Impact of Open-Graded Drainage Layers on the Construction of Concrete Pavements in Illinois

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The first portland cement concrete pavement test section constructed by the Illinois Department of Transportation, which included an open-graded drainage layer, was built in 1989. Since the construction of that project, over 30 centerline km (20 centerline mi) of concrete pavements have been built using an open-graded drainage layer. Although the benefits of using open-graded drainage layers to improve concrete pavement performance are widely accepted, the practical impact of the design details on the constructibility of concrete pavements requires additional attention. Examples of problems encountered during the construction of concrete pavements with open-graded drainage layers include placing the open-graded drainage layer, anchoring dowel baskets to the open-graded drainage layer, obtaining a pavement with adequate ride characteristics, and using the open-graded drainage layer to support paving operations. From the experience acquired while constructing several pavements with open-graded drainage layers in Illinois, it is clear that concrete pavements with open-graded drainage layers can be constructed to meet today's high construction standards.

The concept of providing pavements with proper drainage has received a lot of attention in recent years, but this is not a new concept. McAdam, the grandfather of modern highway engineering, understood the importance of providing pavements with proper drainage. In 1820, he stated, "If water passes through a road and fills the native soil, the road, whatever may be its thickness, loses support and goes to pieces" (*1*). Today, 175 years later, drainage is still one of the most important elements to be considered when designing a pavement cross section.

Lately, positive drainage has become a buzz word in the highway engineering community. Typically, positive drainage includes an edgedrain network, an open-graded drainage layer (OGDL), and a separation layer, which prevents the subgrade from infiltrating the drainage layer. In the early 1970s, the Illinois Department of Transportation (IDOT) first used edgedrains in pavements built to Interstate standards, but it was not until the mid 1980s that IDOT initiated studies concerning the use of OGDL with highways (*2,3*). Since the start of these studies, over 30 centerline km (20 centerline mi) of new portland cement concrete (PCC) pavements have been constructed with drainage layers. Over the past 7 years, it has become evident that the construction of PCC pavements with OGDL is different from standard construction techniques. This report details IDOT experience in constructing PCC pavements with OGDL.

PROJECT DESCRIPTIONS

1989 Test Section

The first PCC pavement test section with an OGDL in Illinois was built in 1989 and is just north of Bloomington on I–39. The exact location of this project is shown in Figure 1. The pavement cross section for this project consists of a 275-mm (10.75-in.) hinge jointed PCC pavement. The hinge joint design used doweled and tied joints to construct longer effective pavement slabs with controlled panel cracks. A detail of the hinge joint panel design is included in Figure 2.

The hinge joint pavement was placed on a 100-mm (4-in.) lean concrete subbase. The subgrade was lime modified to a depth of 400 mm (16 in.), and 300-mm (12-in.) geocomposite edgedrains were placed at the shoulder/mainline joint with outlets every 150 m (500 ft). A 150-mm (6-in.) portland cement stabilized OGDL was substituted for the lean concrete subbase for 365 m (1,200 ft) on this project, in the northbound lanes only. A diagram of the complete pavement cross section is included in Figure 3.

The OGDL mix consisted of crushed limestone aggregate, which met the IDOT CA–7 gradation requirements. The IDOT CA–7 gradation is similar to an AASHTO No. 57 gradation. Both gradations are listed in Table 1. The OGDL mix was prepared in a central concrete mix plant and consisted of 167 kg/m^3 (282 lb/yd^3) of portland cement with a water-to-cement ratio of 0.37.

1990 Test Sections

In 1990, the first continuously reinforced concrete (CRC) pavement with OGDL test sections was constructed in Illinois. These test sections are located south of LaSalle/Peru on I–39, as shown in Figure 1. The typical pavement cross section consisted of a 250-mm (10-in.) CRC pavement, which was placed on a 100-mm (4-in.) lean concrete subbase. The subgrade was lime modified 400 mm (16 in.) deep. The 100-mm (4-in.) plastic pipe edgedrains were placed in a sand trench at the shoulder/mainline joint, with outlets every 150 m (500 ft).

The project contains six 300-m (1,000-ft) long test sections. The test sections include three different cross sections with an asphalt cement stabilized OGDL in the northbound lanes and the same three cross sections with a portland cement stabilized OGDL in the southbound lanes. The three cross sections include a 100-mm (4-in.) OGDL placed directly on the lime modified subgrade, a 125-mm (5-in.) OGDL placed directly on the lime modified subgrade, and a 100-mm (4-in.) OGDL placed on a 75-mm (3-in) dense graded

