

Eccentric (Angled) Loading of Prefabricated Highway Edge Drains

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A new test procedure is described for evaluating the performance of a prefabricated drainage system (PDS) when subjected to loading that is other than normal to the plane of the core. A PDS is an in-plane drain specifically manufactured from polymer materials for subsurface drainage applications, in particular, highway edge drains. A PDS is commonly manufactured from a preformed semirigid polymer core and covered with a geotextile. The major function of the core is to transport water. However, the core must also provide support for the geotextile filter and must resist installation and in-service stress and deformation in order to maintain the design drainage function. One of the factors that can adversely affect the performance of the PDS edge drain is eccentricity of loading or loading occurring at angles other than those normal to the core. Angled loading can adversely affect the compressive failure or collapse of the core, especially a core that is direction dependent. The test apparatus and procedures used in this study are described and results are illustrated for eccentric testing carried out on four popular types of PDS highway edge drains. This type of testing is also suitable for evaluating the eccentric loading that would occur on other types of PDS applications such as sloped walls, vertical or sloped cutoffs, embankments, or landfill side slopes.

One of the newest geosynthetic materials to be applied to civil engineering projects is the geocomposite drain, or prefabricated drainage system (PDS). A PDS is an in-plane drain specially fabricated for subsurface drainage applications such as sloped or vertical walls, embankments, cutoffs, or highway edge drains. A PDS is commonly manufactured from a semirigid formed core (high profile) and typically covered with a geotextile. The major function of the preformed core is to transport water within its plane. However, the core also must provide support for the geotextile and must be structurally designed to resist installation and in-service stress in order to resist crushing or collapse. The geotextile serves two major functions: as a filter between the surrounding soil and the open core and as the outer boundary of the core flow area.

Geocomposite PDSs used for pavement edge drains on highway and airport runway projects have grown from experimental status in 1982 to being widely accepted standard contract items in 1990. These installations have been generally successful, with a few exceptions. Structural problems have occurred where loads have caused large deformations because of core instability. This can be a particular problem on projects in which pavement rubblizing or cracking and seating is done after installation of the edge drain.

The Kentucky Department of Highways has experienced edge-drain structural problems on crack-and-seat pavement

rehabilitation projects on the Western Kentucky Parkway, the Mountain Parkway, and Pennyryle Parkway. Borescope investigations found that post or cuspatation displacement on each of these projects caused collapse or partial collapse of the geocomposite.

In Michigan, New York, and Kentucky, problems have been experienced with localized crushing of cuspatated panels on a number of projects. The cuspatations could have been deformed by shipping and installation in Michigan and Kentucky. The New York State Thruway Authority has experienced panel collapse against subgrade voids during backfill installation procedures.

In all of the foregoing examples, it is possible that the failures were the result of installation stress or postinstallation stress induced at angles other than those normal to the plane of the core. The potential effect of confining stress and installation stress and the resultant reduction in core cross-sectional area (and therefore flow performance) are critical to drain design and performance. Obviously, an important characteristic for the PDS is the ability of the core to resist imposed stress without deforming. To date, stress testing on core structures used as highway edge drains has been limited to normal compressive loading, and the manufacturers report crush resistance of their core using various methods and rigid plate sizes. It has been found that small plates (± 4.25 in. square) are not recommended in testing of semirigid core structures (1). Results of compression tests are useful primarily as an index test for the preliminary comparison or screening of products; however, because of the variability of core structures, larger specimens (± 12 in. square) have been recommended (1).

Normal compressive strength testing is only one relative measure of the short-term ability to withstand stresses on the drain due to adjacent soil pressures, installation method, backfilling method, or loads from vehicular traffic immediately above and adjacent to the drainage trench.

According to Kraemer and Smith (1), factors that can adversely affect the results of compression tests and therefore field performance are small sample size, eccentricity of loading, and the presence of secondary yield phenomena due to the geometry of the core. Eccentricity of loading or loading occurring at angles other than those normal to the core can affect the compressive failure or collapse of a core, especially a core that is highly direction dependent (1).

In an effort to study the effects of loading eccentricity on core type in the laboratory, a special load frame device was designed and used to evaluate core structures when subjected to loading other than normal compressive loading. Results of this testing are the subject of this paper.

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ECCENTRIC LOAD FRAME

A special aluminum load frame was designed and built to accommodate testing of 12-in.-wide geocomposite highway edge drains in a standard compression testing machine. The load frame was also designed to be locked at a desired test angle. Figure 1 is a conceptual drawing of the frame and upper loading platen. Both upper loading platen and lower adjustable load frame have removable surface plates so that the surface friction material can be changed when desired. The rotating base table can be locked into position at increments of 10 degrees from 90 (normal compression test loading) to 10 degrees. Figure 2 shows the load frame positioned in a compression test machine and Figure 3, the test device with specimen in place. The upper platen dimensions are 12.5 in. by 13.0 in., allowing the testing of a full width of nominal 12-in.-wide edge drain by a length of 12.5 in. Specimens were cut a minimum of 15 in. long in an effort to avoid possible edge effects.

