures;
- elasticity characteristics in view of horizontal deformations in the subsoil;
- buckling strength in connection with folding during the compression of the subsoil.

b. Permeability and stoppage of clay and silt
   - minimum permeability in relation to soil permeability;
   - maximum permeability to prevent fine particles from clogging the drain.
c. Discharge capacity
   - minimum discharge capacity, at various total pressures;
   - acceptable reduction in discharge capacity, in case of folding or buckling.
d. Durability and dependability
   - sensitivity to chemical, biological and physical deterioration;
   - sensitivity to the clogging of the vertical discharge passages and blocking of the filter.

As a result of the discussions in the committee on "Vertical Drainage" of the Study Centre for Road Construction, the following recommendations are made.

3.3. The determination of drain properties should be performed with prescribed test methods, according to an outline of quality standards for vertical drains with minimum requirements as described in "Drain Standards", see par. 4.

3.4. Minimum acceptance requirements.
Prefabricated drains for vertical drainage will be accepted for a job only, if a test report in which the properties listed in "Drain Standards" is available at least one month before the tender is brought out.
The test report should be drawn up by an authorized laboratory which has tested the drains with the prescribed test methods.

3.5. Low embankments (< 2,5 m).
All types of drains may be accepted, with which the satisfactory operation can be demonstrated by the tests in "Drain Standards" or by in situ measurements in embankments.

3.6. High embankments (> 2,5 m).
Only those types of drain may be accepted, with which proper functioning can be demonstrated by in situ measurements in embankments under construction, with comparable subsoil conditions and total pressures and with a consolidation period comparable to the required period.

3.7. Earthworks, stability cases.
Earthworks, in which the probability of instability is to be reduced by the application of vertical drains, also need extra requirements for the drains.
Only those types of drain may be accepted, with which proper functioning can be demonstrated by in situ measurements in earthworks under construction having comparable subsoil conditions and which have functioned suitably during the required period of operation.

4. PROPOSAL FOR MINIMUM REQUIREMENTS "DRAIN STANDARDS"

4.1. Tensile Strength

4.1.1. In view of the possibility of uncontrolled penetration of the mandrel during installation, the tensile strength of the drain must be more than 500 N per 100 mm of width, at a maximum strain of 10 %, and at a controlled rate of strain of 200 mm/min.

4.1.2. After the drain has been kept under water for 24 hours, the ultimate tensile strength of the filter sleeve must exceed 120 N per 100 mm at un ultimate strain between 2 % and 10 %; the controlled rate of strain is 2,5 mm/min.

4.2. Filter Quality

4.2.1. The percolation resistance c of the filter sleeve must be less than $5d \times 10^8$ s after a percolation test of at least 40 hours, (d = thickness of the filter sleeve in m).

4.2.2. The filter effectiveness, that is, the ability of the filter sleeve to stop fine particles under pressure, must be such that no particles > 10 µm can pass.

4.3. Discharge Capacity

4.3.1. The minimum vertical discharge capacity must be 300 cm^3/min, with a potential difference of 0,25 m across the drain sample having a length of 0,40 m; the cell pressure is equal to 10 N/cm^2.

4.3.2. The minimum vertical discharge capacity, of a folded drain sample (a flattened s-configuration) having a resulting length of 0,40 m, must be 30 % of the discharge capacity determined in accordance with 4.3.1.

4.4. Durability and Dependability

The requirements and testing procedures are under development.

4.5. Vertical Sand Drains

4.5.1. Sand for drainage purposes must be mineral material. The percentage of mineral particles passing through the 63 µm sieve, must be less than 5 % of the fraction passing the 2 mm sieve. The fraction on the 250 µm sieve, must be greater than 50 %. The loss on ignition of the fraction < 2 mm must be less than 3 %.

4.5.2. The minimum coefficient of permeability is 12 m/24 h ($1,4 \times 10^{-4}$ m/s).

4.6. Testing Procedures

All laboratory tests and in situ measurements must be executed according to prescribed test methods.

