Cement-Stabilized Open-Graded Base Strength Testing and Field Performance Versus Cement Content

MICHAEL HALL

Explored in this study is the use of cement-stabilized open-graded base (CSOGB) to provide a drainage system and construction platform for concrete pavements. Objectives were to (*a*) assess concrete testing methods for CSOGB and (*b*) examine cement content versus performance under construction traffic. Modified concrete testing methods were used to sample, fabricate, cure, and test cylinders, beams, and cores prepared on site. Large sample sizes were used, specimens were compacted by surface tamping, cylinders were cured in plastic molds, and loading rates were reduced. Laboratory-cured compressive and bending, field-cured compressive and split tensile, and core split tensile and permeability tests were conducted. Strength tests were performed successfully and yielded reasonably consistent results. Permeability was successfully measured using a modified New Jersey falling head permeability apparatus. Low, medium, and high cement content material was placed on grade and used as a haul road during paving. The condition of the CSOGB was monitored during construction and trucks, both loaded with concrete and empty, were counted. Performance under load was found to depend on cement content, truck traffic, sub-layer stability, segregation, and surface irregularities. A cement content of 1163 N/m^3 (200 lb/yd^3) was suitable for general use, 873 N/m^3 (150 lb/yd^3) was adequate for low trucking volumes, and 1454 N/m^3 (250 lb/yd^3) was appropriate for high trucking volumes or poor support conditions.

Research indicates that adequate drainage is an essential component of a pavement system. In Wisconsin this has led to the provision of an open-graded base layer under most new concrete pavements. Typically 10.2 cm (4 in.) of an open-graded coarse aggregate over a dense-graded base layer is specified. This system frequently lacks the stability required to support construction activities. Cement stabilization of open-graded material is an an option that simultaneously provides drainage and a stable construction platform.

Paving is safer and more efficient when the grade is used as a haul road. Construction activities can be isolated from regular traffic without the cost of building a temporary road. Full-width paving can be accomplished even when lateral clearance is limited. Pavers equipped with dowel-bar inserters can place material dumped directly on the grade without a spreader in the paving train. These advantages can help the contractor expedite construction and contain costs.

At the time of this project there were no standard testing procedures for cement-stabilized open-graded base (CSOGB) material and little information was available on its ability to support construction traffic. This work represents the collective efforts of the Wisconsin Department of Transportation (WisDOT), the Federal Highway Administration (FHWA), the James Cape & Sons Company, and the Wisconsin Concrete Pavement Association (WCPA) to evaluate the potential of this material.

The primary objectives of this study were to assess (*a*) the use of concrete testing procedures to measure mechanical properties of CSOGB and (*b*) the correlation between the cement content of CSOGB and its performance under construction trucking activities. The research was performed during the 1990 reconstruction of the northbound side of Interstate 90 near Stoughton, Wisconsin, originally opened in 1962. Adjacent southbound lanes carried daily traffic of about 20,000 cars and 5,000 heavy trucks without interruption throughout the course of the project. The old pavement was completely removed and the existing 28-year-old grade was restored. The new structure consisted of 25.4 cm (10 in.) of doweled plain concrete pavement over 10.2 cm (4 in.) of CSOGB over a minimum of 10.2 cm (4 in.) of restored dense-graded base, all over a typically heavy soil subbase.

This job, divided into two portions, was selected because a section of the work was located where an access road would be difficult to construct. The contractor's batch plant was located in the middle of the project to limit haul lengths. Construction proceeded from the ends toward the midpoint. CSOGB placed at each end carried limited trucking whereas that placed nearest the plant carried more trucks.

SPECIFICATIONS AND PROCEDURES

Cylinders and beams were fabricated using CSOGB from the contractor's batch plant. Flexural specimens and half of the compression specimens were subsequently transported to the WisDOT lab for controlled moist curing and testing. Split tensile specimens and the rest of the compression specimens were field-cured and tested by FHWA on site. A 793-m (2,600-ft) test section was established for material of each of three cement contents designated as low, medium, and high. A 122-m (400-ft)-long divided area was provided within each test section to create separate lanes for loaded and empty trucks. Cores were cut from each test section for split tensile and permeability testing.

