Field Evaluation of Various Types of Open-Graded Drainage Layers

T. J. KAZMIEROWSKI, A. BRADBURY, AND J. HAJEK

Pavement drainage layers have been proved to be highly effective in the efficient and quick dissipation of subsurface water from a pavement structure. The Ministry of Transportation of Ontario requires a 100-mm lift of open-graded drainage layer (OGDL) directly beneath the concrete slab as part of the rigid pavement design for expressway facilities. The gradation of the OGDL consists almost entirely of coarse aggregates retained on the 4.75-mm sieve, which provides a highly permeable drainage layer. Because of this uniformly graded coarse aggregate, the drainage layer has proved difficult to construct by conventional means. In order to alleviate this problem, the OGDL is treated with 1.8 percent asphalt cement to increase the stability of the material during construction. The addition of an asphalt cement binder has been used successfully on numerous contracts. In 1990, the Ministry initiated a demonstration project to evaluate alternative methods of increasing the constructibility of the OGDL. The three types of OGDL placed on this project were (*a*) a 1-km section of portland cement-treated OGDL with various cement contents [cement-treated permeable base (CTPB)], (*b*) a 1-km section where no binder was used but the amount of fine aggregate passing the 4.75 mm was increased to improve the stability [untreated permeable base (UTPB)], and (*c*) the asphalt cement-treated permeable base (ATPB) as just mentioned. The design and construction details are elaborated on in this paper, and the OGDL sections are evaluated in terms of permeability, gradation, constructibility, and stability on the basis of falling weight deflectometer test results.

The presence of free water within a pavement structure can lead to the premature deterioration of a roadway (*1*). To prevent this from happening, a layer of permeable granular material can be placed within the pavement structure in order to facilitate the internal drainage. These drainage layers have proved to be highly effective in the efficient and quick dissipation of water from a pavement structure and are used by many state and provincial highway agencies (*1–3*).

The Ministry of Transportation of Ontario (MTO) requires a 100-mm thick lift of a permeable base and drainage layer referred to as an open-graded drainage layer (OGDL) to be placed directly beneath the concrete slab as part of the rigid pavement design for expressway facilities. Because the OGDL is 90 to 100 percent uniformly graded coarse aggregate, it has proved difficult to construct by conventional means.

In order to ensure the constructibility of the OGDL, 1.8 percent asphalt cement (A/C) is added to the aggregate, commonly referred to as an asphalt-treated permeable base (ATPB). Although this has proved to be successful, MTO decided to evaluate two additional techniques for improving the stability of the OGDL material without significantly affecting the layer's permeability: (*a*) the use of portland cement as a stabilizer, a cement-treated permeable base (CTPB), and (*b*) an increase in fine aggregate in an untreated OGDL, also referred to as an untreated permeable base (UTPB).

In this paper the design and construction details will be elaborated on, and these various OGDL materials will be evaluated in terms of permeability, gradation, constructibility, and load and deflection characteristics based on falling-weight-deflectometer (FWD) test results.

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BACKGROUND

In 1989, MTO developed new specifications requiring that a 100-mm layer of OGDL be placed beneath the concrete slab in all new rigid pavement designs. The gradation of the OGDL consists almost entirely of coarse aggregates retained on the 4.75-mm sieve. Although this provides a highly permeable drainage layer, the stability of the material is inadequate to support construction traffic without unacceptable distortion. To alleviate this problem, the OGDL has been treated with 1.8 percent A/C in order to increase the stability of the material during construction. The addition of an A/C binder has been used successfully on numerous contracts (*1*).

In 1990, MTO initiated a demonstration project to evaluate alternative methods of providing a constructible, stable, and permeable OGDL. Highway 115, where 13.4 km of a new portland cement concrete (PCC) pavement was being constructed, was chosen as the site for this demonstration project. The three types of OGDL placed on this project were

1. PCC-treated OGDL (CTPB) at various cement contents,
2. Untreated OGDL (UTPB) in which no binder was used but the amount of fine aggregate passing the 4.75 mm was increased to improve the stability, and
3. The A/C-treated OGDL (ATPB).

In order for the OGDL to function properly, it must be constructed in direct contact with a free-flowing collector system to ensure the efficient and quick removal of any free water. Also, there must be a filter layer between the OGDL and the subgrade material to prevent the intrusion and pumping of the subgrade material into the OGDL (*2,4*). On this project a geocomposite drainage system and a lift of dense-graded granular base material between the subgrade and the OGDL were specified as part of the overall design.

