31, No. 1, March, pp. 17-29 (also in Vertical Drains, Thomas Tedford, Ltd., London, 1982).

15. Hansbo, S. (1979), "Consolidation of Clay by Band-Shaped Prefabricated Drains," Ground Engineering, Vol. 12, No. 5, July, pp. 16-25.

16. Atkinson, M. S. and Eldred, P. J. L. (1981), "Consolidation of Soil Using Vertical Drains," Geotechnique, Vol. 31, No. 1, March, pp. 33-43 (also in Vertical Drains, Thomas Tedford, Ltd., London, 1982).

17. Carillo, N. (1942), "Simple Two-and Three-Dimensional Cases in the Theory of Consolidation of Soils," J. Math and Phys., Vol 21, pp. 1.

18. Long, R. P. and Carey, P. J. (1978), "Analysis of Settlement Data from Sand Drained Areas," NAS-NRC Trans. Res. Board, Trans. Res. Rec., No. 678, pp. 36-40.

19. Long, R. P. (1982), Discussion: Performance of Vertical Drains at Queensborough Bypass, Vertical Drains, Thomas Telford Ltd., London, pp. 146-7.

20. Long, R. P. and Hover, W. H. (1984), "Performance of Sand Drains in a Tidal Marsh," Int. Conf. on Case Histories in Geotechnical Engrg., St. Louis, MO., Vol. III, pp. 1235-44.

21. Long, R. P. and Healy, K. A. (1976), "Analyzing Field Data for Rapid Settlements," NAS-NRC Transportation Research Board, Trans. Res. Rec. No. 616, pp. 74-77.

WICK DRAIN SELECTION AND DESIGN

By

Joseph B. Hannon, P.E.

Senior Materials and Research Engineer
California Department of Transportation

Vertical sand drains have been used effectively in the past by Geotechnical Engineers for accelerating the consolidation of soft compressible foundation soils. However, their use has been virtually eliminated in the United States during the last few years by the use of prefabricated wick drains. The innovative efforts of Caltrans and others have helped stimulate this new technology (1), (2), (3), (4).

The first version of the wick drain originated from the "cardboard wick" invented by Kjellman in 1939 (5). Several other versions later developed into presently available technology.

Prefabricated wick drains or band-shaped drains as they are sometimes called are generally about 4-inches wide and vary in thickness from 1/16 to 1/4 inch. These drains usually consist of a center core of plastic or cardboard providing vertical drainage channels. The core is usually wrapped with an outer sleeve of either pervious paper or a nonwoven synthethic geotextile. Wick drains offer several advantages over vertical sand drains. For example:

1. Wick drains are flexible and can withstand considerable deformation without failure, thus maintaining drainage continuity and function. Sand drains would probably shear under the same conditions and cease to function.

2. Wick drains can also be installed rapidly and at lower cost than sand drains and soil disturbance is generally less.

Wick drains are designed using the same theoretical considerations as sand drains based on Barron's adaptation of Terzaghi's theory of consolidation (6). Because wick drains are not round, to use Barron's equations, an "equivalent sand drain diameter" is necessary, and several interpretations of equivalent diameter have been developed by various investigators. For example, one method gives the equivalent diameter as the diameter of a circle having a circumference equal to the perimeter of the wick drain (7). Another method uses the concept of a "free filter area" of a drain (8).

Since there is considerable disagreement on the proper procedure for determination of equivalent diameter, Caltrans has arbitrarily assumed that the best performing wick drains are approximately equivalent to a 6-inch diameter sand drain. This assumption recognizes the possible existence of sand lenses, which provide more favorable horizontal drainage, and a general conservatism in predicting the coefficient of consolidation. The effect of disturbance is impossible to predict without considerable experience.

To ensure predictable performance of a given installation, proper wick selection is one primary key to a successful project. The second key to success is a reasonable prediction of the coefficient of consolidation of the soft foundation material to be consolidated.

When wick drains were first introduced in California, one consultant was unsure of the performance of this new technology. He therefore applied a "suspender and belt" approach to vertical drain design. His design called for sand drains with wick drains installed in the center of each sand drain. Reliance on wick drains has since improved through several successful installations.

Caltrans has found through field installation and laboratory testing that good performance can be expected from drains supplied by several different vendors, if properly installed and monitored with instrumentation.

Other wick drains may also provide good performance but must be pretested since some may have questionable flow characteristics that are undesirable and can result in excessive pore pressures and foundation instability during loading. New York State's basis for acceptance and specification of wick drain material is described in the following article by Suits and Gemme.

The time required for consolidation for a given installation can be determined for wick drains using the following simplified

Barron-Kjellman formula for radial drainage (Fellenius 8, 9):

$$t = (D^2/8C_h)\ [\ln(D/d_e) - 0.75]\ \ln[1/(1 - \bar{U})] \quad (1)$$

where

t = time,
C_h = horizontal coefficient of consolidation,
D = zone of influence of a drain,
d_e = equivalent diameter of a drain, and
$\bar{U}$ = average degree of consolidation.