5. CONSIDERATIONS FOR THE DETERMINATION OF QUALITY STANDARDS

5.1. Introduction

The aforementioned tests provide a starting point for the determination of standards together with the existing experience obtained from investigations on the initial drain types, while, however, the development in this field has continued.
The given values are based on a relatively small number of laboratory tests performed on the first prefabricated drains available in the Netherlands in the early 1970's and with which also field tests were carried out.
The field tests demonstrated that the drains work, but it is not known to which degree the determined characteristics influence their working.
The relation between laboratory tests and field tests requires more study and research, part of which is being carried out at the present time by the Dutch Study Centre for Road Construction (S.C.W. commission F9).
At any rate, significant differences in the working of the filter medium as well as in the discharge capacity have been demonstrated in the laboratory investigation (Fig. 2).
In general the laboratory tests on drains (3) must be carried out without the surrounding soil in order to obtain reproducible test results.
Only then can the similarity or the difference in performance between drain types be determined.
The filter efficiency, of course, cannot be determined without the presence of soil so that a test procedure has been devised in which a reproducible soil mixture is brought to surround the drain (4).

The intention is to make the quality standards officially known when all the laboratory tests have been formulated; hopefully this will occur at the end of 1982 or the beginning of 1983.

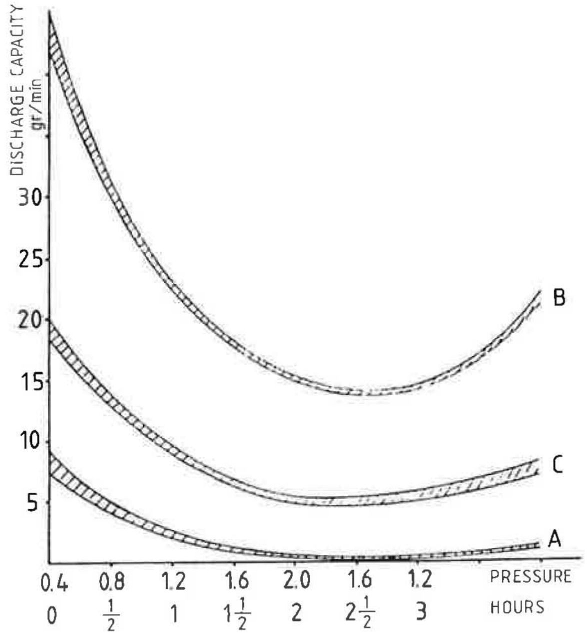


Fig. 2 Discharge capacity at different horizontal pressures.

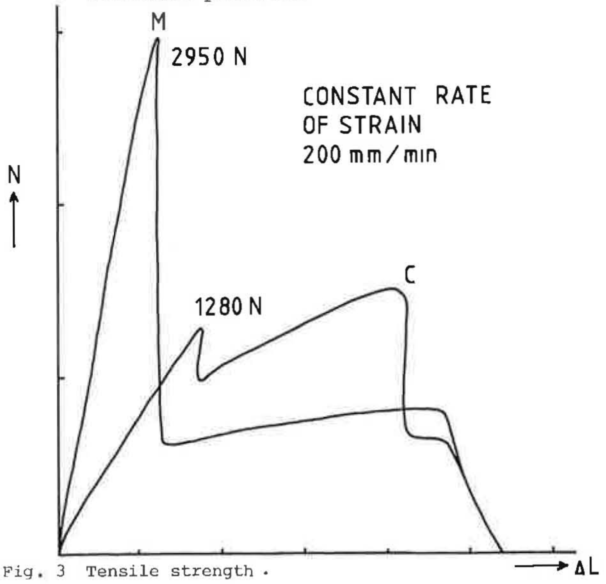


Fig. 3 Tensile strength.

5.2. Description of "Drain Standards"

5.2.1. Tensile Stresses and Strains

The 500 N criterion is based on calculations carried out to estimate the order of magnitude of the tensile forces that can occur during the placing of a drain. A quick tension test in the laboratory is a type of simulation for the field condition. Fig. 3 illustrates the results of the first tension tests performed on prefabricated drain samples.

It is evident that an important consideration concerns the minimum strain value required to prevent failure in tension of any particular component of the drain without total failure. It is clear that the chances of non-functioning drains due to damage during the installation procedure should be minimized.
Consequently, a maximum strain of 10 % has been set as a criterion in order to limit deformations such as reduction in width or in thickness due to installation.
The criteria stated in 4.1.2. is assigned to prevent fundamental alterations in the characteristics of the installated drain such as for example the closing off of the discharge passages due to high horizontal soil pressures.
The determination of a limiting strain value for the filter sleeve presents a problem because the conditions for preventing the choking of the discharge passages in the core conflict with the condition of a high permissible strain value in case of horizontal subsoil deformations.
The above criterion of 120 N strength at 2 % strain has been important in selecting suitable paper filters since in some cases even though their appearance was similar, the behaviour was such that several did not meet the norm.