EXISTING CONDITIONS

Highway 115 is located near the city of Peterborough, approximately 100 km east of Toronto. Figure 1 shows the location of the project.

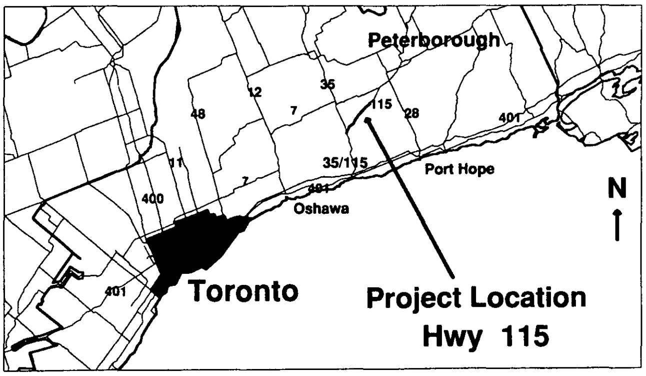

FIGURE 1 Location map.

At the time of construction, Highway 115 was a two-lane arterial highway. The new design called for the highway to be reconstructed as a four-lane divided rural freeway. The two existing lanes would become the eastbound lanes; the two westbound lanes would be new PCC pavement construction.

The annual average daily traffic (AADT) in 1991 on this section of highway was 8,800 vehicles, 8 percent of which were commercial vehicles. This represents approximately 127,000 equivalent single-axle loads (ESALs) in the design lane during 1 year.

The subgrade soils in the area consist of a fine-grained silty sand and sandy silt that is moderately to highly frost susceptible.

PAVEMENT DESIGN

The cross section of the new westbound lanes consisted of two lanes at 7.5-m width with a 0.5-m paved outside shoulder and a 1.0-m paved inside shoulder (see Figure 2 for a typical section).

The pavement structure for the new westbound lanes, shown in Figure 3, consisted of

- 200 mm jointed plain concrete pavement (JPCP) with load transfer devices;
- 100 mm OGDL, A/C treated (ATPB);
- 100 mm granular A; and
- 300 mm select subgrade material (SSM).

The purpose of the 100 mm of granular A was to act as the filter layer between the subgrade and the OGDL. Granular A is a dense-graded base course material that consists of crushed rock or gravel. The gradation for granular A is shown in Figure 4.

The SSM is a nonplastic select borrow material used to provide a uniform, non-frost-susceptible subgrade.

The existing pavement structure of Highway 115 that would become the future eastbound lanes consisted of

- 150 to 175 mm hot mix,
- 150 mm granular A, and
- 450 mm to 1.2 m sand or sandy gravel.

The 13.4-km project incorporated an ATPB throughout the project, except for a 1-km section of untreated OGDL (UTPB) and a 1-km section of CTPB. The CTPB encompassed a section 500 m long consisting of 120 kg of Type 10 portland cement/m^3 of mix and a section 500 m long with 180 kg/m^3 of mix.

The collector system designed to drain the OGDL was a premanufactured drainage system (PDS) commonly known as a geocomposite drain. The type used was a Hitek 25 manufactured by Burcan Industries. The 300-mm by 25-mm drain was placed directly in contact with the OGDL. Outlet pipes were placed every 100 m into the ditch along the edge of pavement. The typical location of the geocomposite drain within the pavement structure is shown in Figure 3.

After construction of the concrete pavement, the PDS was installed in a trench 100 mm wide excavated by a Vermeer cutter. The trench was backfilled with the compacted excavated material.

CONTRACT SPECIFICATIONS

Highlights of the construction specifications for the three OGDL materials used are as follows:

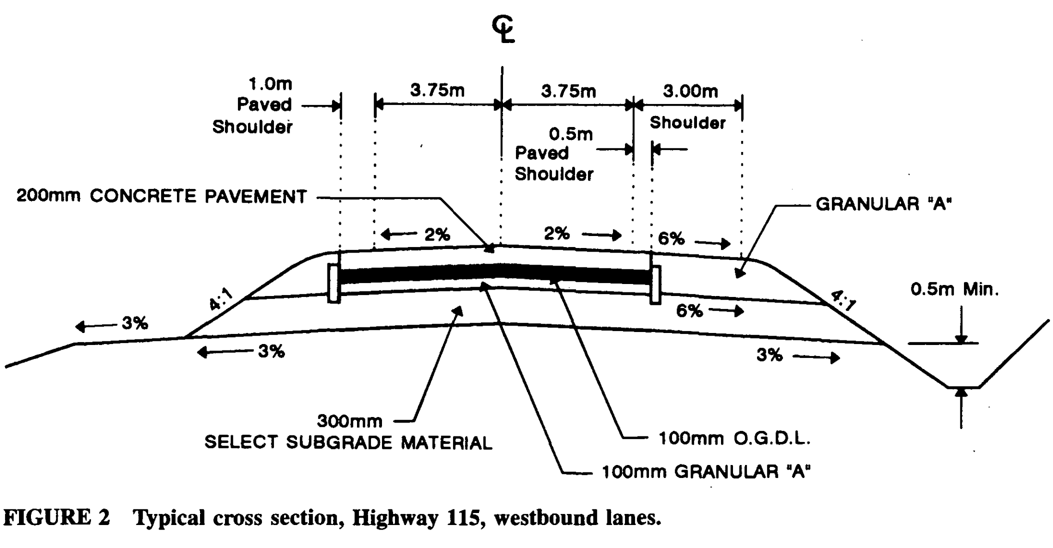

FIGURE 2 Typical cross section, Highway 115, westbound lanes.

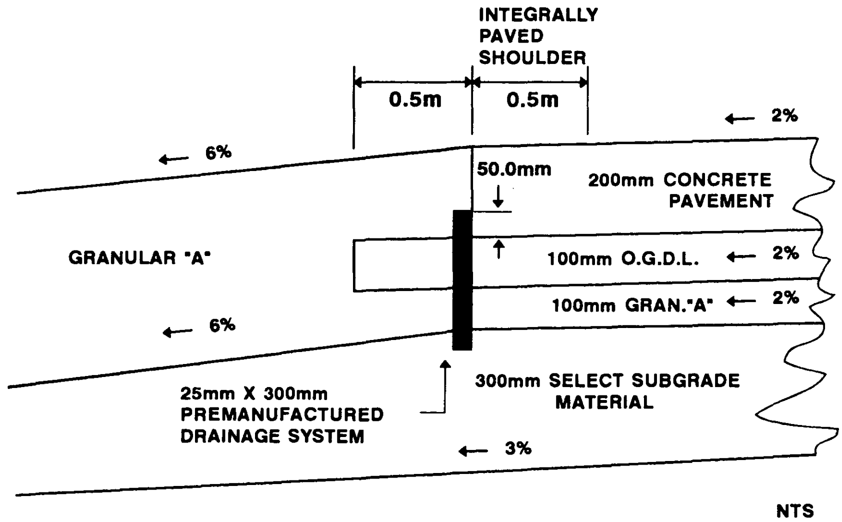

FIGURE 3 Drainage system, Highway 115.

- The aggregates should have 100 percent crushed faces produced by crushing bedrock (steel slag or reclaimed asphalt pavement should not be used).
- Construction traffic should not be permitted on the OGDL except for the paving train during placement of the overlying pavement. Haul trucks should not be allowed on the OGDL except to discharge material directly into the paver.
- The OGDL should be covered with the concrete pavement within 30 days of placement to prevent contaminations resulting from prolonged exposure. The OGDL should be protected from dirt or dust during construction.
- Compaction of the ATPB should consist of three to five passes of a class S2 roller (mass per millimeter of roll width, 4.5 kg) weighing 9 to 11 tonnes. The final compaction should be such that the OGDL can support the weight of the paving equipment. Pneumatic-tired or vibratory rollers should not be used.
- The final grade of the OGDL should not deviate more than 5 mm above or 10 mm below the specified grade and cross section. The surface of the OGDL should not deviate more than 10 mm at any place with a 3-m template. No problems were encountered during construction in meeting these tolerances.
- A Marshall mix design procedure is not required for ATPB.