Although concrete testing procedures as prescribed by the American Society for Testing and Materials (*1*) were followed as closely as possible, modifications were made to accommodate special characteristics of the material and unique conditions encountered in the field.

Specifications

Compositions of the test mixes are tabulated in Table 1. The target dry weight for the 0.19-cm (0.75-in.) top-sized crushed limestone

---

Wisconsin Concrete Pavement Association, 7609 Elmwood Avenue, Middleton, Wis. 53562.

TABLE 1 Test Mix Compositions

	Component weights (N/m^3)[a] for each test mix					
	Lab-Cured			Field-Cured		
	Low	Medium	High	Low	Medium	High
Type I Cement	873 (150)	1163 (200)	1454 (250)	873 (150)	1163 (200)	1454 (250)
Dry Crushed Limestone	14793 (2543)	14909 (2563)	14764 (2538)	14798 (2544)	14909 (2563)	14816 (2547)
Dry Recycled Sand	337 (58)	343 (59)	349 (60)	349 (60)	343 (59)	355 (61)
Net Water	820 (141)	605 (104)	683 (118)	829 (143)	605 (104)	683 (118)
Water/Cement Ratio	0.94	0.52	0.47	0.95	0.52	0.47

[a] Values in parentheses are in lb/yd^3

coarse-aggregate was 14,793 N/m^3 (2,543 lb/yd^3), the same quantity used in the concrete on the job. The contractor also added 337 N/m^3 (58 lb/yd^3) of recycled sand. The resulting total gradation conformed to specifications for American Association of State Highway and Transportation Officials No. 67 stone (*2*). Cement contents of 873 N/m^3 (150 lb/yd^3), 1163 N/m^3 (200 lb/yd^3), and 1454 N/m^3 (250 lb/yd^3) were used. Water content for each mix was determined from assessment of the material as it was placed to minimize separation of the paste. The water/cement (w/c) ratio thus varied between mixes. Mixing procedures were essentially the same as those used for concrete with mixing time extended from 60 to 70 sec for each 8.4 m^3 (11 yd^3) batch.

CSOGB was transported in open box dump trucks and agitor trucks and placed with a slightly modified finegrader. Augers spread material laterally and a blade was used to establish the grade. Compaction was provided by a full-width vibratory steel plate. A small vibratory plate was used to resurface the material in the trackline of the finegrader. Plastic sheeting was applied immediately after placement to limit evaporation during a 3- to 4-day curing period. A 92-m (300-ft) section was left uncovered to assess the importance of covering.

Test sections for each cement content were located in areas with no visible subgrade problems. Low-cement material was placed near the beginning of the project where the least amount of trucking would occur. Medium-cement material was placed where significant one-way hauling was done. High-cement material was placed where extensive two-way operation was required. Observations were also made of material placed outside the formal test sections. Several variations were tried, but medium-cement material was used on most of the project.

Procedures

Samples for controlled laboratory curing were delivered in the contractor's trucks to an indoor casting site on the project and field-cured samples were taken on grade. Large samples were used to minimize evaporation and provide enough material for each series of specimens. About 0.76 m^3 (1 yd^3) of the 8.4-m^3 (11-yd^3) load was discharged onto a plastic sheet. The sheet was folded over the material to prevent moisture loss. Material was taken from different areas of the sample throughout the casting process to ensure uniformity among the specimens. Surface material was continually discarded as it dried out.

Specimens for testing at each age were produced consecutively in groups of three to minimize variability. Cylinders for compression testing at each of four ages (3, 5, 7, and 28 days) and beams for flexural testing at each of three ages (3, 5, and 7 days) were cast for each cement content and marked for laboratory curing. Field curing was specified for compression cylinders cast for testing at 3, 5, and 7 days (low cement) and at 3, 5, 7, and 28 days (medium and high cement). Field-cured split tensile cylinders for each cement content were cast for testing at each of four ages (3, 5, 7, and 28 days).

