

Field and Laboratory Comparison of Pavement Edge Drains in Kentucky

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A new test procedure developed by Kentucky Transportation Center investigators for testing highway panel drains is introduced. Because of installation problems and possible siltation problems, the Kentucky Department of Highways, since 1989, has been installing panel drains on the back side of the trench with the more open side of the panel facing a sand backfill. A test procedure was developed to simulate field installation conditions.

Kentucky Transportation Center investigators have been evaluating panel-type edge drains since 1985. Several edge drain failures occurred in earlier installations. The majority of the earlier panel drains were placed next to the concrete pavement and backfilled with the excavated trench material, which was dynamically compacted. The dynamic compaction (vibrating tamping skid or shoe) tended to collapse the core of the edge drains. In response to this problem, Kentucky Department of Highways officials reevaluated the installation procedure. Since 1989, the edge drains have been installed on the shoulder side of the trench and backfilled with a sand slurry. The sand is flushed into the trench using approximately one gallon of water per linear foot of edge drain. The sand slurry minimizes construction problems (if the sand is properly densified), and the sand provides an extra filter medium. In the past 6 years, hundreds of sites have been examined with a borescope. In almost all cases, the edge drains installed with the sand slurry are performing much better than installations installed under the old procedure. It is apparent that even under current installation procedures distress occurs in some of the weaker and less-rigid edge drains and some cores perform better than others. It was evident that laboratory testing should be performed to compare with field data. Current laboratory test methods were reviewed and it was the opinion of the authors that the flat parallel plate test (ASTM D1621) is not a suitable test procedure. Work done by Frobel (1) on eccentric (angle) loading of panel drains simulates shear-type forces that are placed on panels during and after installation, but does not model the full vertical component. It appears that most of the distress in the panels is occurring because of vertical compression and eccentric loading. In response to this, a vertical edge drain compression chamber that closely simulates in-situ conditions was constructed. This paper discusses the test chamber, test method, test results using the chamber, and compares the results with field performance data and other laboratory test methods.

LABORATORY EVALUATION

Vertical Edge Drain Compression Chamber

In 1991 a vertical edge drain compression chamber was constructed to test edge drains under conditions similar to field conditions. The chamber is 311.14 mm (12.25 in.) long (I.D.), 106.68 mm (4.20 in.) wide (I.D.), and 501.65 mm (19.75 in.) tall. The front and back of the chamber are made of ½-in. tempered glass for viewing the specimen. The remainder of the chamber is constructed of stainless steel and high grade aluminum alloy. The bottom of the chamber is perforated to allow water to escape. A 101.6-mm (4-in.) × 279.4-mm (11-in.) aluminum plate 25.4 mm (1 in.) thick is used as a loading plate. The chamber is shown in Figures 1 and 2.

Method of Testing

The vertical dimension of the cores was not modified, except for the Type F panel. Initially Type F was a 457.20-mm (18-in.) panel that was modified to a 304.8-mm (12-in.) panel for testing. Six different brands of edge drain panels were tested in this study. Their core profiles are shown in Figure 3. Four series of tests were conducted on each panel. The edge drain samples were cut into 298.45-mm (11.75-in.) lengths. The cores of the samples were cut so that the filter fabric was approximately 6.35 mm (0.25 in.) longer than the ends of the core. The sample was placed in the chamber against the wall parallel with the long dimension of the chamber. Plexiglass inserts 6.35 mm (0.25 in.) thick were placed between the sample and viewing windows. The specimen was then backfilled with a coarse clean sand. The sand was placed to a height of 101.6 mm (4 in.) above the top of the panel. The loading plate was placed on top of the sand. The chamber was then placed into an MTS load frame. The initial height of the sample was measured. A fluorescent light was secured to the back glass window. The illuminated core of the drain was traced onto 215.9-mm (8.5-in.) × 355.6-mm (14-in.) graph paper (The area of the traced cores was later calculated using a planimeter.) The load was applied at a rate of 45.39 kg (100 lb) or 15.65 kP (2.27 psi)/minute. The vertical deflection of the panel was recorded at 45.39-kg (100-lb) increments and the core was traced every 113.39 kg (250 lb) or 156.51-kP (5.68-psi) increment. The load was held constant for approximately 2 min while the core was traced. The test was discontinued at a load of 453.59 kg (1,000 lb) or 156.51 kP (22.7 psi). The resulting horizontal stresses developed from the 453.59-kg (1,000-lb) vertical load were derived from finite