TEST METHOD

The test method was designed to evaluate the effect of eccentric (angled) loading other than loading normal to the plane of the drainage core. After numerous preliminary test

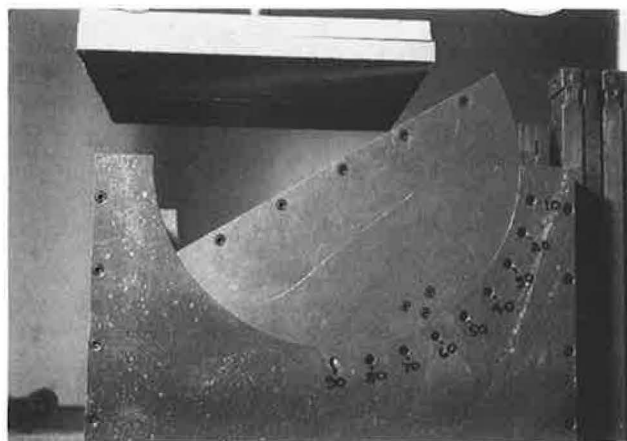


FIGURE 2 Load frame.

runs on different types of PDS cores and angles, and at various rates of loading, it was decided to run all tests, including normal compressive loading, at 0.5 in./min as specified in ASTM D2412-87. This speed enabled testing to be carried out efficiently at all test angles, and it more closely approximates "instantaneous" loading such as that found during or immediately after installation. This testing did not address the potential problems associated with creep of polymer cores

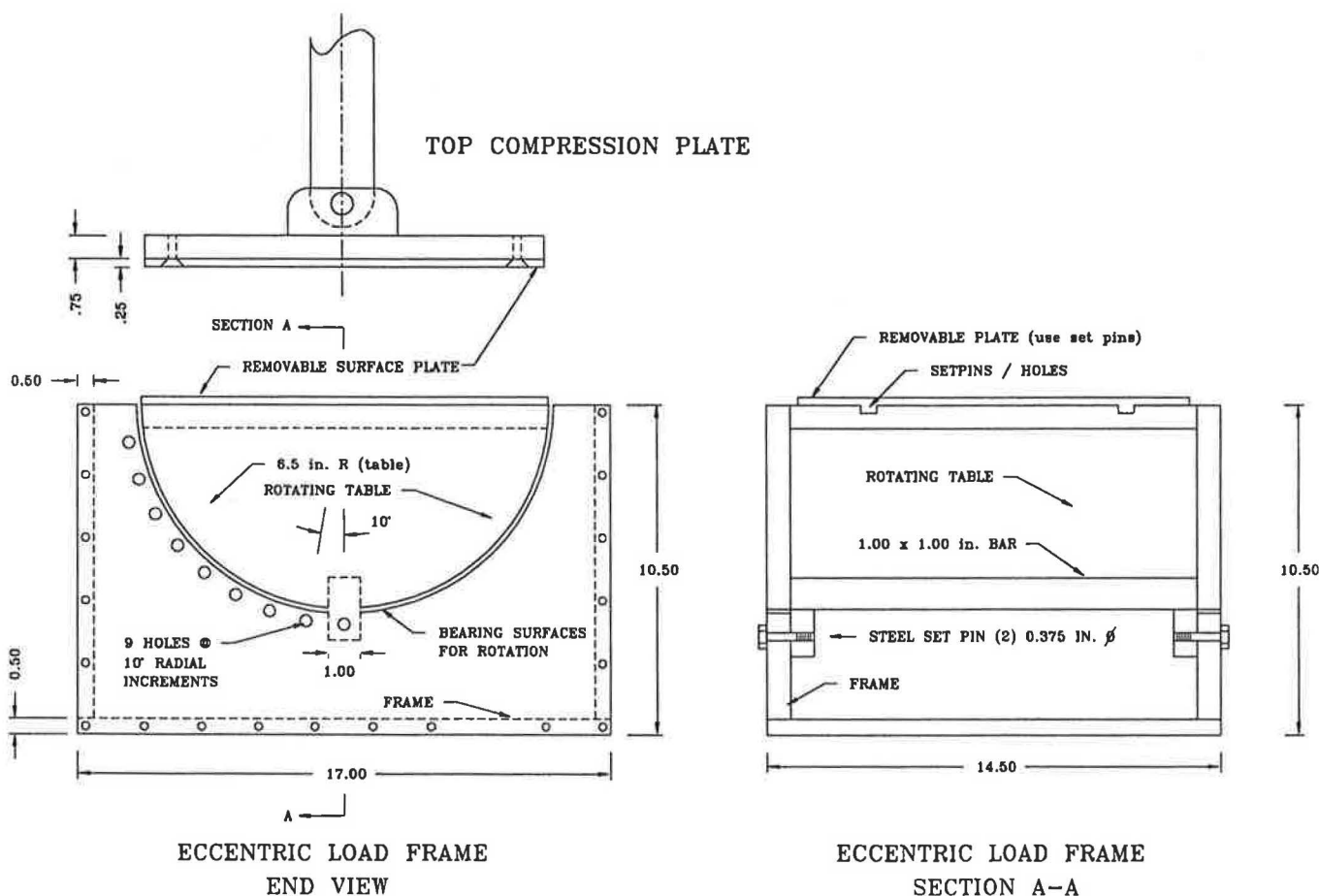


FIGURE 1 Design drawing of load frame device.