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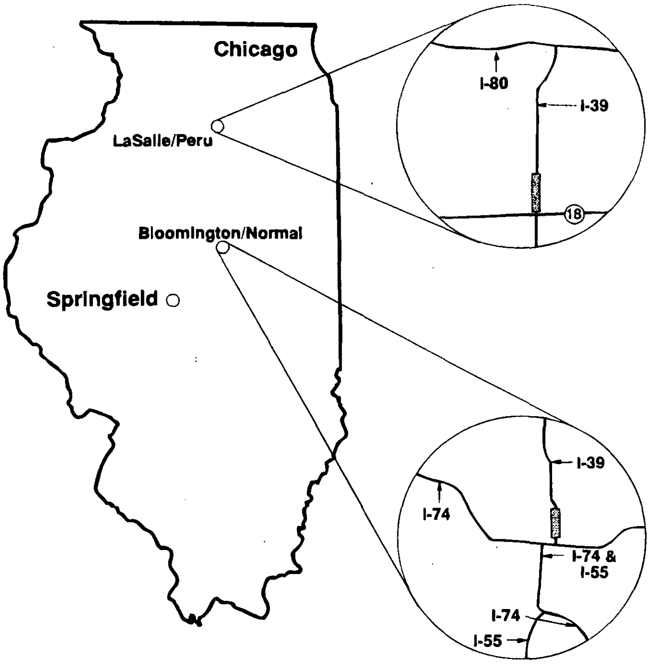

FIGURE 1 Location map of test sections.

aggregate base course, which was placed on the lime modified subgrade. The layout of the test sections is included in Figure 4.

In each test section, the longitudinal edgedrains were placed 1 ft in from the outside edge of the shoulder, because the drainage layer was extended out underneath the shoulders. The top of the edgedrain trench was covered with a geotextile fabric to prevent the sand from infiltrating the drainage layer. The typical cross section for this project is included in Figure 5.

The mix design for the portland cement stabilized OGDL was the same as the mix design used in the 1989 test section. The asphalt cement stabilized OGDL mix design consisted of 2 to 3 percent AC–20 and a crushed limestone aggregate that met the CA–7 gradation requirements. The dense graded aggregate met the IDOT CA–6 gradation requirements listed in Table 1.

1992 Demonstration Project

With the experience acquired while designing and constructing the 1989 and 1990 test sections, the scope of IDOT research was expanded to include using an OGDL on a project 14.5 km (9 mi) long. The location of this project, as shown on Figure 6, is near El Paso on I–39. The typical cross section for this project includes a 250-mm (10-in.) CRC pavement, a 100-mm (4-in.) portland cement stabilized OGDL, a 400-mm (16-in.) lime modified subgrade, and 100-mm (4-in.) pipe edgedrains, which were placed in aggregate backfilled, fabric-wrapped trenches 0.3 m (1 ft) in from the outside edge of the shoulder. A dense graded aggregate separation layer was placed between the OGDL and the lime modified subgrade on the southern portion of the project. On the northern end of the project, the OGDL was placed directly on the lime modified subgrade. A diagram of the typical cross section is included in Figure 7.

The mix design for the portland cement stabilized OGDL consisted of crushed limestone aggregate that met the requirements for the CA–11 gradation (similar to the AASHTO No. 67 gradation), as shown in Table 1 and 142 kg/m^3 (240 lb/yd^3) portland cement. The water-to-cement ratio was 0.50.

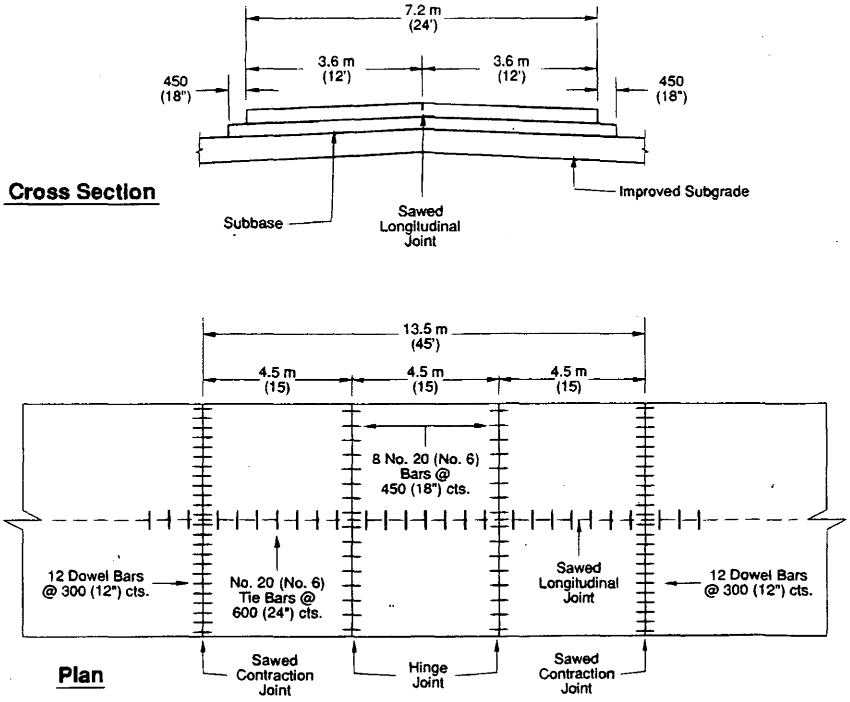

FIGURE 2 Hinge jointed pavement standard.