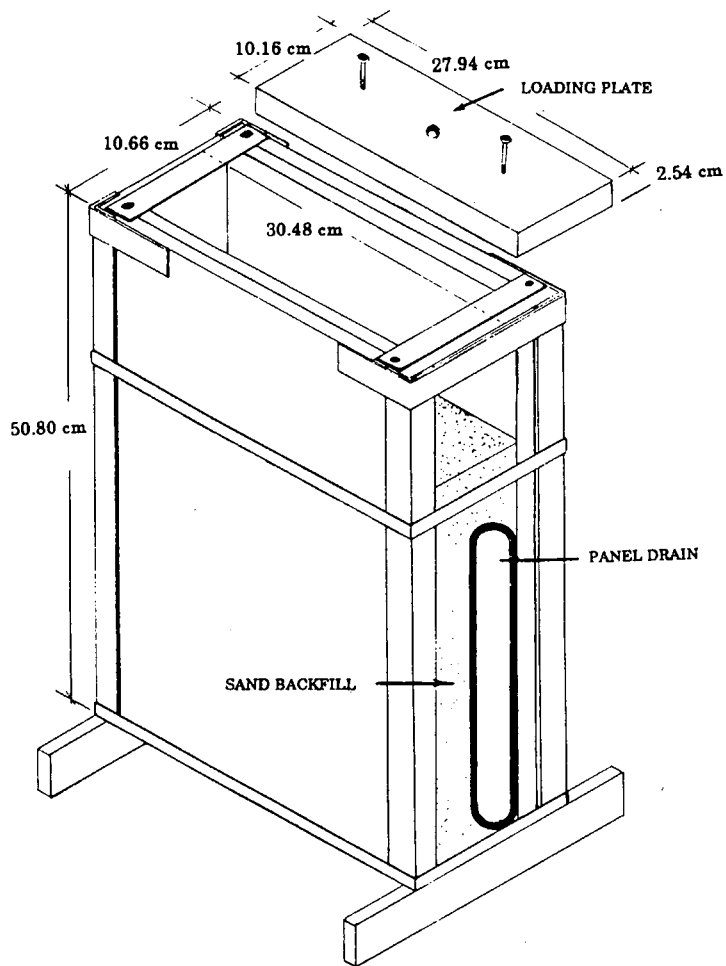


FIGURE 1 Edge drain compression chamber.

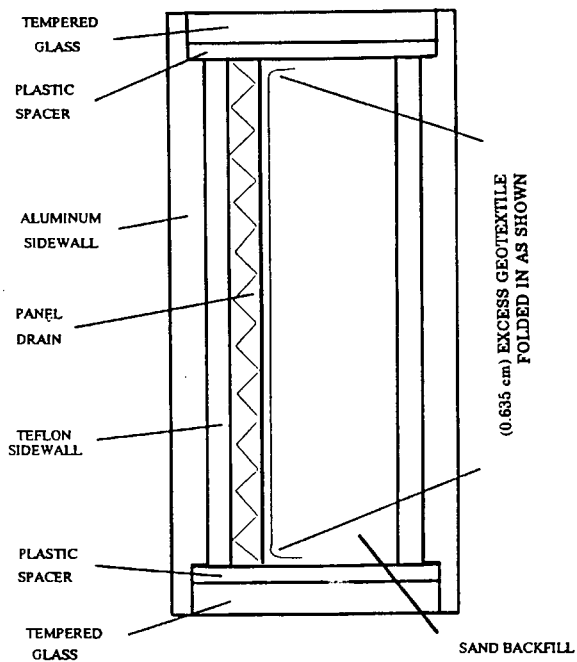


FIGURE 2 Top view of compression chamber.

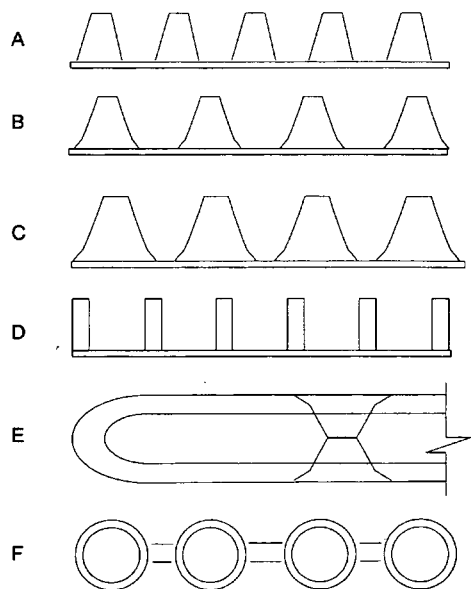


FIGURE 3 Profile of edge drains tested.

element modeling and directly measured using an earth pressure meter. The derived and measured horizontal stresses are discussed in later sections.

Series of Vertical Compression Tests

In Series 1, the tests were conducted with the sand dry (approximate moisture content of 4.0 percent) and loose [approximately 1329.53 kg/m^3 (83 lb/ft^3)], with the open side of the drain facing the sand backfill. In Series 2, the tests were conducted with the sand wet and dense, with the more open side of the drain facing the backfill. The sand was densified to approximately 1601.84 kg/m^3 (100 lb/ft^3) by pouring 3.78 L (1 gal) of water on top of the sand (the amount of water per linear foot of drain used to densify the sand during actual field installations). In Series 3, the tests were conducted with the more open side of the panel facing the wall of the chamber and the sand was not densified. In Series 4, the panels were tested in the same manner as in Series 3, except the sand was densified.

Results of Series 1

The vertical deflection measurements are given in Figure 4 and Table 1. Core Type E deflected the least of the panels tested. At 156.51 kPa (22.7 psi) of pressure, Type E deflected 6.09 mm (0.24 in.), which is 1.9 percent of the vertical height. Type D panel deflected the most. At 156.51 kPa (22.7 psi) of vertical pressure, Type D deflected 52.83 mm (2.08 in.), which is 16.8 percent of the vertical height.

The changes in core capacity of each panel drain at 156.51 kPa (22.7 psi) are shown in Figure 5 and Table 2. The two enclosed cores performed the best (Type E and F). The core capacity of Type E increased by 2.1 percent and Type F decreased by 2.46 percent. The capacity of Type D core reduced the most at 57.6 percent. The capacity for each core type for a given load is shown in Figure 6 and Table 3.