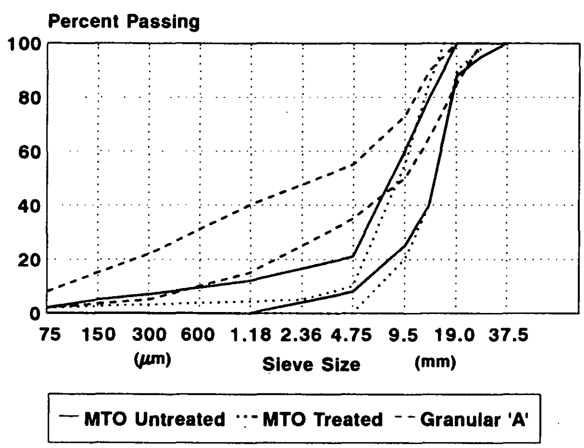

FIGURE 4 Specification limits for aggregate gradations.

CONSTRUCTION

CTPB

The contractor chose to place the CTPB with the Gamaco 3000 concrete slipform paver using a stringline for grade control. The same equipment was used to place the overlying concrete pavement (*5*).

A water-to-cement ratio of 0.42 to 0.43 was used for both the 120-kg/m^3 and 180-kg/m^3 mixes. Initially the lack of fines and low cement volume made it difficult to feed the material through the augers of the slipformer and caused segregation. This was solved by slowing the process down. Consolidation was achieved by activating only half the number of spud vibrators on the slipform machine. There were no noticeable differences in placing the two mixes at the two cement contents (*5*).

Both mixes of the CTPB appeared to be stable, well bonded, and relatively smooth after placement. There was no sloughing of the material at the edge of the pavement. During placement of the concrete pavement, minor breakdown of the surface of the OGDL was caused by the trucks carrying the concrete, especially in the section with only 120 kg/m^3; however, the section was paved last and therefore carried more accumulated truck traffic than the 180-kg/m^3 section.

Curing commenced one day after placement. It was achieved by sprinkling water from a truck-mounted tank in a fine spray every 2 hr for an 8-hr period.

ATPB

The ATPB with 1.8 percent A/C content was placed in two 50-mm lifts with a conventional hot-mix paver (Barber Green 200). It was compacted using a Dynapac CC-04 vibratory roller ballasted at 15.5

tonnes with a 2.13-m wide drum in the static mode. Although the roller used was heavier than that specified, the contractor obtained the required compaction without damaging the mat.

It is expected that stripping will occur in the ATPB over the long term, but the A/C is only a stabilizer to hold the aggregate together during construction to provide stability. It is not expected that there will be any long-term performance problems caused by stripping.

UTPB

The UTPB was placed by trucks and a grader; the final grade was achieved utilizing a profile machine. The compaction was achieved with three to five passes of a smooth drum roller. It was visually stable after compaction.

There were no problems achieving acceptable compaction levels and surface tolerances with the UTPB. Water was used sparingly to keep the dust under control and facilitate compaction.

The UTPB sloughed at the edge of the lift. This became a concern when the PDS was placed along the edge of the concrete by trenching techniques because it caused a void under the concrete slab. This void was small and is not expected to cause any short-term damage to the concrete slab, although it could result in long-term performance problems.

Cores were taken in the pavement within the UTPB section after construction, and although the profile grade of the OGDL was within specifications, the depth of the UTPB ranged from 65 to 100 mm.

EVALUATION

Laboratory Permeability Tests

At present, there is no standard laboratory test for permeability of granular materials. MTO tests the permeability of an OGDL using a Constant Head Test. The Constant Head Test (MTO Test No. LS-709) used is based on ASTM D2434 and AASHTO T-215-70 (*1*). This test utilizes proctor molds with the granular material compacted to its optimum density or a 150-mm diameter core taken in the field. The core is wrapped in paraffin wax and tested in the same manner as the proctor molds. The results from this test are useful as a relative comparison between the different granular materials, but they cannot be used as a direct comparison with the results of other permeability testing methods.

All permeability results referred to in this paper are based upon MTO's laboratory testing methodology.

TABLE 1 Average Permeability Results

	Coefficient of Permeability (cm/sec)
Untreated OGDL (UTPB) (from roadway samples)	7.5×10^{-2}
A/C-treated OGDL (ATPB) (field cores at 1.8% A/C)	8.6×10^{-2}
Cement-treated OGDL (CTPB) (field cores)	5.9×10^{-2}
Aggregate for treated OGDL (aggregate from stockpile)	6.3×10^{-2}

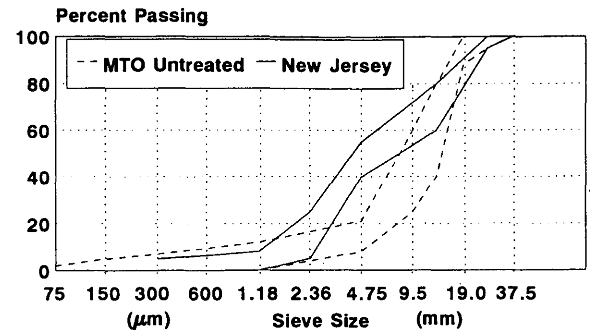

FIGURE 5 Gradations for UTPB: MTO versus New Jersey.