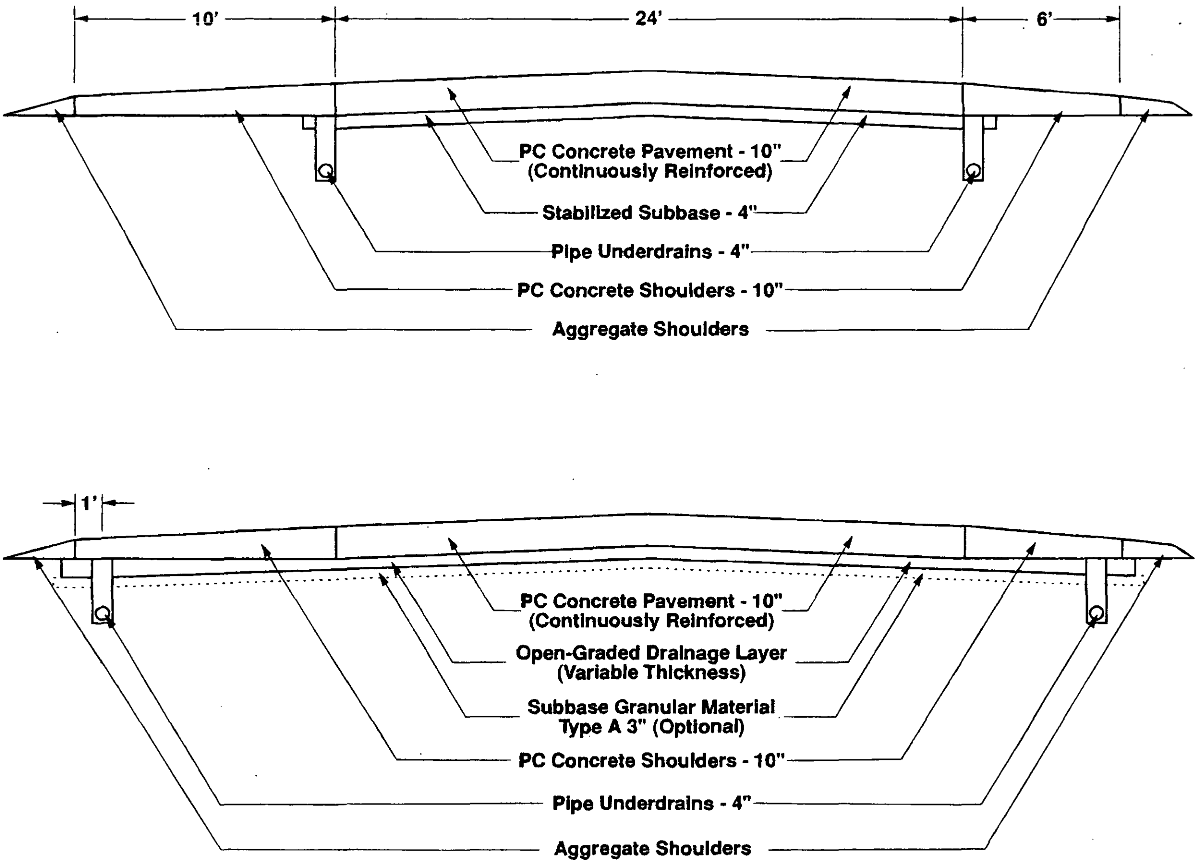

FIGURE 3 1989 test section cross section.

TABLE 1 Aggregate Gradations

	Sieve Size (Percent Passing)								
GRADATION	37.5 mm (1.5 in)	25 mm (1 in)	19 mm (0.75 in)	12.5 mm (0.5 in)	9.5 mm (0.38 in)	4.75 mm (No. 4)	2.36 mm (No. 8)	1.18 mm (No. 16)	75 m (No. 200)
Dense-Graded Aggregate									
CA-6	100	90-100		60-90		30-56		10-40	4-12
CA-10		100	90-100	65-95		40-60		15-45	5-13
Open-Graded Aggregate									
CA-7	100	90-100		30-60		0-10			
AAHSTO No. 57	100	95-100		25-60		0-10	0-5		
CA-11		100	84-100	30-60		0-12		0-6	
AASHTO No. 67		100	90-100		20-55	0-10	0-5		

Reconstruction of I–80

In 1993, IDOT reconstructed a 9.6-km (6-mi) segment of I–80 near Morris, as shown in Figure 6. The typical cross section for this project included a 295-mm (11.5-in.) CRC pavement, a 100-mm (4-in.) portland cement stabilized OGDL, and a 305-mm (12-in.) lime modified subgrade. The 100-mm (4-in.) pipe edgedrains were placed 0.3-m (1-ft) in from the outside shoulder in aggregate backfilled, fabric-wrapped trenches. The typical cross section for this project is the same as the typical cross section for the 1992 demonstration project.

The mix design for the OGDL consisted of recycled concrete crushed to meet the CA–7 aggregate gradation requirements. The portland cement content ranged between 118 and 142 km/m^3 (200 and 240 lb/yd^3), with a water-to-cement ratio of 0.50. A water-reducing additive was added to the mix to ensure that the aggregate was completely coated.