Results of Series 2

The tests in Series 2 (dense sand) were performed at the same rate, and data were recorded at the same frequency as in Series 1. In most cases, increasing the density of the sand increased the performance of the panel drain.

At 156.51 kPa (22.7 psi), Type E deflected the least. Type E core deflected 4.57 mm (0.18 in.), which is 1.4 percent of the vertical height. Type B deflected the most at 23.36 mm (0.92 in.) or 8.1 percent of the vertical height. The deflection of each panel is shown in Figure 4 and Table 1. Type A drain was the only edge drain that increased in vertical deflection when the sand was densified. The most significant change in vertical deflection occurred in the Type D and Type F drains. Vertical deflection of Type D decreased by 62 percent, and Type F decreased by 68 percent.

The change in core capacity at 156.51 kPa (22.7 psi) is shown in Figure 5 and Table 2. The core capacity of Type E increased by 1.1 percent, and Type B core decreased by 33.80 percent. The most significant change in core capacity when

the sand was densified was the Type D drain, which increased 32 percent. The capacity of each core type for a given load is shown in Figure 6 and Table 3.

Comparison of the results from these tests makes it apparent that Type E performed better than the other panels. The core capacity of the two enclosed cores (Type E and the Type F) deflected less than the other four more open cores. The more open cores (Type A, B, C, and D) had core losses equal to or greater than 25 percent. It appears that fabric intrusion between the support columns and rolling over of the top and bottom rows of support columns were causing the reduction in core area.

Results of Series 3

To help eliminate fabric intrusion, a third and fourth set of tests were conducted on the open type cores. In these series, the panels were turned backwards in the compression box.

It is also possible to turn these panels backwards in the field because they have a high percentage of open area on the backside. The backside of the Type B core was 15.3 percent open; Type C was 13.5 percent open; Type A was 11.3 percent open; and Type D was 47.6 percent open. The open area of Type E was 3.9 percent on one side and 5.8 percent on the other. Type F core was 0.80 percent open.

The panels were tested with the more open side of the panel facing the wall of the chamber and the sand in a loose state. Type A drain had the least vertical deflection (1.6 percent) at 156.51 kPa (22.7 psi), and Type D drain deflected the most at 12 percent. In all cases, the more open panels deflected less in Series 3 than in Series 1 (Figure 4 and Table 1).

In most cases, the reduction in core capacity was less in Series 3 than in Series 1 and 2. Panel Types A, B, and C had less core reduction in Series 3 at 156.51 kPa (22.7 psi). Type D had greater core loss in Series 3 than in Series 2 (Figure 5 and Table 4). The capacities of each core type for a given load are given in Figure 6 and Table 3.

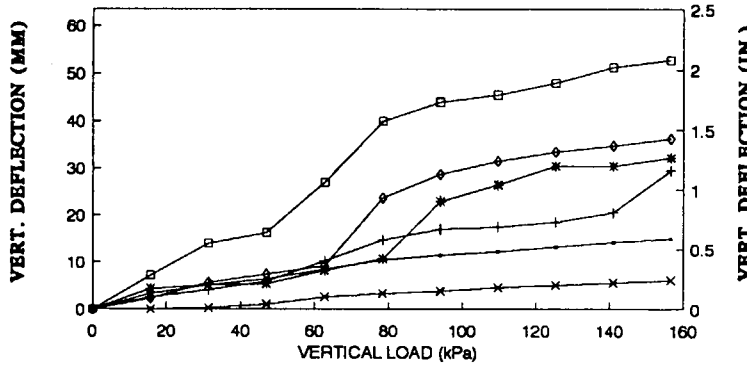
Results of Series 4

The performance of the open-type cores in most cases increased when the panels were turned backwards and the sand densified. Type A core deflected the least in the vertical direction. Type A deflected 3.1 percent at 156.51 kPa (22.7 psi) and Type B deflected the most at 5.0 percent (Figure 4 and Table 1).

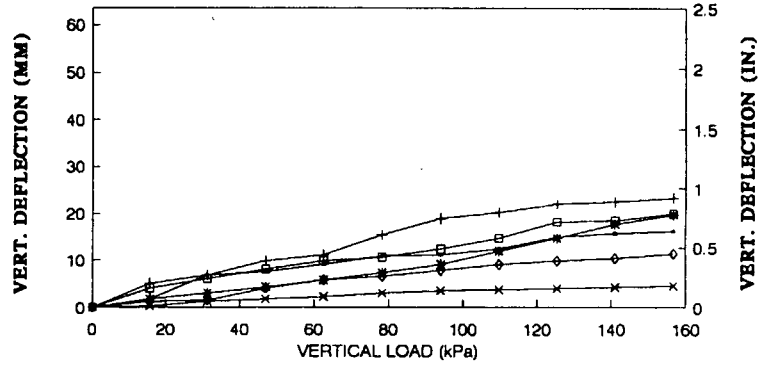
The percent change in the core capacities for a given load are shown in Figure 5 and Table 4. At 151.68 kPa (22 psi), Type A core had less capacity loss and the Type C had the greatest capacity loss of 15.2 percent. The capacities of each core type for a given load are given in Figure 6 and listed in Table 3.