The average permeability test results are shown in Table 1. The ATPB had the highest permeability as determined from cores, 8.6 10^{-2} cm/sec, whereas the UTPB from roadway samples had comparative results at 7.5 10^{-2} cm/sec. Samples of the aggregate used for the CTPB and ATPB from the stockpile were also tested. The aggregate had permeability results of 6.3 10^{-2} cm/sec. The CTPB cores had the lowest permeability, 5.9 10^{-2} cm/sec.

The granular A used as a filter material has results ranging from 2 10^{-2} cm/sec to 2 10^{-6} cm/sec depending upon where the gradation falls within the allowable band for granular A (*1,2*) as shown in Figure 4.

Ideally the permeability of a granular base should be on the order of 10^{-4} cm/sec or greater (*6*). An OGDL layer should have a permeability on the order of 10^{-2} cm/sec (*6*).

The results of MTO's permeability testing are an order of magnitude less than the test results reported in FHWA-TS-80-224. The difference is due to different laboratory testing procedures. Figure 5 shows the New Jersey gradation for UTPB and Figure 6 shows the AASHTO 57 gradation for a treated OGDL; both are compared with the MTO required gradation. Figures 5 and 6 show slight differences between the gradations, indicating that the two materials would have similar permeabilities.

Extraction Tests

Extraction tests were carried out on the cores taken from the ATPB. The A/C content of the cores ranged from 1.52 to 1.73 percent. This is slightly less than the required 1.8 percent A/C, however, the specification does allow for a ±0.2 percent deviation from this requirement.

Aggregate Gradation

Figure 4 compares the requirements of the untreated, treated, and granular A (filter layer) gradation bands. The treated and untreated bands are similar in the coarse aggregate range but differ in that the untreated allows more fine material for stability. The granular A band is much wider and much more uniformly graded than the OGDL gradation bands.

Gradation tests were completed on the aggregate samples from the stockpile used for both the ATPB and the CTPB. Tests were also carried out on the cores taken from the ATPB. For obvious

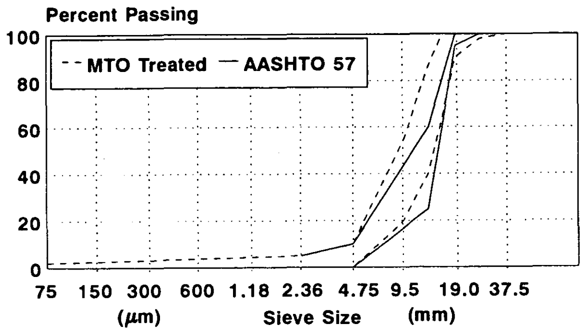

FIGURE 6 Gradations for treated OGDL: MTO versus AASHTO 57.

reasons, it was not possible to do gradation testing on the cores taken from the CTPB. Tests were also done on the UTPB aggregate from field samples. These results are shown in Table 2.

The results indicate that the aggregate gradations meet specifications except for the ATPB from cores. The 2.36 sieve is out by +0.1 percent and the 0.075 sieve is out by +0.5 percent. Both of these encroachments are minimal.

The gradation curves for the averages of all samples are shown in Figures 7 and 8.

Aggregate Quality Testing

The limestone aggregate used for both the untreated and treated OGDL was from the Buckhorn Quarry, approximately 20 km north of Peterborough. The material was specified to meet the requirements of a medium-quality hot-mix aggregate. Table 3 shows the test results for the untreated and treated aggregate. All test requirements were met. The aggregate was 100 percent crushed from bedrock. Previous test sites where OGDL was placed using a crushed gravel proved to be very unstable and difficult to compact even with the addition of A/C as a stabilizer.

Although the aggregate used for both the treated and untreated OGDL was from the same quarry, it was obtained from separate stockpiles because of the different gradations. This could be an explanation for the differences between the quality testing results.