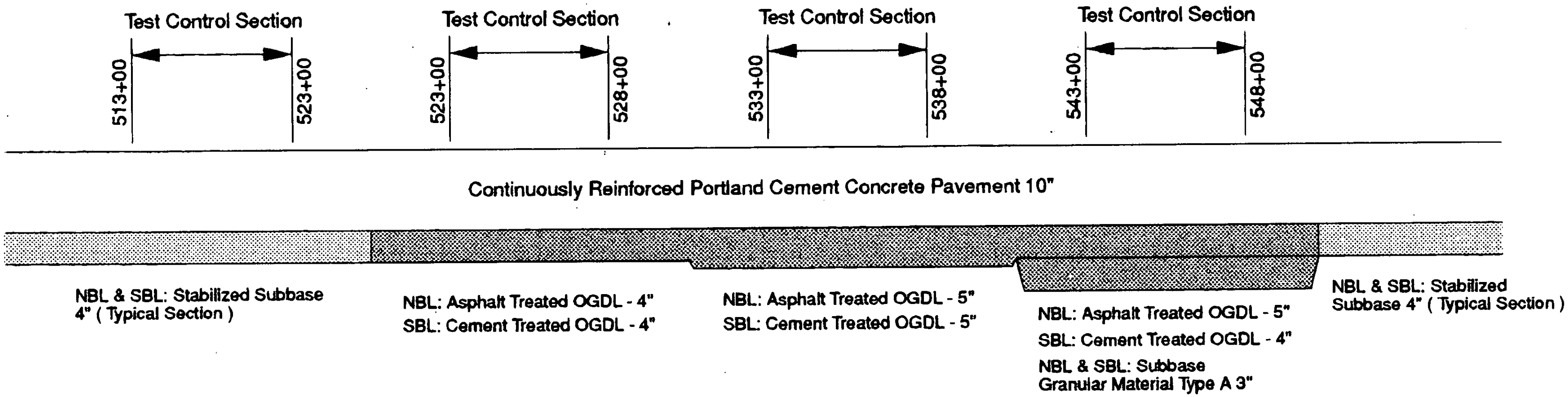

FIGURE 4 1990 test sections layout.

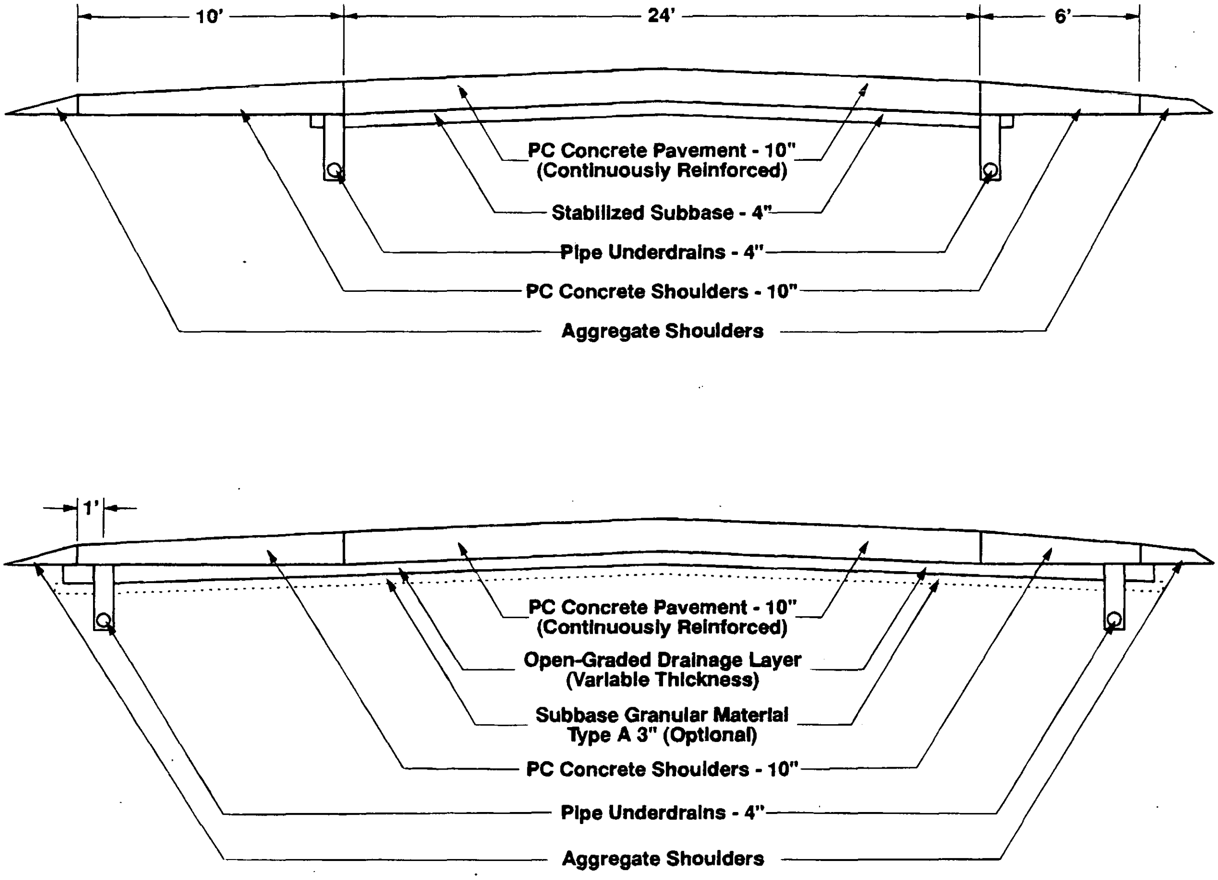

FIGURE 5 1990 test section cross section.