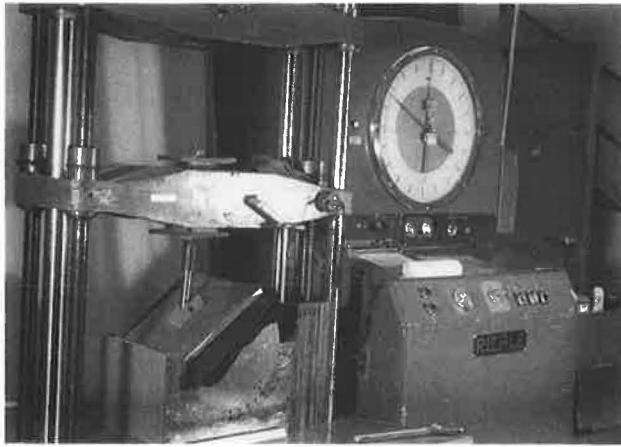


FIGURE 3 Load frame with test specimen in place and positioned in compression test machine.

under normal or eccentric loading. Creep of cores in normal compressive loading has been reported by Smith and Kraemer (2). The following is a summary of the test methodology used.

Test Equipment

Test Machine

Any suitable compression test machine capable of operating at a constant rate of traverse and capable of stress-strain measurement by autographic recorder can be used. It is desirable that the load cell be located in the base of the test machine as opposed to on the moving crosshead.

Test Base Frame

The frame is a specially designed rotational frame that allows the specimen to be rotated on a platen between 10 and 90 degrees to the vertical and that can be locked in place at minimum 10-degree increments (see Figure 1).

Upper Loading Platen

The upper loading platen should be attached to the moving crosshead and allowed 2 degrees of freedom in movement. Platens should be covered with a removable high-surface-friction material such as a cellular neoprene or 40-grit commercial-grade abrasive paper.

Load Indicator

The load indicator should have a precision of ± 0.1 percent.

Deformation Indicator

The deformation indicator should have a precision of ± 0.1 percent.

Test Specimens

Test specimens should be the manufactured width (± 12 in.) and 15 in. long. Width dimension should be positioned on the lower platen in the direction of eccentric loading and placed against the stop. The specimen should be allowed to extend beyond the sides of the loading frame to prevent edge effects.

Test Condition

The test should be conducted in standard laboratory atmosphere of $23^\circ \pm 2^\circ\text{C}$ ($73.4^\circ \pm 3.6^\circ\text{F}$) and 50 to 65 percent relative humidity.

Test Procedure

Platen Alignment

The bottom platen should be set to the desired angle, the upper platen lowered to within 0.5 in. of the bottom, and the test frame adjusted to accommodate upper platen movement with a fully loaded specimen.

Crosshead Motion

The load should be applied so that it is distributed uniformly over the entire loading surface of the specimen. Rate of crosshead movement should be 0.5 in./min (± 0.01 in./min).

Crosshead movement should be continued until a yield point or collapse is reached or until the specimen has been compressed to approximately 25 percent of its original thickness. Once a yield point has been reached, movement of the crosshead should be continued another 3 percent.

Calculation

A calibrated X-Y plotter or autographic recorder should be used to accurately record load-deflection curves and the estimated 10 and 20 percent and yield point deflection loads.

Report

The report should contain specimen identification, including the thickness and manufactured width, weight, type of geotextile; the angle of the lower platen; the number of specimens tested; the load and deformation values at 10 and 20 percent, yield, and failure; and observations of deflection mode and failure modes.

Compressive Properties

Normal Loading

All specimens should be tested for standard compressive strength characteristics using ASTM D 2412 with the following changes:

Specimen size: width (± 12 in.) by 15 in.;
Upper platen size: 12.5 in. by specimen width; and
Number of specimens: minimum of five.

Eccentric (Angled) Loading

All specimens should be tested at the desired inclination, with a minimum of five specimens for each angle.

PDS HIGHWAY EDGE-DRAIN SAMPLES USED

Four types of the most common and geometrically different cores used as highway edge drains were chosen for this testing:

- A: double cusped (Hitek-type);
- B: single cusped, truncated conical cusps with perforated base;
- C: oblong (elongated) corrugated pipe section with slotted perforations; and
- D: high-profile columns with perforated base.

All the above products are manufactured from polyethylene base resin. Core Types A and D polyethylene resins are classed as low-density polyethylene (LDPE), whereas Type B and C resins are classed as high-density polyethylene (HDPE). The core profiles used in this testing and their approximate dimensions and weights are shown in Figure 4.