Pavement Drainage

In addition to the laboratory testing of the OGDL materials, a full-scale field evaluation of the subdrainage system performance was conducted about a year after construction. The field evaluation was done by introducing a controlled quantity of water into the OGDL material through a core hole in the PCC pavement and observing water discharge rates at outlets. The procedure effectively engaged the OGDL (both its permeability and cross-sectional slope), permeability of granular material underneath the OGDL, interface between the OGDL and the PDS, the PDS (flow capacity and longitudinal slope), and, finally, the function of the outlet pipes.

The full-scale testing was motivated in part by a concern for the relative impermeability of the backfill material used during the PDS installation. The installation was completed using a modified Vermeer trencher and the excavated material was used as backfill. The backfill consisted of a mixture of granular A, pieces of OGDL material, and select subgrade material. The permeability results obtained previously for this mixture had a coefficient of permeability of about $1.0 + 10^{-4}$ cm/sec. The low-permeability backfill material can contaminate the interface between the OGDL and the PDS since the installation trench wall is rough. The rough surface creates a space in front of the PDS that can be filled with backfill fines.

Testing Procedure

To achieve a significant inflow rate, a hole with a diameter of 15 cm was cored through the PCC pavement and the OGDL in the right traffic lane. The results reported here are for core holes located 2.3 m from the PDS (cross-sectional distance) and about 12 m from the nearest downstream outlet (longitudinal distance). The pavement grade (longitudinal slope) ranged from 1 to 1.5 percent. The pavement elevation was about 1 m above the terrain. Only the ATPB and CTPB sections were evaluated using the above arrangement. It was not possible to establish a corresponding location for the UTPB.

The inflow rate of water poured into the core hole was maintained constant at 22 L/min throughout the main portion of the test. The system could easily accommodate the inflow rate of 22 L/min without flooding the OGDL material (i.e., the water level was well below the bottom of the concrete slab). Precautions were

TABLE 2 OGDL Aggregate Gradation

Sieve Size		Untreated, % Passing		Treated, % Passing		
Millimeters	Inches	MTO Requirements	Field Samples (n = 3)	MTO Requirements	A/C-Treated from Cores (n = 3)	Aggregate from Stockpile (n = 3)
37.5	$1^1/_2$	100	100			
26.5	1	95–100	100	98–100	100	100
19.0	$^3/_4$	88–10	97.9	90–10	98.9	95.7
13.2	$^1/_2$	40–80	72.0	40–86	67.7	64.2
9.5	$^3/_8$	25–60	49.7	20–55	36.5	33.9
4.75	No. 4	8–21	12.7	0–10	7.9	3.0
1.18	No. 16	0–12	2.9	N/A	4.0	1.4
0.300	No. 50	0–7	1.7	N/A	3.1	1.0
0.150	No. 100	0–5	1.4	N/A	2.9	0.9
0.075	No. 200	0–2	1.0	0–2	2.55	0.8

taken to minimize erosion of the granular materials by the water poured into the hole. Overall, the field testing procedure used can objectively evaluate the performance of the whole pavement drainage system.

Results

Both the ATPB and the CTPB sections exhibited similar performance. After the inflow started, it took 25 to 27 min before water appeared at the downstream outlets and 40 to 47 min before the outflow reached a relatively steady discharge rate of 8.6 to 9.6 L/min. When the inflow rate was increased from 22 to about 25 L/min, the reaction time to the increased flow at the outlet was about 2.5 to 4 min. After the inflow was stopped, water continued to discharge for 19 to 29 min.

From the total inflow of 22 L/min, less than 50 percent of the flow was reaching the outlet pipes despite the fact that the inflow was only 12 m from an outlet (outlets were spaced at about 100-m intervals) and the longitudinal grade of the pavement was at least 1 percent. The difference in the input and output flows was draining by alternative means even though the underlying granular A has much lower permeability than the OGDL material or the geotextile covering the PDS. In general, the amount of water retained in the pavement structure depends not only on the permeability of the material below the OGDL, but also on the interface between the OGDL and the PDS.

It may be argued that the results of the full-scale testing are undesirable since more than 50 percent of the water fails to reach the outlets and penetrates the pavement structure. However, there are no comparable results for other types of subdrainage systems incorporating OGDL. To further test the influence of the interface between the OGDL and the PDS, the MTO is now installing a PDS in a trench backfilled with a manufactured sand with high permeability. The results of the full-scale performance testing of this system incorporating high-permeability backfill, as well as results from other drainage systems, would enable a better interpretation of the existing results.