5.2.2. Filter quality

Conflicting criteria also present a problem for filter specifications. The greater the permeability of the filter, the greater the risk of clogging the discharge passages with silt and clay particles will be.
The upper limit of the filter resistance given in 4.2.1. is initially determined from the resistance of the filter paper of drains (3) that apparently have functioned satisfactorily in the field (Fig. 4).

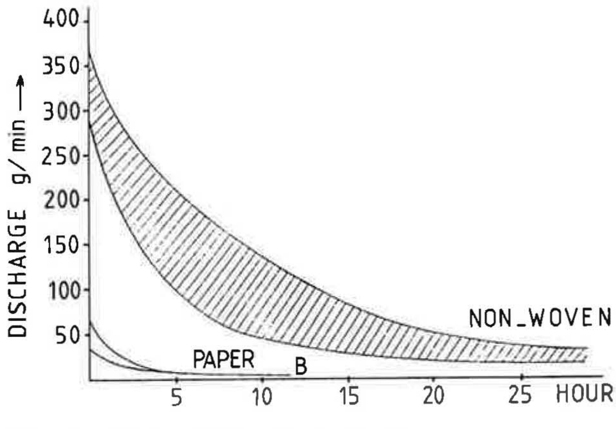


Fig. 4 Filter permeability in wet condition.

Such an upper limit is acceptable for a set of minimum criteria such as those presented in "Drain Standards". The determination of the optimum filter resistance with respect to the soil being drained is beyond the scope of this paper.
The laboratory testing device, apart from some small modifications, is similar to the pressure cell shown in Fig. 5. Very few laboratory tests have been performed for the determination of the required filter efficiency (4.2.2.) and especially with respect to the possibility of blocking the filter.
A research program to study this aspect is being carried out in the Netherlands at the present time.
Useful results are given by Den Hoedt (4) for drains that have been succesfully applied in various projects.

The article also gives an interesting theory concerning the development of a natural filter in the subsoil surrounding the drain. However, the actual occurence of such a phenomenon is difficult to verify.

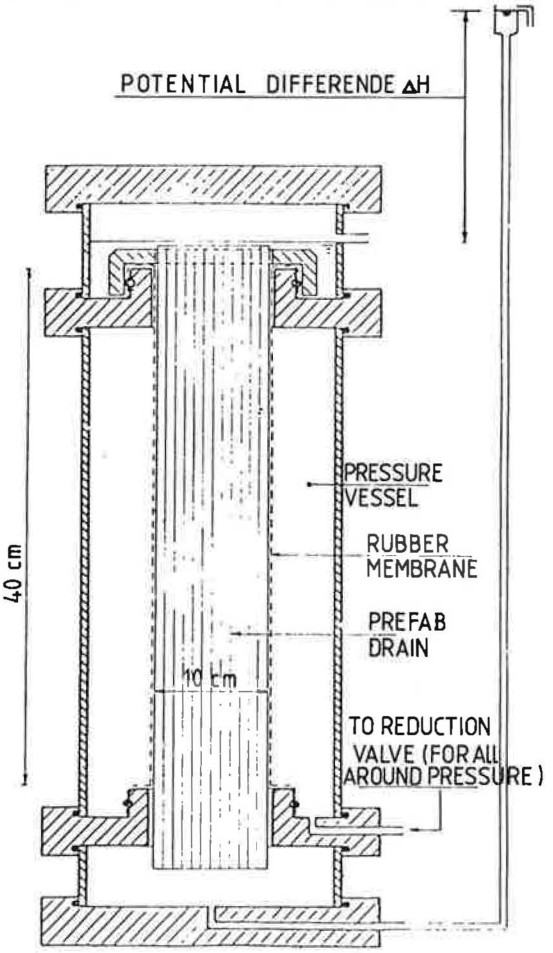


Fig. 5 Test cell.

The ideal manner to confirm this, would be to measure pressures on both sides of the filter sleeve with tiny pore pressure probes.

5.2.3. Discharge Capacity

The discharge capacity of the available drains as measured in the laboratory (3) has in most cases been more than sufficient. At the same time, however, it appears that the vertical discharge capacity can be reduced greatly because of high horizontal pressures (Fig. 5, laboratory testing configuration; Fig. 2, test results).
Furthermore, drains which have been placed in soft soil layers where large vertical strains will develop, may be subjected to strong distortions so that the discharge capacity can be restricted. In the most extreme circumstances, depending on the elastic properties of the drain, it may be folded completely double or even ruptured (Fig. 6).
The lower limit of the vertical discharge capacity is based on those of vertical sand drains. The proposed discharge capacity values of a drain folded double (4.3.2.) has not yet been checked by measurements; this check will most certainly have to be carried out in the future.