This equation assumes that 1) both soil permeability and compressibility are constant 2) Darcy's law is valid; and 3) only radial and horizontal flow takes place.

In addition to proper wick drain selection, proper spacing and correct installation method, each installation project should include construction controls on rate of loading and a detailed instrumentation monitoring program to ensure stability during critical loading periods. Such a system is described by Walsh in his companion article on construction control. Also, a research film report by Caltrans, titled, "The Dumbarton Experience" is available. This film describes soils instrumentation and the use of wick drains and other technology such as lightweight fill and geotextiles to construct highway embankments over soft compressible bay mud soils.

REFERENCES

1. W. George, "Experimental Evaluation of Vertical Plastic Drainage Wicks 'Alidrains' in Illinois", FHWA, Highway Focus, Vol. 12, No. 2, Apr. 1980.

2. J. Hannon and T. Walsh, "Wick Drains, Membrane Reinforcement, and Lightweight Fill for Embankment Construction at Dumbarton", Transportation Research Record 897, p. 37-42, Jan. 1982.

3. C. Seim, T. J. Walsh and J. B. Hannon, "Wicks, Fabric and Sawdust Overcome Thick Mud", Civil Engineering, ASCE, p. 53-56, July 1981.

4. A. Morrison, "The Booming Business in Wick Drains", Civil Engineering, ASCE p. 47-51, March 1982.

5. W. Kjellman, "Accelerating Consolidation of Fine-Grained Soils by Means of Cardboard Wicks", Proceedings, Second International Conference on Soil Mechanics and Foundation Engineering, Vol. 2, 1948.

6. R. A. Barron, "Consolodation of Fine Grained Soils by Drain Wells", Transactions, ASCE, Vol. 113, 1948.

7. S. Hansbo, "Consolidation of Clay by Band-Shaped Prefabricated Drains", Ground Engineering, Vol. 12, No. 5, July 1979.

8. B. H. Fellenius, "The Background and Theory of Vertical Drains with Particular Reference to the Alidrain", Lecture Notes, Skelleftea, Aug. 1977.

9. B. H. Fellenius, "Consolidation of Clay by Band-Shaped Prefabricated Drains", Ground Engineering, Vol. 14, No. 7, Oct. 1981.

NEW YORK STATE DEPARTMENT OF TRANSPORTATION'S (NYSDOT) BASIS OF ACCEPTANCE AND SPECIFICATION FOR PREFABRICATED WICK DRAINS

By

L. David Suits, Soils Engineer Lab. Supervisor
Raymond L. Gemme, Associate Soils Engineer

The basis of acceptance and a specification for the use of prefabricated wick drains on NYS DOT projects was developed following an extensive three stage testing program of thirteen (13) prefabricated wick drains presently on the market. The three stages of testing included large diameter consolidation (LDC), crimp, and lateral pressure (crush) tests. The following is a summary of that test program. Reference 1 provides a detailed review of this program.

Following this is the present NYS DOT wick drain specification which is an "Approved list" type of specification. The ten drains which were determined to be acceptable for use on NYS DOT projects in 1985 are listed.

The results of the LDC testing program indicated that most of the prefabricated drains tested produced average equivalent sand drain diameters of between 1.5 and 2.5 inches. A 2.5 inch equivalent diameter drain will drain a soil 20% faster than a 1.5 in. equivalent diameter drain. What this means in a field application is that a 2.5 in. equivalent diameter prefabricated drain installed at a 5.5 ft. drain spacing is as effective as a 1.5 in. equivalent diameter prefabricated drain installed at a 5 foot drain spacing. In other words, the range in the average equivalent diameter drains for most of the prefabricated drains tested had very little effect on the required prefabricated drain spacings. We therefore assumed prefabricated drains, with average equivalent diameter drains between 1.5 and 2.5 inches, to be equal in performance and to be acceptable.

Those prefabricated drains that were not allowed in the specification were those which had average equivalent sand drain diameters less than 1.5 inches or those which did not have a rigid core, or both. The laboratory crush tests have indicated a 12± percent loss in core flow capacity for rigid core prefabricated drains subjected to a crush load of 13.5± psi. On the other hand, a 50 to 90% loss in core flow capacity was experienced for the soft core prefabricated drains subjected to the same crush load.

The laboratory flow through the rigid core prefabricated drains noted in the specification in a crimped state ranged from 30 cc/sec to 210 cc/sec. The crimped flow for the soft core prefabricated drains was 16± cc/sec. The crush test further reduced this number to as low as 1.6 cc/sec. The flow was further reduced to 0.3± cc/sec when taking into account the theoretical loss in flow due to the length of a typical prefabricated drain field installation (60 ft. long in this study). This is considered insufficient to accommodate the consolidation flow of water emerging from the surrounding soil in a typical field application.

Based on the results of the testing program