Specimens were compacted using a tamper consisting of a 11.4-cm (4.5-in.) diam pipe flange on a 4.76-cm (1.88-in.) diam pipe nipple 25.4 cm (10 in.) long. Consistent compactive effort was achieved by dropping the 15.3-N (3.44-lb) tamper from about 2.5 cm (1 in.) above the surface of the material.

Cylinders were cast in 15.2-cm (6-in.) diam × 30.5-cm (12-in.) long plastic molds. Material was placed in 10.2-cm (4-in.) lifts and tamped 25 times/layer. The final layer was overfilled to adjust for subsidence of the material. The surface provided by tamping was superior to that produced if a strike-off was attempted.

Beams were cast in 15.2-cm × 15.2-cm × 53.3-cm (6-in. × 6-in. × 21-in.) steel molds. Material was placed in 7.6-cm (3-in.) lifts and tamped 63 times, once for every 12.9 cm^2 (2 in.^{2}) of surface area layer. A darby was used to strike off the beams, with care taken to avoid loss of surface aggregate.

Individual plastic bags were placed on the cylinders. Each group of specimens was covered with plastic sheeting laid down tightly over the surface of each beam. Laboratory-cured specimens were transported to the WisDOT lab after 24 hr. Field-cured cylinders were moved to the on-site FHWA testing facility after 3 days and recovered. Specimens were left in their molds and padded during transportation to avoid damage from early handling.

Controlled moist curing at 22.8°C (73°F) was provided for laboratory-cured specimens. Cylinders were left covered and in their molds and beams were stripped. Field-cured specimens were stored on site until tested. Material on grade was exposed to drying conditions between removal of the plastic sheeting and the time it was paved over. Corresponding field-cured specimens were uncovered for 3 days to simulate this exposure and were then recovered. Field temperatures fluctuated from day to night but were, on average, within 5 percent of the laboratory value.

Three 15.2-cm (6-in.)-diameter cores were cut from each formal test section and from the uncovered section for split tensile testing. Three 10.2-cm (4-in.)-diameter cores were also cut from the high-cement test section for permeability testing.

ASTM (*1*) concrete testing procedures, with lower loading rates to avoid early failure, were followed for compression, split tensile, and third-point bending tests. Split tensile tests were also done on 15.2-cm (6-in.)-diameter cores only 10.2 cm (4 in.) long. The 10.2-cm (4-in.)-diameter cores were adapted for testing in a modified New Jersey falling-head permeability apparatus (*3*).

RESULTS OF PHYSICAL TESTING

Results of compression, bending, and split tensile tests performed on prepared specimens are shown in Table 2 and split tensile test

TABLE 2 Strength Tests of Prepared Specimens

			Strength (kPa) [a] for each test specimen			
	Cement Content	Age (days)	1	2	3	Average
Lab Compression	Low	3	1,220	1,220	1,330	1,256
		5	1,454	1,578	1,557	1,530
		7	1,909	1,585	1,578	1,690
		28	2,246	2,122	1,977	2,115
	Medium	3	1,481	1,612	1,495	1,530
		5	1,647	1,750	1,805	1,734
		7	1,867	1,909	2,060	1,945
		28	2,701	2,584	2,963	2,749
	High	3	5,188	4,837	5,250	5,092
		5	5,464	5,388	5,588	5,480
		7	6,601	5,009	5,043	5,551
		23	6,249	6,601	6,132	6,327
Field Compression	Low	3	1,020	937		978
		5	1,144	1,082	1,164	1,130
		7	1,116	1,068	1,027	1,070
	Medium	3	3,045	3,004	2,832	2,960
		5	2,942	2,963	2,880	2,928
		7	2,894	2,811	2,928	2,878
		28	3,362	3,597	3,796	3,585
	High	3	3,293	3,569	3,500	3,454
		5	4,492	4,127	4,175	4,265
		7	3,824	4,334	4,403	4,187
		28	4,699	5,154	5,360	5,071
Lab Flexural	Low	3	287	413	316	339
		5	482	431	453	455
		7	442	488	460	463
	Medium	3	387	425	425	412
		5	396	345	431	390
		7	482	505	505	497
	High	3	1,062	1,108	1,189	1,120
		5	1,209	1,177	1,223	1,203
		7	1,120	1,235	1,321	1,225
Field Split Tensile	Low	3	117	123		120
		5	168	156	191	172
		7	212	263	243	239
		28	204	274	251	243
	Medium	3	372	422	389	394
		5	553	570	627	583
		7	601	469	616	562
		28	554	520	487	520
	High	3	588	466	551	535
		5	768	745	686	733
		7	807	588	688	694
		28	898	859	931	896