FWD Testing

Deflection testing was done utilizing the FWD in order to determine the load and deflection characteristics of the OGDL. Measurements were taken at 10-m intervals in the outside wheel path of the driving lane on the granular A layer; on the surface of the CTPB, the UTPB, and ATPB; and on the surface of the concrete pavement.

Tests on the granular A were done using a 450-mm diameter loading plate. A 300-mm diameter loading plate was used for the various OGDL and concrete pavement layers. The deflection data are based on a normalized 40-kN dynamic load and are reported without a temperature correction factor. Tests were done from May 29, 1992, to July 19, 1992. Additional FWD testing was done on the concrete pavement on July 6, 1993. These new tests were taken in the center of every fifth slab (approximately every 20 m).

It is difficult to reliably determine the moduli of the different pavement layers from the data collected through backcalculation, because the programs available are limited in their ability to calculate the moduli of granular layers and of layers beneath a rigid concrete layer. For this reason, the results of FWD testing are reported as average peak deflections.

Shown in Figure 9 are the average peak surface deflections of the various layers for all three types of OGDLs. The deflections give an indication of the comparative strength and stability of the different layers. Because of the difference in the size of the load-

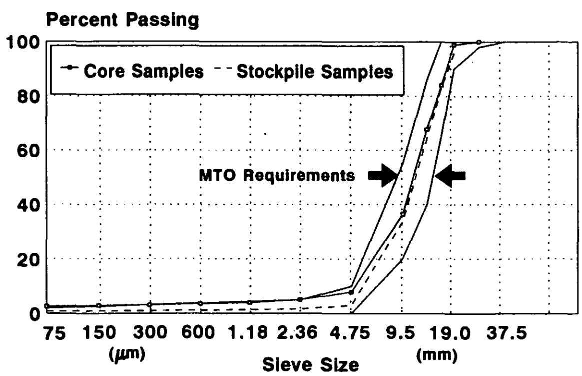

FIGURE 7 Gradation curves for treated OGDL aggregate.

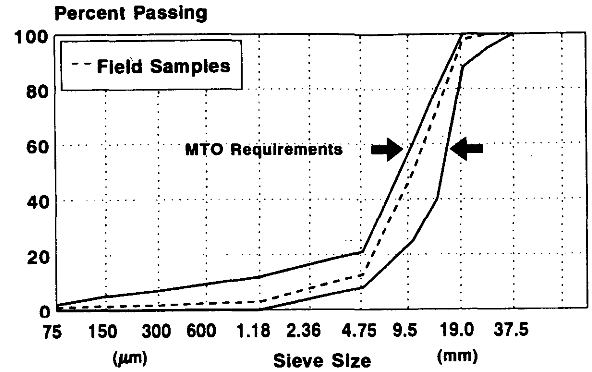

FIGURE 8 Gradation curves for UTPB aggregate.

TABLE 3 OGDL Aggregate: Physical Requirements and Test Results

	MTO Lab Test No.	MTO Requirements	Untreated Aggregate	Treated Aggregate
Los Angeles abrasion, % maximum loss	LS-603	35	27	28
Magnesium sulfate soundness, 5 cycles, % maximum loss	LS-606	12	1	4
Petrographic number, maximum	LS-609	160	106	101
Flat and elongated particles, % maximum	LS-608	20	N/A	17
Freeze-thaw maximum loss %	LS-614	10	9	N/A

NOTE: N/A = not available.

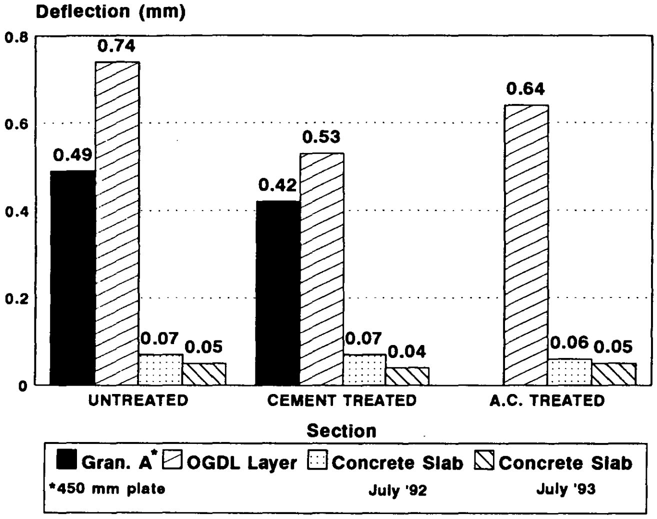

FIGURE 9 Average deflection measurements.

ing plates, the results for the granular A layer should not be compared with those shown for other material layers. The granular A results are similar under the UTPB and CTPB. The CTPB has the highest modulus with an average deflection of 0.53 mm, whereas the UTPB has the highest deflection, 0.73 mm, indicating the lowest modulus. The ATPB with a deflection of 0.64 mm is in between.