Summary of Vertical Compression Tests

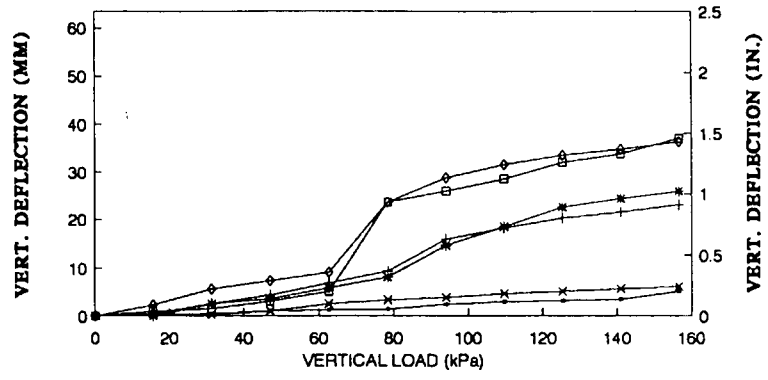
Information obtained from the four series of tests performed indicates that Type E panel performed the best of the six panels. Type E panel had the least amount of vertical de-



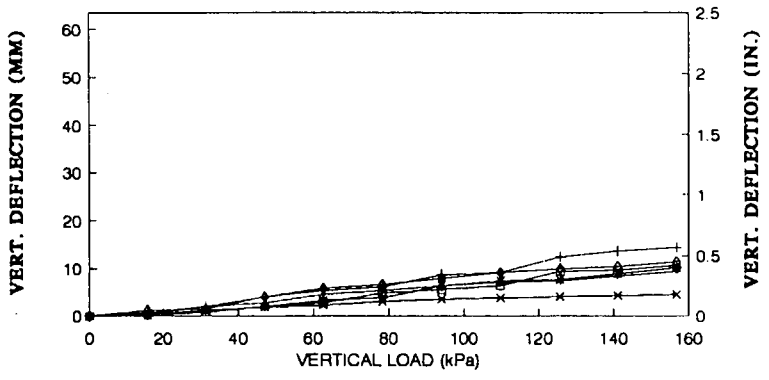
(a) — TYPE A + TYPE B * TYPE C
 — TYPE D x TYPE E ◇ TYPE F



(b) — TYPE A + TYPE B * TYPE C
 — TYPE D x TYPE E ◇ TYPE F



(c) — TYPE A + TYPE B * TYPE C
 — TYPE D x TYPE E ◇ TYPE F



(d) — TYPE A + TYPE B * TYPE C
 — TYPE D x TYPE E ◇ TYPE F

FIGURE 4 Vertical compression: (a) Series 1, vertical compression (sand backfill, loose); (b) Series 2, vertical compression (sand backfill, dense); (c) Series 3, vertical compression (sand loose, panels backwards); (d) Series 4, vertical compression (sand dense, panels backwards).

TABLE 1 Percentage Vertical Compression at 156.51 kPa

Panel Type	Open Side of Panel Facing Sand Backfill		Rigid Back Side of Panel Facing Sand Backfill	
	Series 1. Backfill Loose	Series 2. Backfill Dense	Series 3. Backfill Loose	Series 4. Backfill Dense
Type A	4.9%	5.3%	1.6%	3.1%
Type B	10.2%	8.1%	8.0%	5.0%
Type C	10.0%	6.5%	8.5%	3.3%
Type D	16.8%	6.5%	12.0%	3.5%
Type E	1.92%	1.4%	1.92%	1.4%
Type F	11.7%	3.7%	11.7%	3.7%

*Type E and Type F are solid cores and are identical on both sides of the panel. The data are contained in series 3 and 4 comparison.

flection and the least amount of core reduction in most of the four series of tests. Type E core also had the largest amount of core flow area. The test data indicate that solid type cores (Types E and F) had the least amount of core reduction in all the tests. Type E core area actually increased by 1 to 2 percent in all the tests. The Type F core decreased 2 to 4 percent. Although the Type F core showed little core reduction in all the tests, compression occurred in the webs linking the round flow tubes when the sand was loose. The more open cores (Type A, B, C, and D) are prone to loss of core flow area because of the top rows of support columns rolling over and the rigid backing folding and compressing. In all cases, the more open cores performed substantially better when the more open side was placed against the wall of the chamber. Type A core showed the least amount of distress of the open-type cores. The Type A core is of similar design to Types B and C, but is more rigid because of its chemical composition. The Type A core is PVC, and the other cores are high-density polyethylene.

Flat Parallel Plate Test

Flat parallel plate tests were conducted according to ASTM D1621. The load was recorded at 10 percent strain except for the Type A core. The Type A core exceeded the limits of the testing equipment, and the test was aborted at 8 percent strain. At 8 percent strain, Type A core was 574.33 kPa (83.3 psi). The full results are given in Figure 7.

HORIZONTAL STRESS

Measured in Laboratory

Horizontal stress on the side wall of the chamber was measured using a round 228.6-mm (9-in.) diameter earth pressure meter. The measured horizontal force was approximately 19 kPa (2.76 psi) at 156.51 kPa (22.7 psi) vertical load.