[a] 1 kPa = 0.145 psi

TABLE 3 Tests of Core Samples

Cement Content	Age (days)	Split tensile strength (kPa)[a] for each test specimen 1	2	3	Average
Low	8	391	438	338	389
Medium	7	680	475	531	562
High	7	476	1,038	650	721
High (uncovered)	7	669	457	558	561

Cement Content	Age (days)	Permeability (m/day)[b] for each test specimen 1	2	3	Average
High	28	878	1178	766	941

[a] 1 kPa = 0.145 psi

[b] 1 m/day = 3.279 ft/day

results of cores are presented in Table 3. Results of falling-head permeability tests performed on cores of the high-cement content material are also presented in Table 3.

Strength Versus Age Relationships

Laboratory-cured compressive strengths (Figure 1) show a moderate increase from low to medium cement with a much larger increase for high cement. Laboratory-cured flexural strengths (Figure 2) show almost identical results for the low and medium cement with marked improvement for the high cement. Flexural strength curves are extended to 28 days for visual comparison with the other plots but this extrapolation is not intended to predict the strength beyond 7 days. Field-cured compressive and split tensile strengths (Figures 3 and 4) showed a more uniform increase with cement content.

Measured strength depended on the test method and curing condition. The parallel nature of the regression lines shown in Figures 1 through 4 indicates a relatively consistent correspondence among samples. Further testing with multiple replicates for each sample will be required to accurately assess and explain these differences.

Review of Findings

The unique characteristics of CSOGB led to modification of typical procedures. Observations during fabrication, handling, and testing, and the numerical results suggest that the modifications were effective.

Use of a single large sample to produce all the specimens for each cement content and curing condition helped minimize variability. This approach, however, meant that one bad sample could

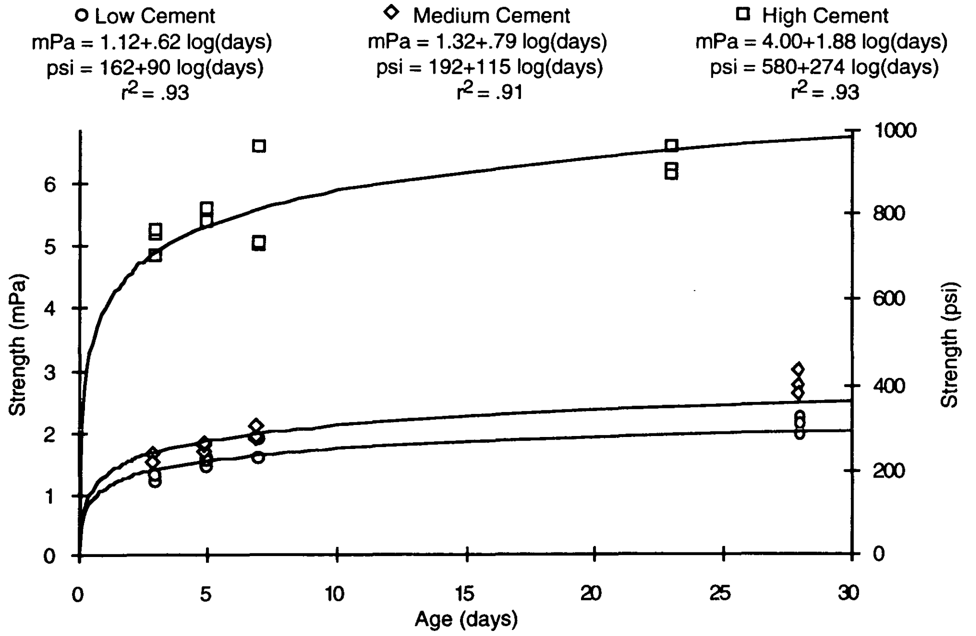

FIGURE 1 Laboratory-cured compressive strength versus age.