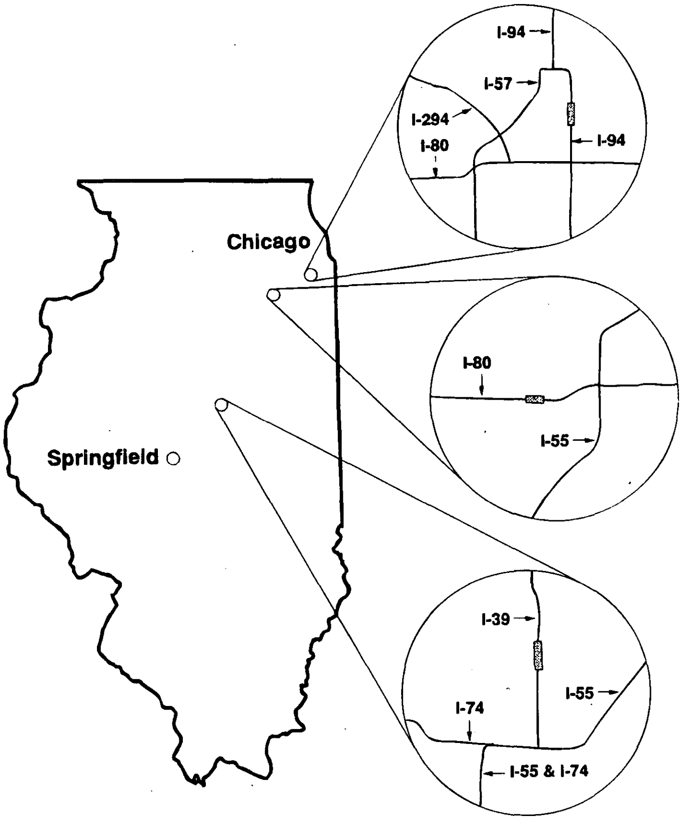

FIGURE 6 Location map of projects.

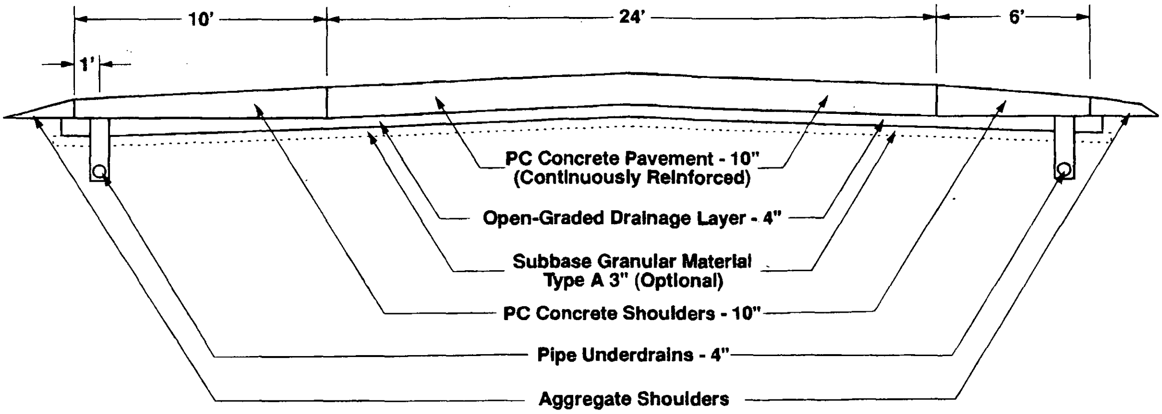

FIGURE 7 1992 demonstration project cross section.

Reconstruction of Calumet Expressway

In 1993, IDOT also reconstructed a segment of the Calumet Expressway in Chicago. The location of this project is shown in Figure 6. The typical cross section for this project included a 320-mm (12.5-in.) CRC pavement, a 100-mm (4-in.) asphalt cement stabilized OGDL, a 305-mm (12-in.) aggregate subbase, and a porous granular embankment subgrade, as shown in Figure 8. The 100-mm (4-in.) pipe edgedrains were placed 460 mm (18 in.) from the shoulder/mainline joint in sand-backfilled trenches, which were wrapped in a geotextile fabric to prevent contamination.

The asphalt cement stabilized OGDL mix consisted of 2.2 percent AC–10 and a crushed limestone aggregate that met the gradation specification for CA–11. The mix also included 0.5 percent anti-strip additive.

CONSTRUCTION EXPERIENCE

OGDL Construction

Portland Cement Stabilized OGDL

Paving Operations During the construction of the 1989 and 1990 test sections, it became evident that a standard concrete paver could not place the harsh portland cement stabilized OGDL mix. The OGDL mix did not flow through the concrete paver, and a standard concrete paver did not have enough power to spread the mix. Because of the slow advancement of the paver, the OGDL started to achieve an initial set before passing through the paver. In these instances, the mix was spread with a backhoe and then placed with the concrete paver. On these first two projects, the pavers broke down many times, resulting in costly construction delays.