Finite Element Modeling

Finite element modeling was conducted to evaluate horizontal forces produced during loading of a panel drain system. A modulus of elasticity [$E = 68\,947.6$ kPa (10,000 psi)] and Poisson's ratio ($\nu = 0.35$) was assumed for the sand backfill, and a modulus of elasticity [$E = 3\,447.38$ kPa (500 psi)] and Poisson's ratio ($\nu = 0.45$) was assumed for the edge drain panel. As shown in Figure 8, at a depth of 152.4 mm (6 in.), which is the center of the panel, the resulting horizontal force at 156.51 kPa (22.7 psi) vertical load is approximately 16.54 kPa (2.4 psi). The finite element plot indicates that higher horizontal stresses occur at the top and the bottom of the panel. A horizontal stress of approximately 96.52 kPa (14 psi) occurs near the top and approximately 48.26 kPa (7 psi) at the bottom of the panel. These points are probably higher than actual field values because the panel was modeled as a rigid structure and the node points (nodes between the sand and the panel) were attached not allowing the sand to migrate around the panel.

Field Measurements

Horizontal and vertical stresses were measured in the field during construction using a round earth pressure meter 228.6 mm (9 in.) in diameter and two 50.5-mm \times 254 mm (2-in. \times 10-in.) rectangular earth pressure meters. One of the rectangular earth pressure meters was placed close to the surface of the backfill to measure vertical load, and the other rectangular meter and the round meter were used to measure side wall pressures. One was placed against the trench wall and the other against the panel. Actual installation pressures were not attainable because of the nature of the contractor's schedule. Loads were applied to the top of the sand backfill using a crew cab pickup truck and a loaded Class 7 Dump Truck, with the third drop axle raised. At the first test site, using the crew cab pickup truck for loading, a vertical pressure of 194.77 kPa (28.25 psi) was measured. A horizontal pressure

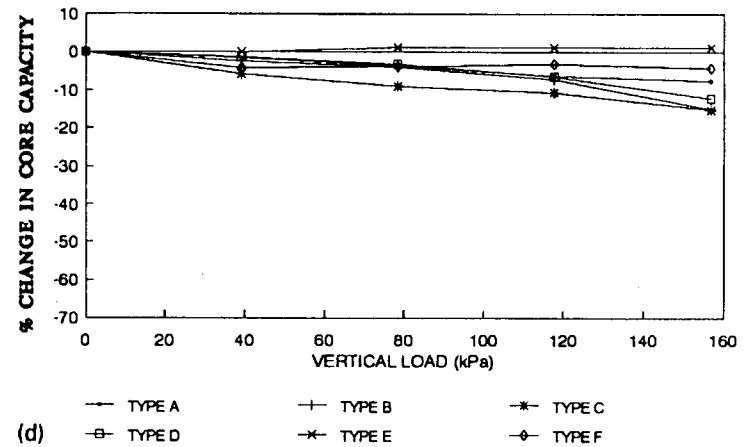
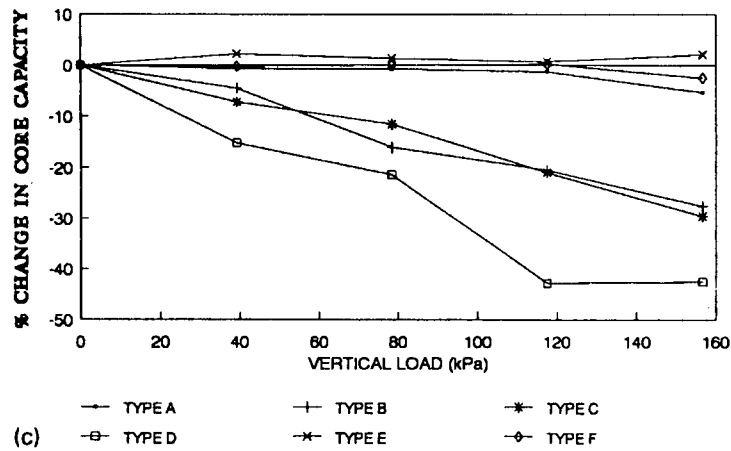
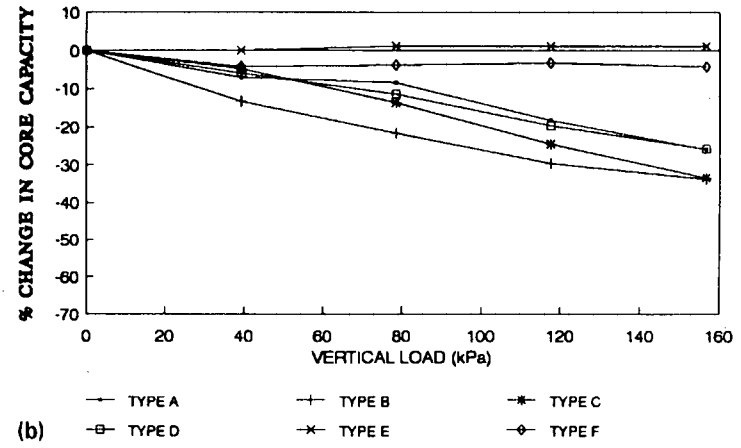
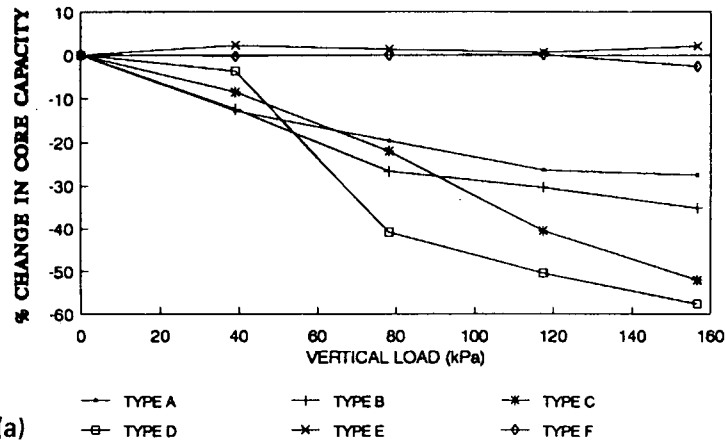