All cores were wrapped with a nonwoven, needlepunched geotextile. Two core types (A and D) were wrapped and adhesively or thermally bonded to all of the cusps or columns, as well as to the base (in the case of Core D). Bonding of the geotextile will impart greater stiffness to the core structure and give added stability under load, especially loads occurring other than normal to the plane of the drain core. For the cusped or column-type cores (A, B, and D), the geotextile must act as a part of the structural composite or outer boundary and also as a soil filter. For Core C, the geotextile acts only as a soil filter. The geotextile selected for use with Cores B and C could be varied for given soil conditions without affecting the structural performance. The geotextiles used on the cores tested were as follows:

Core Type Geotextile

- A Nonwoven, needlepunched staple fiber polypropylene, heat set on one side, adhesively bonded to all cusps; weight, 4 oz/yd²
- B Nonwoven, needlepunched continuous-filament polyester; weight, 4.1 oz/yd²
- C Nonwoven, needlepunched staple fiber polypropylene, heat set on one side; weight, 3.5 oz/yd²
- D Nonwoven, needlepunched staple fiber polypropylene, heat set on one side, thermally bonded to base and all columns; weight, 4.5 oz/yd²

SUMMARY OF TEST RESULTS AND OBSERVATIONS

Throughout the following discussion, test samples will be referred to by structure or core type letter as shown in Figure 4.

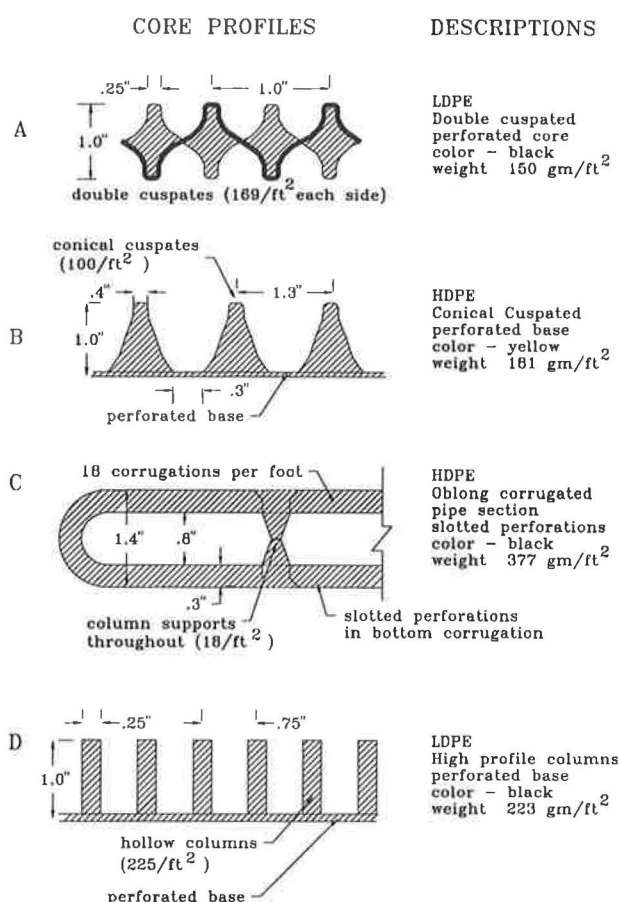


FIGURE 4 Drain core structural profiles.

In general, all the core structures were testable at 90, 70, and 50 degrees. However, the stiffer, heavier-weight Cores B and C were difficult to test at higher angles and resulted in surface slippage and no significant deformations beyond 10 percent. Cores A and D were more prone to deformation and could be tested at all angles. At 10 degrees, Core D deformed easily but could not be accurately measured as to load versus deflection.

Normal compressive testing (90 degrees) was carried out on all core types as a basis for comparison with eccentric load angles. Table 1 shows the normal loads when tested at 0.5 in./min. Figures 5 through 8 are load deflection curves for Cores A through D tested at various angles. As a general method of comparison, loading at approximately 20 percent deflection will be examined in the following paragraphs.

Core A (Figure 5) exhibited only a 17.6 percent drop in load at 70 degrees as compared with normal loading but showed

TABLE 1 AVERAGE NORMAL LOADING OF CORE TYPES

Core Type	Deflection (%)		Failure
	10	20	
A	2,157	5,650	8,832
B	1,498	5,540	11,324
C	2,563	6,307	7,305
D	3,600	15,100	16,000

NOTE: Normal loads are given in pound-force per square foot.

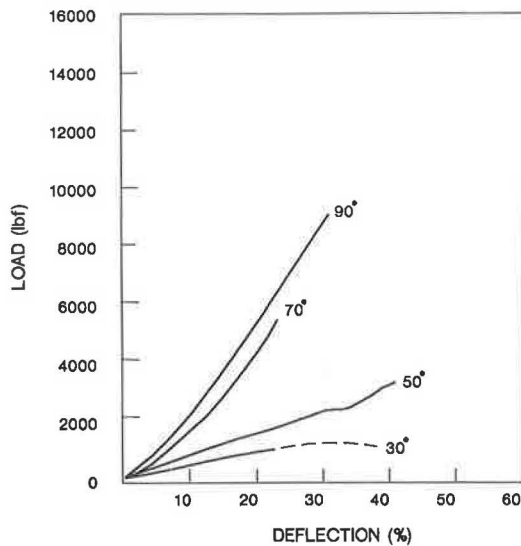


FIGURE 5 Load deflection curves: Core A.