As a result of the placement problems encountered on the test sections, IDOT altered the mixture and construction requirements for portland cement stabilized OGDL. The portland cement content requirement was reduced from 167 kg/m^3 (280 lb/yd^3) to 118 to 167 kg/m^3 (200 to 280 lb/yd^3) of mix. The engineer would determine the exact amount of portland cement required to ensure all of the aggregate was coated. In addition, the water-to-cement ratio was increased from 0.37 to 0.50 to increase the workability of the mix. Finally, IDOT required a subgrade planer to place the mix based on the success the Wisconsin Department of Transportation (DOT) was having in placing OGDL to the specified tolerances with a subgrade planer.

These mixture and construction modifications were used for the first time on the construction of the 1992 demonstration project. The modifications had a positive effect on the placement of the drainage layers so that over 1.6 km (1 mi) of 8.2-m-wide (27-ft-wide) OGDL material could be placed in 1 day. A picture of the modified subgrade planer is included in Figure 9.

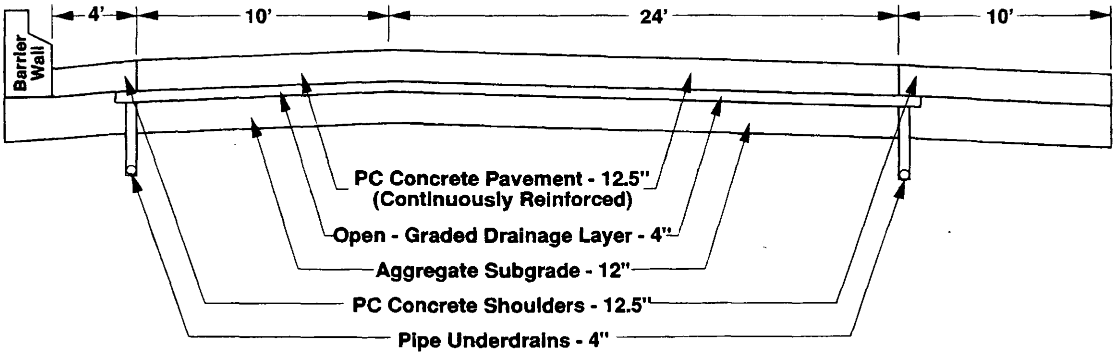

FIGURE 8 Calumet expressway cross section.

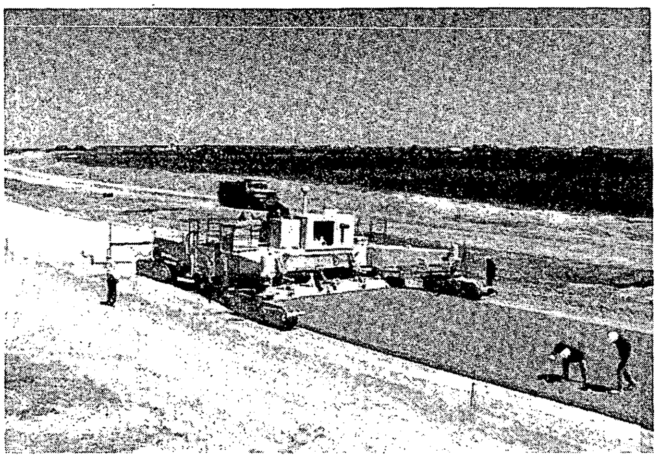

FIGURE 9 Modified CMI.

The changes made to the OGDL mix did not significantly decrease the overall strength of the OGDL. It is interesting that, during the placement of the OGDL on the 1993 reconstruction of I–80, the OGDL was exposed to a heavy rain hours after placement. The OGDL in this area was seen as strong as that which had already cured before the rain.

Compaction Techniques The 1989 and the 1990 test sections were compacted with tandem steel-wheeled rollers. Although the rollers were successful in providing satisfactory compaction of the OGDL material, the rolling operations often resulted in an uneven OGDL surface. The grade control for the PCC pavement is usually taken from the surface of the subbase material in Illinois. As a result, the uneven surface of the rolled OGDL resulted in an uneven pavement surface.

This problem could have been addressed by requiring the grade control for the PCC pavement to be taken off a stringline. This option would restrict the contractor's flexibility during the placement of the PCC pavement, however, which could result in higher PCC pavement costs. To find alternatives, IDOT reviewed the portland cement stabilized OGDL compaction techniques used by other states. Wisconsin DOT did not roll the portland cement stabilized OGDL to achieve compaction; instead, vibratory pans were attached to the subgrade planer to compact the OGDL material. IDOT tried this method on the construction of the 1992 demonstration project. Not only did this technique provide the necessary compaction of the OGDL, but it also provided a very smooth surface to use for grade control during the placement of the PCC pavement. The overall California profilograph rating for the pavement was 4.

Curing The 1989 test section was cured by spraying the portland cement stabilized OGDL with water and then covering it with polyethylene sheets. The OGDL placed on the 1990 test sections was cured with a water spray only. The curing on both projects was not started until late afternoon, long after the first OGDL material was placed. Because of the porous surface of the OGDL, the material that was placed in the morning had already achieved initial set. When the curing was completed, there was no distinguishable difference between the material cured immediately after placement and the material that had achieved initial set before curing.