FIGURE 5 Change in core capacity: (a) Series 1, change in core capacity (sand backfill, loose); (b) Series 2, change in core capacity (sand backfill, dense); (c) Series 3, change in core capacity (sand loose, panels backwards); (d) Series 4, change in core capacity (sand dense, panels backwards).

TABLE 2 Change in Core Capacity: Open Side of Panel Facing Sand

Panel Type	Vertical Load kPa>>	Series 1. Sand Backfill Loose					Series 2. Sand Backfill Dense				
		0	39.2	78.3	117.2	156.5	0	39.2	78.3	117.2	156.5
Type A	Percent	0	-12.7	-19.5	-26.2	-27.4	0	-7.0	-8.4	-18.3	-25.9
Type B	Change in	0	-12.3	-26.5	-30.2	-35.0	0	-13.3	-21.6	-29.6	-33.7
Type C	Core	0	-8.4	-21.9	-40.4	-52.0	0	-4.7	-13.6	-24.5	-33.4
Type D	Capacity>>	0	-3.6	-40.7	-50.4	-57.6	0	-5.9	-11.4	-19.6	-25.7
Type E		0	+2.2	+1.3	+0.6	+2.1	0	0	+1.1	+1.1	+1.1
Type F		0	-0.2	0	+0.2	-2.46	0	-4.1	-3.7	-3.1	-4.1

of 15.16 kPa (2.2 psi) was measured with the round gauge, and 41.36 kPa (6 psi) was measured with the rectangular gauge. At the second test site, using the loaded dump truck, a horizontal pressure of 61.02 kPa (8.85 psi) reading was recorded. The full vertical pressure reading was not obtained because of the slow reaction time of the earth pressure meter and a tight construction schedule; however, a vertical pressure of 468.84 kPa (68 psi) (plus) was recorded before the test was aborted.

FIELD PERFORMANCE OF PANELS

To date, only four of the six cores tested have been monitored in the field (Types B, C, D, and E). Before 1989, edge drains were installed on the pavement side of the trench and backfilled with existing excavated trench material. The material was compacted with a vibratory compactor. Many miles of an earlier design of Type D core were installed in this manner. All five sites that were borescoped and excavated showed similar signs of core collapse (column collapse) as indicated by Frobels eccentric loading testing. Slight to moderate core compression was noticed in field inspections of the earlier Type E core.

Since 1989, numerous miles of edge drains have been installed on the backside of the trench and backfilled with a sand slurry. Two miles of a core similar to Type B core and several miles of Type E core were installed on the Mountain Parkway and on Interstate 75 in Kentucky. At both sites, the core similar to Type B was installed with the fabric facing the sand backfill. In both cases, the top row of support columns was rolled over and slight fabric intrusion had occurred in areas. Series 1 and 2 laboratory tests showed similar signs of this type of roll over starting in the very early stages of the tests. Failure of the filter fabric on the similar edge drain to Type B core was observed on Interstate 75. The support columns had pushed through the filter fabric and slight to moderate post compression had occurred. This failure was very localized and occurred in the first 25 to 50 ft of the installation. The remaining mile of installation appears to be in satisfactory condition. The Type E drain installed at both sites appears to be in excellent condition. There were no signs of vertical or horizontal compression.

Several miles of the new Type D core were installed on Interstate 64 in 1990 and 1991. Type D core was installed

with the more open side facing the shoulder. Rolling over of the top row of support columns occurred during installation. It was apparent during installation that the sand was not being properly densified. Substantial trench settlement resulted. The resulting settlement caused the bottom four rows of support columns to "J," forcing the bottom of the edge drain toward the center of the trench. Cracking of the rigid backing occurred at the start of the "J." The top two rows of support columns were partially rolled over.

Type C and E drains were installed on the Bluegrass Parkway in 1991. Type C drain was installed with the more open side facing the sand backfill. The top row of support columns had partially rolled over during installation. Slight fabric intrusion was occurring in some areas. The Type E core appeared to be in excellent condition.

CONCLUSIONS

It is apparent that the panels are distressed more under the old method of installation using excavated trench material and dynamic type compaction. Furthermore, it is apparent that using the sand slurry reduces the chances of installation damage. Proper density needs to be achieved during installation of the sand backfill or damage will occur from trench settlement. In most cases, increasing the density of the sand increased the performance of the panel drain.

Information obtained from the four series of tests performed indicates that Type E panel performed best of the six panels tested. The more solid type cores (Types E and F) had the least amount of core reduction. Type D and Type F were the most susceptible to vertical compression when the sand was loose. Type D core was also the most susceptible to reduction in core capacity when the sand was loose. The open cores (Types A, B, C, and D) are prone to loss of core capacity because of the top rows of support columns rolling over and the rigid backing folding and compressing. In all cases, the open cores performed substantially better when the more open side was placed against the wall of the chamber. The Type A core showed the least amount of distress of these types, probably because of its chemical composition (PVC).