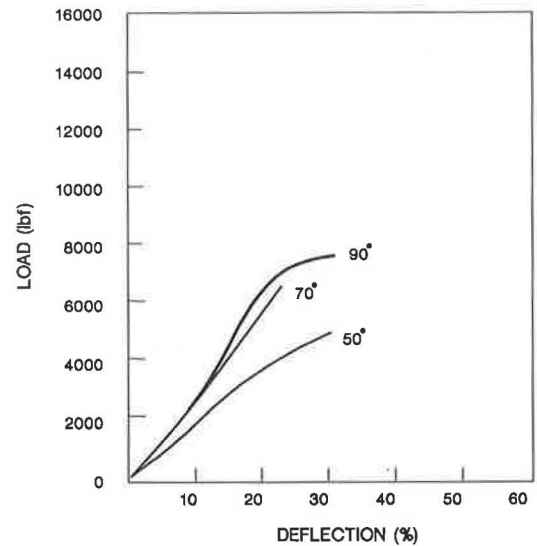


FIGURE 7 Load deflection curves: Core C.

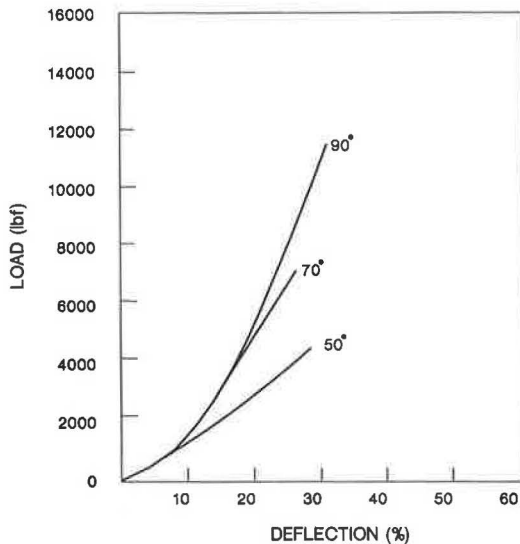


FIGURE 6 Load deflection curves: Core B.

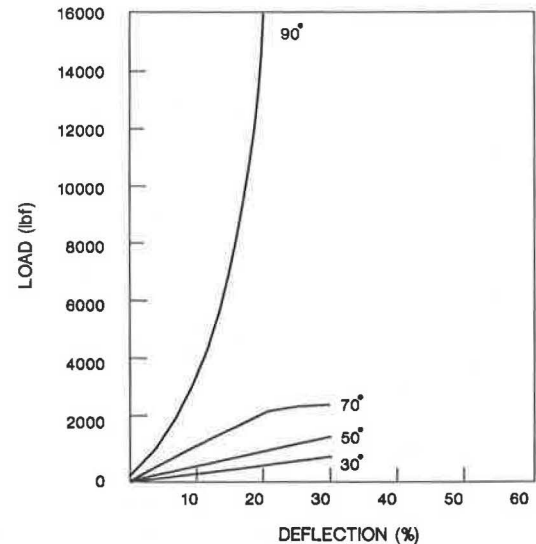


FIGURE 8 Load deflection curves: Core D.

a 71.5 percent loss at 50 degrees and an 83 percent loss at 30 degrees. At the higher angles of 20 and 10 degrees, it was difficult to obtain accurate readings because of the "rolling over" of the core cusps. Also, the adhesive bonds between geotextile and core were observed to break under stress. Core failure was predominantly due to buckling of the extended part of the cusps, as shown in Figure 9. The relatively inconsistent quality, low mass, and polymer type were contributing factors in the low failure loads exhibited. Total failure of the core occurred at varying deflections between 22 and 40 percent.

Core B exhibited only a 6.5 percent drop in load at 70 degrees as compared with normal loading and a 49 percent drop at 50 degrees. Because of the relatively stiff structure of the cusped cones, testing at 30 and 10 degrees resulted in surface slippage and rebounding of the cusps to their original position. The upper edge of the core tended to roll as

the geotextile pulled at high-angle loading, as shown in Figure 10. Failure of the cusps occurred at the weakest cross section approximately 0.3 in. from the top, as shown in Figure 11. Failure was by collapse or folding of the cusps in the direction of load. Because of the stiff properties of the core, there was no change in loading at 10 percent deflection for 70 degrees and only an 11.5 percent drop for a 50-degree angle. However, the amount of loading to fail the core at 50 degrees dropped by 62 percent from that at 90 degrees (normal). Ultimate core failure occurs at between 28 and 30 percent total deflection.