The concrete slab deflections from the June 1992 testing ranged from 0.07 to 0.06 mm for all sections. The deflections of the concrete slab taken a year later range from 0.04 to 0.05 mm. It is not expected that a 200-mm thick concrete slab would be affected by minor variation in the deflection characteristics of the various underlying OGDL layers, although the long-term performance of the concrete pavement would be influenced by an unstable or nonuniform base layer.

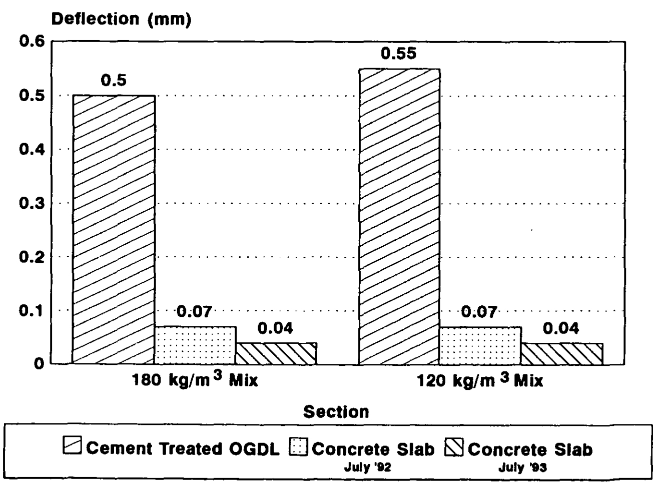

FIGURE 10 CTPB deflection measurements.

Figure 10 indicates the difference in deflections between the two CTPB mixes. As anticipated, the results indicate that the deflections for the 180-kg/m^3 mix are slightly lower than those for the 120-kg/m^3 mix based on deflection values, but both are higher than those for the UTPB or ATPB (Figure 9).

CONCLUSIONS

The following conclusions have been made:

- All three types of OGDL met the requirements for permeability and stability; that is, the OGDL mat was able to carry construction traffic without any significant damage or break-up.
- The FWD measurements indicate that the deflection of the CTPB is 17 percent less than that of the ATPB and some 28 percent less than that of the UTPB. On the basis of these values, a similar strength characteristic (modulus) relationship would exist among the three materials.
- The relative rigidity of the concrete pavement based on the FWD measurements is not expected to be affected by the type of OGDL used.
- The placement of the ATPB and CTPB layers within acceptable tolerances may require a slight adjustment to conventional construction practices but requires no specialized equipment.
- The overall performance of the pavement drainage system can be objectively evaluated by the field drainage test; however, more comparative data are required for reliable interpretation of the results.
- There is a concern with sloughing that occurs at the edges of the UTPB (at the edge of the 0.5-m paved shoulder), nonuniform thickness, as well as its somewhat lower strength characteristic as indicated by the deflection testing.
- The 1.8 percent A/C provides adequate stability to the OGDL aggregate accommodating construction practices and equipment.
- The gradations of both the untreated and treated OGDL aggregates provide excellent permeability.
- There appear to be no significant differences between the 180-kg/m^3 and 120-kg/m^3 cement-treated OGDL mixes with regard to construction, permeability, and strength characteristics.

RECOMMENDATIONS

The following recommendations are made:

- The contractor should be allowed to choose between an ATPB and a CTPB on selected projects. This would allow the contractor to choose the most economical materials and methods of construction available.
- The cement content of the CTPB should be specified as 120 kg/m^3.
- The placement and use of the UTPB need to be reviewed further. It appears that it is impractical to use this material with a collector system that is installed by a trenching operation. Preinstallation of the collector system and backfilling with a permeable filter material are required. The minimum depth of UTPB should be increased to 150 mm to address inaccuracies in placement operations.

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