To date, the maximum horizontal pressure measured in the field was 61.02 kPa (8.85 psi). It is the opinion of the authors that this was measured under extreme conditions and that actual installation pressures are probably less.

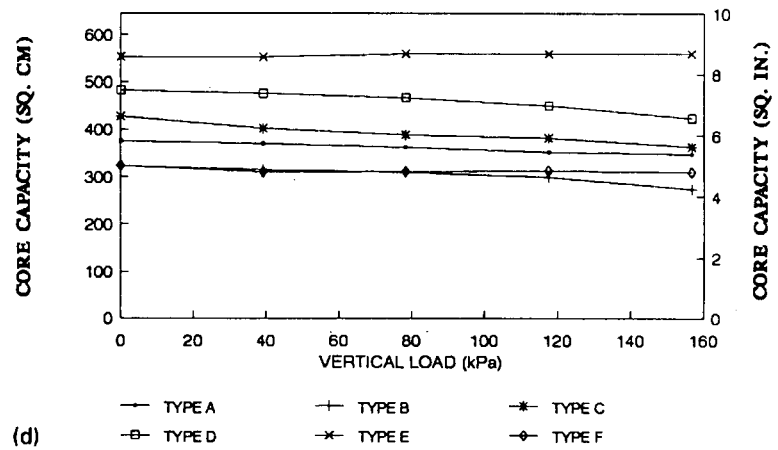
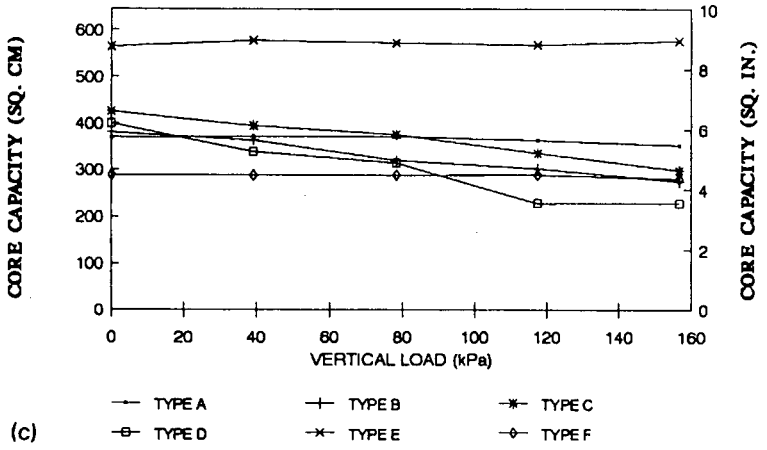
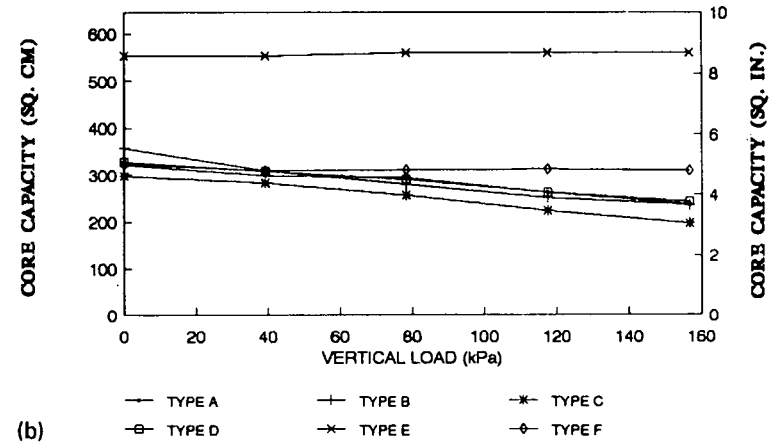
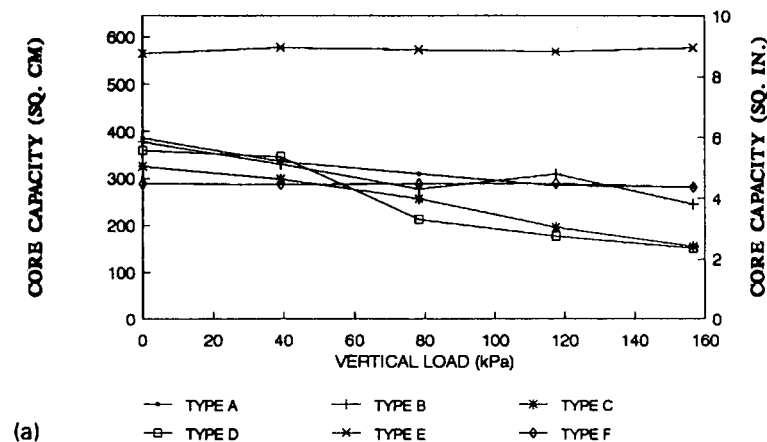


FIGURE 6 Core capacity: (a) Series 1, core capacity (sand backfill, loose); (b) Series 2, core capacity (sand backfill, dense); (c) Series 3, core capacity (sand loose, panels backwards); (d) Series 4, core capacity (sand dense, panels backwards).