At the time these observations were made, a paper was published noting that there was no definite benefit from curing an OGDL to achieve stability (*4*). This conclusion, along with IDOT observations, led to the decision not to cure the portland cement stabilized OGDL. The portland cement stabilized OGDL in the 1992 demonstration project and the 1993 I–80 reconstruction project were not cured, and the OGDL on these projects was stable enough to support paving operations without raveling.

Asphalt Cement Stabilized OGDL

Asphalt Cement Stabilized OGDL Mixtures The first time asphalt cement was used to stabilize an OGDL in Illinois was on the construction of the 1990 test section, in the northbound lanes of I–39. During the construction of this project, it was clear that mixing of the OGDL material in the asphalt plant was different from mixing hot mix asphalt concrete. The open nature of the aggregate gradation made it difficult to control the temperatures at the plant. Many of the batches of asphalt cement stabilized OGDL were not well-coated with asphalt cement, and many went to the construction site below the required temperatures.

To address this problem, IDOT reviewed the required mixing temperatures and placement temperatures of the asphalt cement stabilized OGDL. The minimum mixing temperature was 115°C (240°F) and was not lowered because a lower mixing temperature could lead to problems with the stability of the asphalt cement. The minimum placement temperature was lowered to 95°C (200°F) from 110°C (230°F). The OGDL material was open and cooled quickly. Therefore, to achieve a placement temperature of 110°C (230°F), the mixing temperature had to be higher than 115°C (240°F). By lowering the OGDL placement temperature to 95°C (200°F), the mixing temperature could be set to 115°C (240°F), which allowed more control of the mixing operations at the plant.

This new requirement was used on the reconstruction of the Calumet Expressway and resulted in a uniform OGDL mix, which guaranteed that the aggregate was completely coated.

Compaction Techniques The compaction of the asphalt cement stabilized OGDL was achieved by a tandem steel wheeled roller making two passes on the construction of the 1990 test sections. This technique was successful in compacting the OGDL mix but resulted in an uneven OGDL surface. The grade control for the PCC pavement on this project was taken from the surface of the OGDL, which subsequently led to an uneven pavement surface.

Due to the nature of the asphalt cement stabilized OGDL mix, it was clear that the asphalt cement stabilized OGDL could not be compacted with the same techniques as those successfully used on the construction of the portland cement stabilized OGDL on the 1992 demonstration project. Instead, the rolling temperatures for the OGDL were lowered and two rollers instead of one were required to achieve compaction. The first roller served as a breakdown roller and achieved the initial compaction of the OGDL. The second roller made two passes at a lower temperature to smooth the surface of the OGDL. This technique was used on the 1993 reconstruction of the Calumet Expressway and resulted in a smooth pavement surface.

Portland Cement Concrete Pavement Construction

Anchoring Dowel and Hinge Joint Baskets

Typically in Illinois, the dowel and hinge joint bars are set in baskets before paving the PCC pavement. During the construction of the 1989 test section at Bloomington, significant difficulty was encountered when tacking the dowel and hinge joint baskets to the OGDL. In Illinois nails are used to hold the dowel and hinge joint baskets in place. The same nails, however, could not be driven into the portland cement stabilized OGDL. This problem caused construction delays until a pneumatic nailer could be located to drive the nails into the OGDL.

In addition to the problems with driving the nails into the OGDL, the nails that were driven would often pull free from the OGDL. To solve this problem, longer nails were used to secure the dowel and hinge joint baskets.

Concrete Yield

When IDOT first considered using an OGDL on an entire PCC pavement project, there was concern that the porosity of the OGDL surface would drastically reduce the percent of concrete yield, even though research was published that indicated that an OGDL would not have a significant impact on the percentage of concrete yield (*5*). Concrete yield is calculated by subtracting the required quantity of concrete from the used quantity of concrete and dividing that number by the quantity of concrete required. The percentage of concrete yield is calculated by multiplying this value by 100 percent. Typically, on a concrete paving project, the concrete yield is expected to be around +10 percent or less. The additional quantity is due to a combination of concrete that is left in the bottom of the haul trucks, concrete that is added to ensure the required pavement thickness is achieved, concrete that is added to ensure the minimum paving width is achieved, and concrete left in the batching plant.

On the construction of the 14.5-km (9-mi) 1992 demonstration project on I–39, the average concrete yield was 7.1 percent with a standard deviation of 2.48 for 27 days of paving. The average concrete yield for the 1993 reconstruction of I–80 was 9.0 percent with a standard deviation of 4.18 for 31 days of paving. The average concrete yield percentages were weighted by the amount of concrete produced each day. From the information collected on these projects, it is clear that the OGDL has a minimal impact on the concrete yield percentages for projects of considerable length.

OGDL Stability

Before construction of the 1989 test section, there were concerns that the OGDL would not be stable enough to support a paving train. The first test section proved that a CA–7 aggregate gradation, in combination with 127 kg (280 lb) of portland cement and a water-to-cement ratio of 0.37, had the required strength to easily support paving operations.