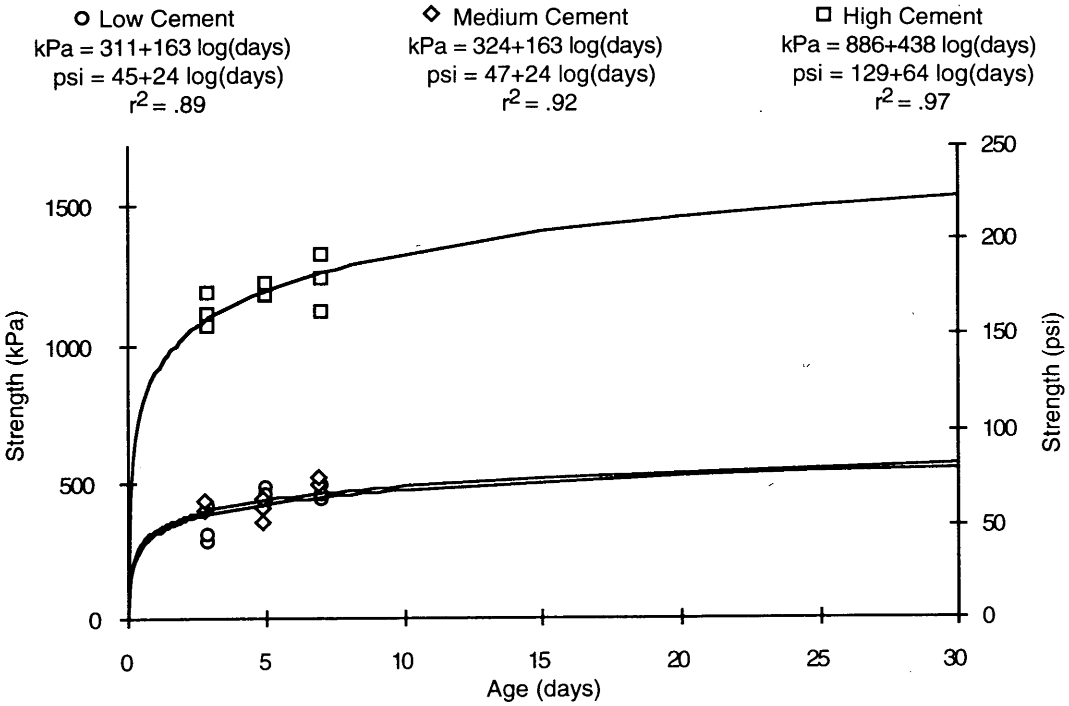

FIGURE 2 Field-cured compressive strength versus age.

jeopardize the validity of several specimens. The usefulness of all the data generated from the laboratory-cured medium-cement sample is thus limited. The relationship between cement and strength for Figures 1 and 2 is consequently obscured.

Examination of strength data and test specimens revealed no significant problems attributable to the fabrication process. Compaction was fairly uniform throughout the cylinders. Separate lifts were identifiable in some cases, but did not seem to affect the behavior during testing. The individual test results for each age are generally tightly grouped.

A rectangular tamper should be used for beams to provide for uniform compaction in the corners. Care should be taken to avoid