Core C was unique in structure in that it is essentially an oblong corrugated pipe section with the corrugations running in the direction of angled loading. The core structure derives its stiffness from the corrugations and interior columns. This product exhibited a relative loss in loading of 12.6 percent at 70 degrees as compared with normal loading and 43.5 percent

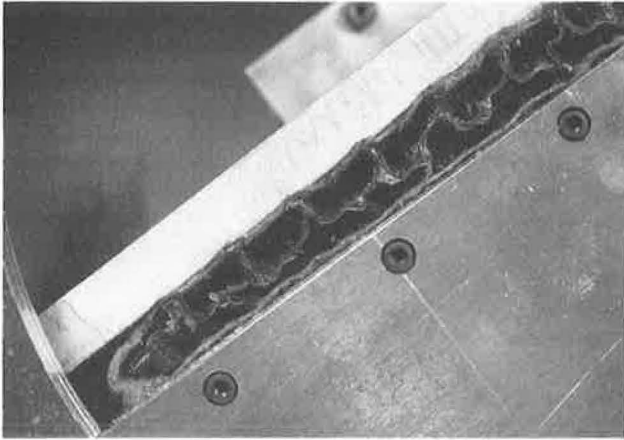


FIGURE 9 Core A: failure mode.

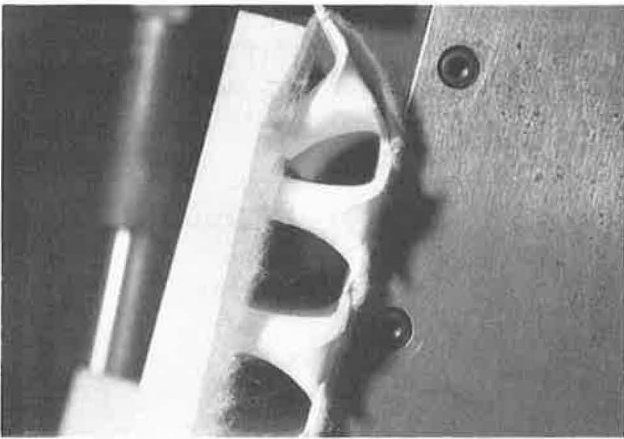


FIGURE 10 Core B: upper edge rollup.

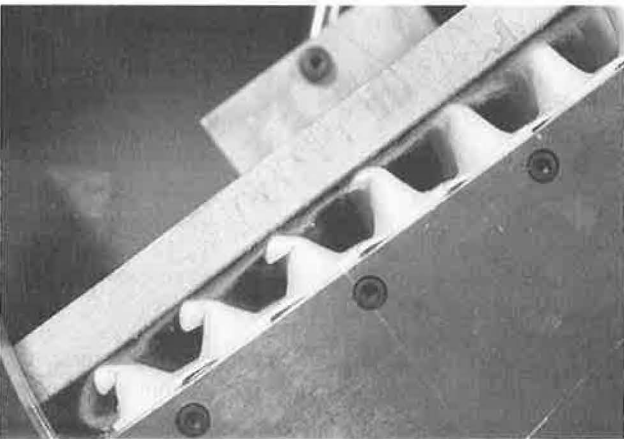


FIGURE 11 Core B: failure mode.

at 50 degrees. As with Core B, accurate load deflection readings were not possible at high angles because of surface slippage and stiff core properties. Failure at 50 degrees required less loading (35 percent drop in load) than at 90 degrees. Ultimate failure always occurred at approximately 25 to 30 percent deflection. Figures 12 and 13 show the core before loading and deformation at 20 percent deflection.

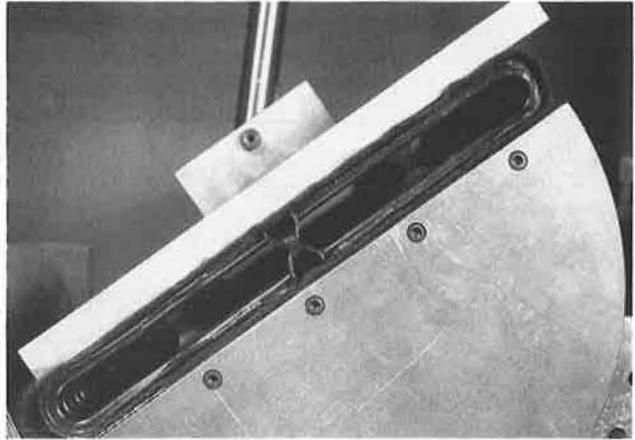


FIGURE 12 Core C: before testing.

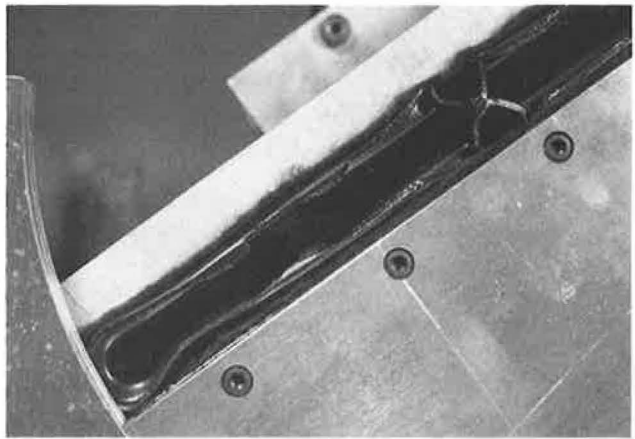


FIGURE 13 Core C: deformation at 20 percent deflection.