On the 1992 demonstration project, the portland cement content was reduced to 142 kg/m^3 (240 lb/yd^3), the water-to-cement ratio was increased to 0.50, and the curing requirement was removed. These factors could have combined to result in a weaker OGDL, which might have been incapable of supporting paving operations. For the most part, this was not the case. In isolated instances, the dense graded aggregate base course became saturated and was undrained. The saturated dense-graded aggregate base course failed to provide adequate support to the OGDL during paving operations and resulted in the OGDL fracturing under paving operations. Typical pictures of this problem are included in Figures 10 and 11. This problem can be easily addressed by providing the dense-graded aggregate base course with proper drainage.

CONCLUSIONS

Over the past 7 years, IDOT has acquired extensive experience in constructing PCC pavements with OGDL. As with any new construction material, early attempts at placing an OGDL and the subsequent PCC pavement were successful on a limited basis only. Later attempts were successful as IDOT experience increased. Through the construction of over 30 centerline km (20 centerline mi) of PCC pavements with OGDL, the following items were learned:

- The portland cement stabilized OGDL mix is harsh and must be placed with a subgrade planer or like equipment with the ability to spread the harsh mix the width of the highway.
- The compaction technique used on the OGDL must be capable of providing a smooth surface to reduce the impact that the OGDL has on the overall ride quality of PCC pavement.
- It is not necessary to cure the portland cement stabilized OGDL either to achieve adequate support for paving operations or prevent the OGDL from experiencing problems from inadequate curing, such as raveling.
- Special attention must be directed toward the placement of dowel and hinge joint baskets on the OGDL. Standard construction techniques and materials will not secure the baskets to a portland cement stabilized OGDL.
- The OGDL does not have a large impact on the percentage of concrete pavement yield. The concrete yields on the two largest construction projects built to date were under +10 percent.
- The OGDL has sufficient stability to support paving operations. The only time the OGDL fractured under paving operations is when the dense-graded aggregate base course underneath the OGDL was saturated.

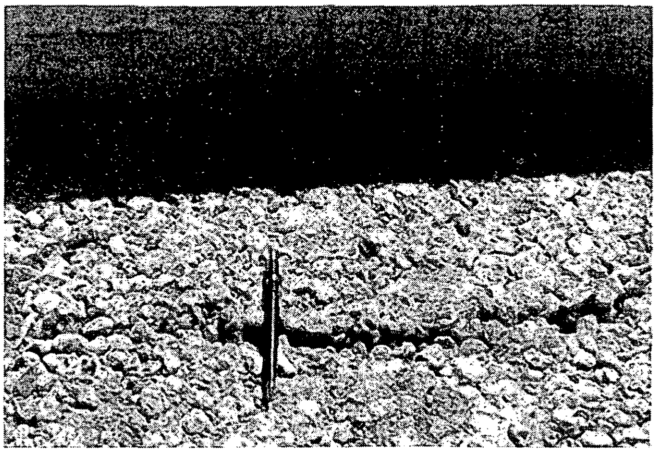

FIGURE 10 Broken OGDL.

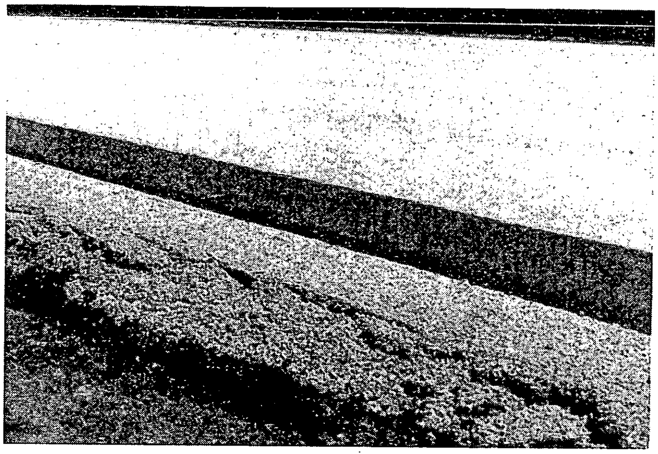

FIGURE 11 Broken OGDL.

Experience proves that given proper attention to construction details, PCC pavements can be built to today's standards with an OGDL as part of a positive drainage system. At this time, the pavement sections discussed in this report are too young to provide sufficient data to discern differences in performance between the various OGDL mix designs, placement techniques, and compaction procedures. The impact of these variations on pavement performance will be studied as more information becomes available.

REFERENCES

1. McAdam, J. L. *Report to the London Board of Agriculture*. London, England, 1820.
2. Crovetti, J. A., and B. J. Dempsey. *Pavement Subbases.* Report UILU-ENG-91-2005. Department of Civil Engineering, University of Illinois, May 1992.
3. Reed, C. M. *Design and Construction of Open-Graded Base Courses.* Illinois Department of Transportation, Bureau of Materials and Physical Research, Springfield, Ill. June 1993.
4. Hall, M. *Cement Stabilized Open-Graded Base: Strength Testing and Field Performance Versus Cement Content.* Wisconsin Concrete Pavement Association, Nov. 1990.
5. Cedergren, H. R. *Drainage of Highway and Airfield Pavements.* John Wiley and Sons, Inc., New York, 1974.

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