TABLE 3 Core Capacity at 0 and 156.5 kPa (in.²)

Panel Type	Open Side of Panel Facing Sand Backfill				Rigid Back Side of Panel Facing Sand Backfill			
	Series 1. Backfill Loose		Series 2. Backfill Dense		Series 3. Backfill Loose		Series 4. Backfill Dense	
	0 kPa	156.5 kPa	0 kPa	156.5 kPa	0 kPa	156.5k Pa	0 kPa	156.5 kPa
Type A	385.8	279.9	321.2	238.1	369.0	349.0	375.5	347.1
Type B	377.4	245.2	357.4	236.7	380.6	275.5	322.6	274.2
Type C	325.8	156.1	297.4	198.1	425.2	298.7	427.7	362.6
Type D	359.3	152.2	327.7	243.2	399.3	229.0	482.6	423.8
Type E	564.5	576.7	570.9	560.0	564.5	576.7	553.5	560.0
Type F	288.4	281.3	323.2	309.6	288.4	281.3	323.2	309.7

TABLE 4 Change in Core Capacity: Rigid Back Side of Panel Facing Sand

Panel Type	Vertical Load kPa>>	Series 3. Sand Backfill Loose					Series 4. Sand Backfill Dense				
		0	5.68	11.36	17.0	22.7	0	5.68	11.36	17.0	22.7
Type A	Percent Change in Core Capacity>>	0	+0.7	+0.7	-1.3	-5.3	0	-1.5	-3.6	-6.3	-7.5
Type B		0	-4.5	-16.1	-20.5	-27.6	0	-2.4	-4.0	-7.2	-15.0
Type C		0	-7.2	-11.6	-21.0	-29.6	0	-5.8	-9.0	-10.7	-15.2
Type D		0	-15.3	-21.4	-42.8	-42.6	0	-1.3	-3.2	-6.5	-12.1
Type E		0	+2.2	+1.3	+0.6	+2.1	0	0	+1.1	+1.1	+1.1
Type F		0	-0.2	0	+0.2	-2.46	0	-4.1	-3.7	-3.1	-4.1

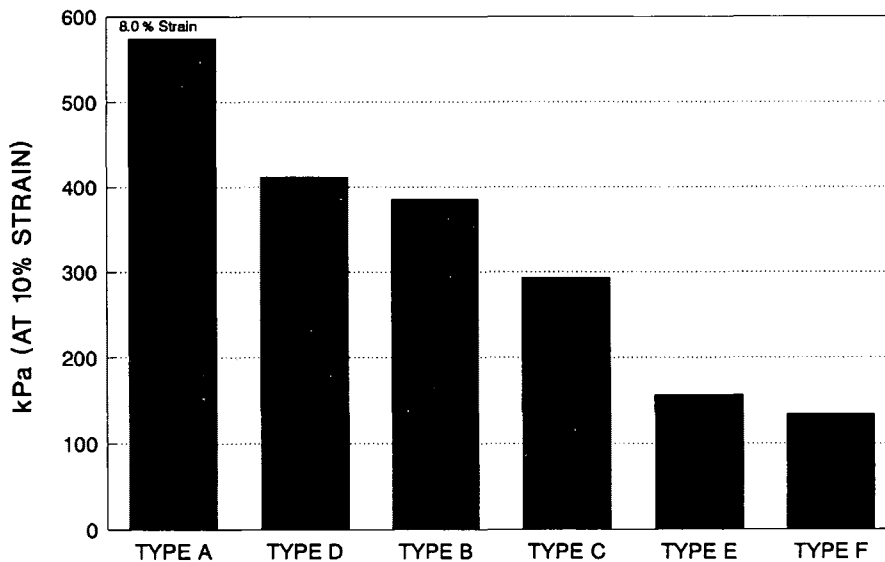


FIGURE 7 Flat parallel plate test (10 percent strain).

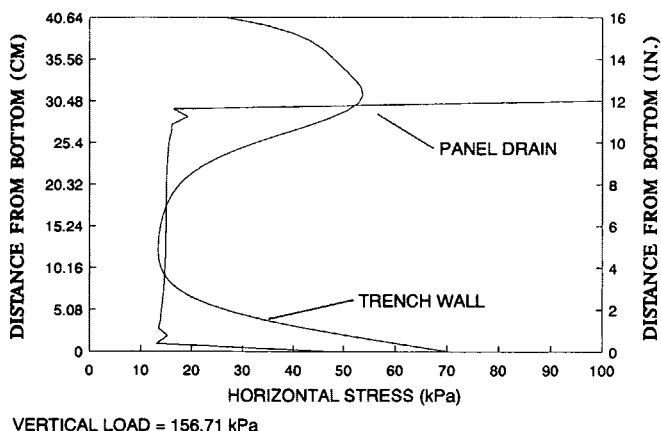


FIGURE 8 Finite element modeling (stressed introduced at panel).

The distress observed in the panels at 156.51 kPa (22.7 psi) vertical pressure from the laboratory testing exceeds most distresses that have been observed in the field since 1989 (using sand slurry for backfill). Further field monitoring is necessary to confirm the maximum load needed for laboratory testing and edge drain design.

The flat parallel plate test does not correlate with field performance. The Type E panel is one of the weaker panels in the flat parallel plate test, but its performance appears to be the best of all the panels installed in Kentucky. However,

the flat parallel plate is a relatively simple test that may be used for monitoring quality control.

It is the opinion of the authors that the vertical edge drain compression test does an excellent job of modeling in situ conditions in Kentucky.

ACKNOWLEDGMENTS

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