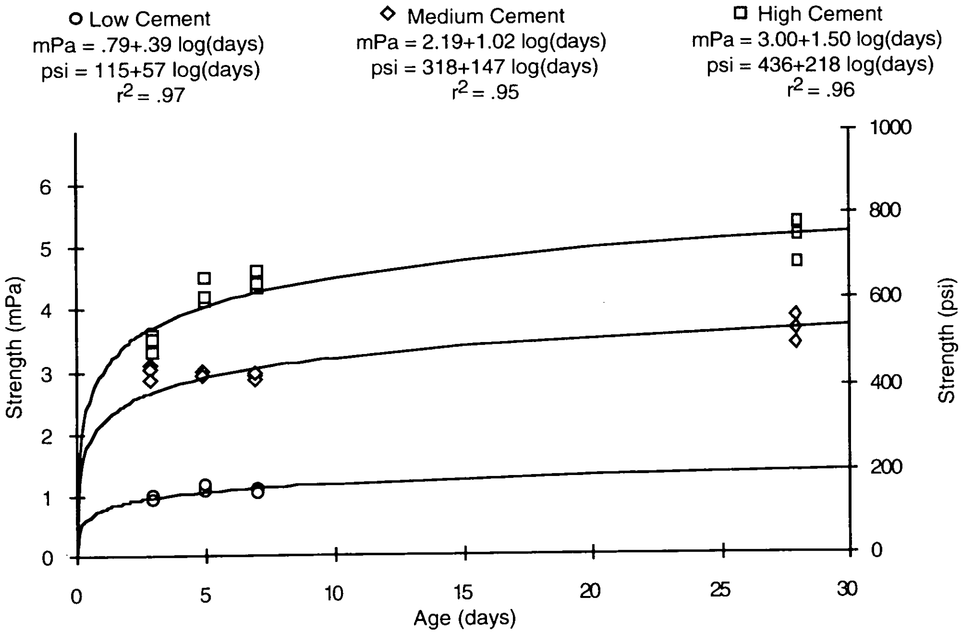

FIGURE 3 Laboratory flexural strength versus age.

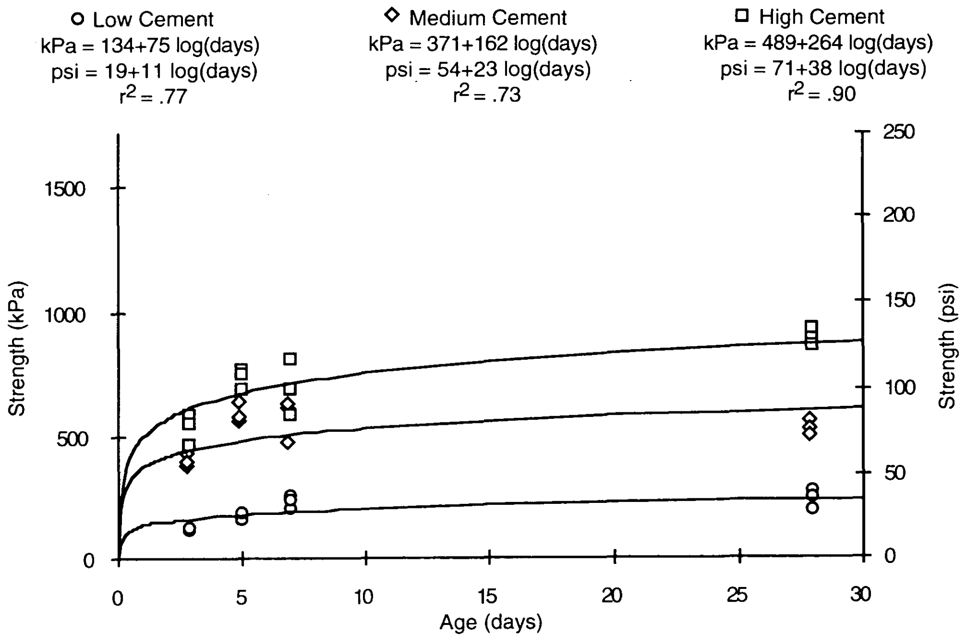

FIGURE 4 Field-cured split tensile strength versus age.

aggregate fracture during tamping. Use of a wooden tamper instead of the steel one employed in this work might be advisable.

No major problems occurred during transportation or handling. However, two low-cement content field-cured cylinders were broken during stripping for the 3-day tests. If precautions are taken, problems associated with excessive drying and mechanical damage can be avoided.

In this work, field-cured specimens were uncovered for 3 days in the middle of their curing period to mimic the exposure of the material on grade. Because field conditions are variable, and for simplicity, specimens should probably be left covered until tested.