Core D, although exhibiting very high normal loading (16,000 lbf/ft²), showed a distinct disadvantage when subjected to angled loading in that the high-profile hollow tubular columns tended to bend and collapse, sometimes instantaneously. At 20 percent deflection (also the failure deflection), Core D showed a significant change in loading values. At 70 degrees, it exhibited an 83 percent drop in load as compared with normal, a 93 percent drop at 50 degrees, and a 96 percent drop at 30 degrees. Most significant, however, even at a low angle of 50 degrees, the ultimate failure load or crush strength dropped from 16,000 to 2,250 lbf, and 85 percent drop in loading. Failure occurred by column foldover, with ultimate base fracture at the connection of column to base (Figures 14–16 show the column collapse mechanism).

For comparison purposes, Figures 17–20 show all products tested at a given angle of inclination. Again, with the load at 20 percent deflection, one can see from Figure 17 that there is a significant difference among Cores A, B, C, and D. As soon as the angle of loading is changed to only 70 degrees (Figure 18), Cores A, B, and C vary between 9 and 18 percent of each other, whereas Core D drops off significantly, exhibiting less than 50 percent of the loading that the other core types will sustain. At an angle of 50 degrees (Figure 19) there is an even greater difference in load deflection curves; Core C exhibits the best overall performance and the highest com-

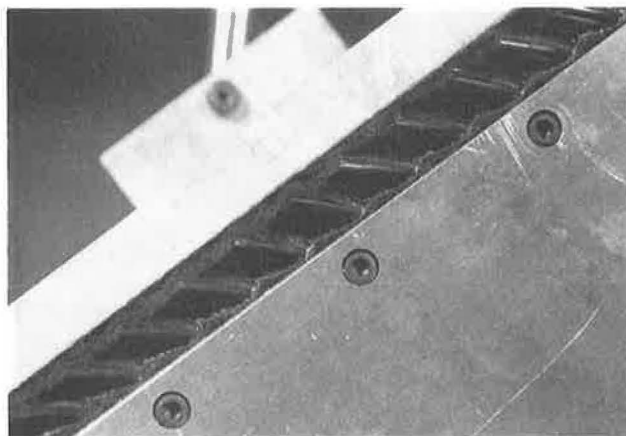


FIGURE 14 Core D: failure mode (column bending).

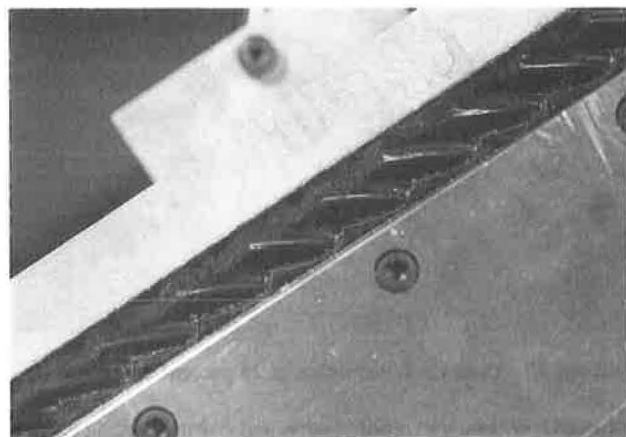


FIGURE 15 Core D: column collapse.

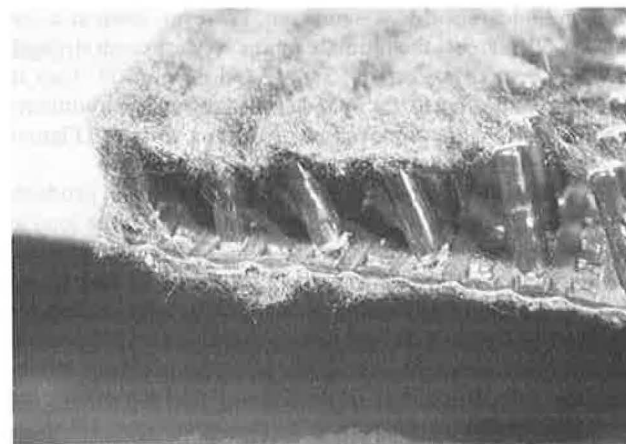


FIGURE 16 Core D: column base fracture.

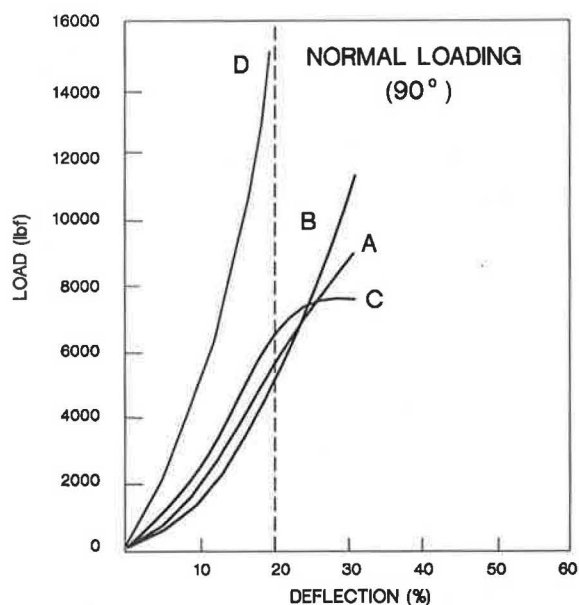


FIGURE 17 Load deflection curves: normal loading.