5.2.4. Durability and Dependability

To promote the durability and dependability of vertical sand drains, requirements are particularly placed upon the installation procedure, such as a thorough washing of the borehole with clean water, a check on the size of the borehole and a check on certain grain fractions of the filter sand. The filter sand is not subject to any form of deterioration. On the other hand, prefabricated drains may very well experience deterioration, which could be of a chemical, biological or physical nature. However, at the present time little insight is available as far as the deterioration hazards are concerned which various subsoil environments may bring about. As a result, different methods have been examined in which recovery of the drain is possible after an extended period in the soil. A method in which a large diameter casing which was meant to surround the column of soil in which the drain was placed (in order to be able to retrieve the soil plus the drain) did not succeed because of the wedge forming of the soil in the casing.

Fig. 6 Drain folded by vertical strain.

An innovative solution has been found in which the drains are attached to a timber pile in an indentation in the wood. By making a small adjustment to the cross-section of the pile (Fig. 7) the drains will be protected from damage when the pile is extracted.
The disadvantage that the drain is exposed to and drains the soil on one side only is acknowledged.
A set of 6 test piles with 5 different types of drains has been installed at the Diemen test site (2).
The drains will be retrieved at regular 6 months inter-

vals. The tests are being carried out under the auspices of the S.C.W. commission F9 from 1982 to 1984 after which the results will be published.

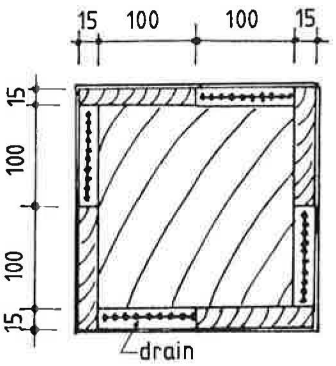


Fig. 7 Cross section of pile for durability test.

5.2.5. Vertical Sand Drains

Up to now, only a few requirements have been placed on the composition of the granular filter material.
A requirement involving the gradation of the sand which can exert an important influence on the working of the drain is not taken into consideration, even though generally moderate permeability test results have been obtained on approved filter sand.
Furthermore, the utilization of a coarse filter sand is important to facilitate the settlement process during the drain installation. The use of fine sands may result in an arch action in the borehole and clay and silt inclusions may also occur.
Along with the material description, the determination of a suitable field procedure was seen as sufficient for the installation of the drains especially in a time of abundant finances and a wide choice of drain materials. However, the current poor economic situation together with the new availability of prefabricated drains have resulted in the need for a more defined formulation of requirements with respect to the material composition, the characteristics and the installation of the drains.

6. ADDITIONAL QUALITY STANDARDS

Drains which are used to facilitate settlements under low embankments are permitted on the basis of an inspection test report according to "Drain Standards" as described in 3.5.
In cases where more stringent criteria are to be applied due to the nature of the works (e.g. a high surface load, marginal slope stability, a limited time for consolidation) or the nature of the subsoil (e.g. low permeability of the soil, very thick soft deposits, high compressibility, low shear resistance) the drains are subject to additional quality standards. This may be achieved by specifying higher limiting values for the tests described in "Drain standards" or by requiring is situ measurements during and after construction periods or during field tests.
To attain this goal, a general procedural method is planned to be set up in which different types of ground works are described with different requirement levels.
In view of the fact that in practice many parameters are involved which influence the working of the drain and are dependent on the soil-structure interaction, it is reasonable to set as an initial acceptance criterion the demonstrated succesful operation of the drain in a certain project for soil works in which more demanding conditions are to be expected.
In addition to developing quality standards which are adapted to the in situ application as well as the specific task of the drain in a certain work, a more deliberate method of choosing the drain and determining the drainage design is afforded the engineer as well as the contractor and the supplier.
Also for these additional quality standards the laboratory tests as well as the field measurements must be clearly described.

7. CONCLUSION

To ensure the succesful operation of vertical drains quality specifications have to be determined.
It has been shown that with the aid of laboratory tests a set of minimum criteria may be applied to the drain. More in situ measurements, preferably of a simple nature, need to be carried out to establish a better relation between the laboratory test criteria and the field results. At the same time, these measurements will stimulate the optimalization of drain design.
It will be greatly appreciated if comments or additions are given on the proposals described in this paper.

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