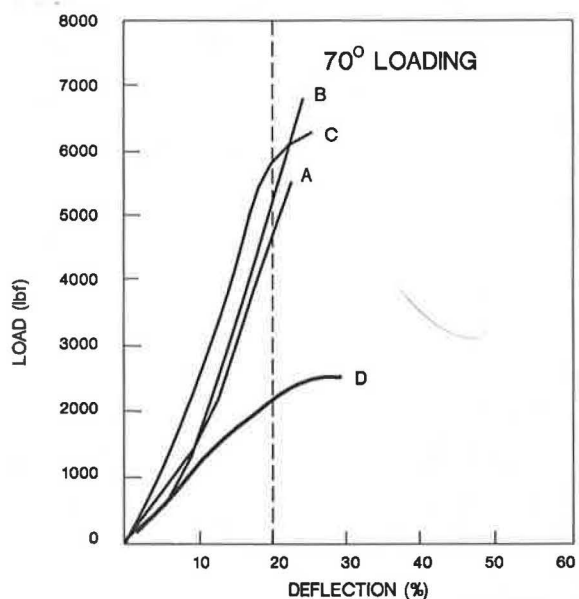


FIGURE 18 Load deflection curves: 70-degree loading.

pressive modulus. Core D exhibits the greatest reduction in initial modulus, loading at 20 percent deflection, and ultimate failure load.

SUMMARY AND CONCLUSIONS

A special laboratory method has been presented designed to evaluate core stability for prefabricated core structures. Although this testing does not represent actual in situ conditions, it does illustrate the significant difference in load deflection properties of PDS cores when subjected to eccentric (angled) loading. Loading of this type can and does occur during in-

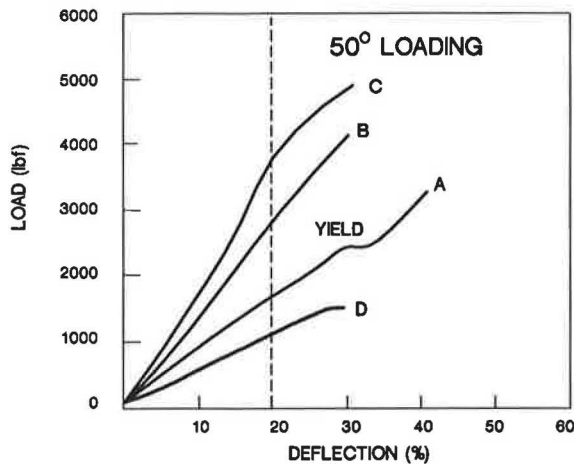


FIGURE 19 Load deflection curves: 50-degree loading.

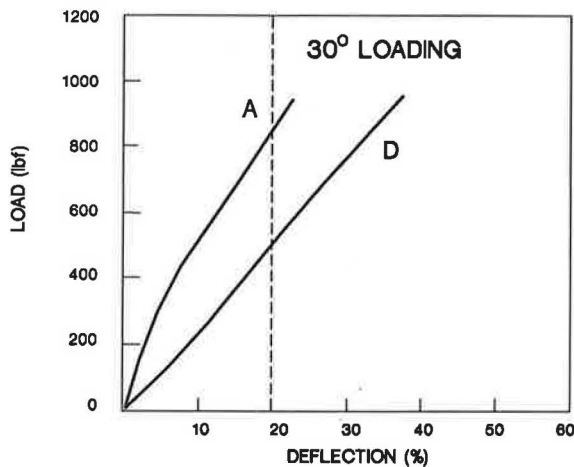


FIGURE 20 Load deflection curves: 30-degree loading.

stallation and compaction and after installation and may account for observed field failures (collapse) of certain core types. This type of testing is relevant as an index test for PDS cores used in sloped or vertical walls, cutoffs, embankments, or highway edge drains.

For this study, four commercially available highway edge-drain products were tested at selected angles of loading. The four products were chosen to represent the extremes in core geometry found in today's PDS highway edge drains. Two of the core structures (Cores B and C) were found to be relatively stable under angled loading, whereas Cores A and D were prone to collapse.

It is obvious that this type of laboratory testing should be examined further as a method to determine PDS core stability when subjected to loads other than those normal to the core. Both normal compressive load tests and testing at a predetermined angle or angles should be accomplished on all types of high-profile prefabricated drain cores. Curves of normal compressive stress versus deformation are virtually useless as a design tool in determination of factors of safety if a product's compressive stress drops by more than 50 percent upon application of load at even a small eccentric angle.

ACKNOWLEDGMENT

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