Mechanisms observed during failure of CSOGB were similar to those seen with regular concrete. Low-cement content compression and split tensile specimens tended to fail with disintegration of material over the entire cross section, a mechanism common for low-strength concretes. Higher-cement content specimens had shear or cone failures in compression and a surprisingly clean failure plane in split tensile tests. All bending tests had clean fracture surfaces near mid span. These observations tend to support the validity of the testing procedures.

Strength versus age plots for laboratory-cured specimens show a nonuniform increase in strength with cement content, whereas field-cured plots and core strengths indicate a more uniform strength gain. This inconsistency makes it difficult to come to a definitive conclusion about the correlation between strength and cement content. This problem is thought to have been caused by the inclusion of a nonrepresentative sample (outlier) for the laboratory-cured medium cement content.

Marginal effectiveness of cement additions may vary with cement content. Cement at the points of contact between aggregate particles provides bonding, whereas cement coating open surfaces contributes little to the strength. This mechanism could account for some nonuniformity in the cement content versus strength relationship.

The w/c ratio of the low-cement mix (0.94) is substantially higher than that of the medium-cement mix (0.52) and the high-cement mix (0.47). Based on this, the strength of the low-cement material should be significantly lower than that of the other two materials. This, however, was clearly not the case. Higher w/c may facilitate the migration of the paste toward the points of contact and thus tend to improve the strength of CSOGB material.

Strength development mechanisms for CSOGB are potentially more complicated than those for regular concrete. These mechanisms must be more thoroughly understood before a reliable mix design procedure can be developed. This work implies that cement content instead of w/c is a better indicator of strength for CSOGB. Until data from more tightly controlled testing are obtained, design decisions should probably be based on cement content.

Cores were taken without difficulty for each of the three cement contents. Split tensile tests were undertaken because the cores were too short for a valid compression test. Although more variable, strengths are similar to those obtained for field-cured cylinders. Higher variability is probably caused by segregation during placement and the smaller size of the cores.

Curing, requiring several workers to place and later remove plastic sheeting, was expensive. Cores of material left exposed showed lower average strengths (Table 3) than covered material but there was some overlap in the data. If exposure does not cause significant strength loss, more cement can be used without covering to provide a potentially better product at reduced cost.

Permeability tests (Table 3) indicate that, even with high cement material, CSOGB provides adequate drainage. Core tests show an average flow rate of 930 m/day (3,085 ft/day) whereas WisDOT specifies a minimum of 305 m/day (1,000 ft/day).

EFFECTS OF CONSTRUCTION TRUCKING OPERATIONS

Test Section Observations

Observations were made of formal test sections provided for each cement content. Distinction is made between one-way and two-way trucking. Under one-way conditions, the grade is used primarily for return traffic operating unloaded at relatively high speeds. Loaded trucks are channeled onto the grade at about 0.8-km (0.5-mi) intervals, and operated at lower speeds, primarily in reverse. With two-way hauling, the entire project is trucked, at speed, by both empty and loaded trucks. Passage of about 310 trucks/km (500 trucks/mi) of pavement was required.

The typical empty truck had 44.5 kN (10 kip) on a single front axle with about 66.8 kN (15 kip) on a tandem rear axle. Fully loaded with a 6.88 m^3 (9 yd^3) batch of concrete, the front axle carried about 89.0 kN (20 kip), with about 151 kN (34 kip) on the rear tandem and an additional 44.5 kN (10 kip) on the auxiliary rear axle.

Low Cement Content

The test section for low-cement material was laid out near the north end of the project to minimize the one-way trucking that it would carry. The condition of the subbase was good, with no significant areas of soft or wet spots. Some segregation was evident with crescent-shaped light and dark streaks characteristic of the placement procedure throughout this project. The center of the placement was somewhat undercompacted, whereas the material near the edges was more stable. The surface was generally smooth, with some roughness caused by worker footprints in the fresh material.

Material subjected to 250 empty trucks running at relatively high speeds sustained only surface damage. Raveling developed quickly with some expansion of initial problem areas but, at the time they were paved over, the worst were no more than 2.5 cm (1 in.) deep. Loose material was dispersed and some aggregate fracture was observed. About 5 percent of the surface, corresponding to the locations of crescent-shaped segregation bands, was affected. Deterioration also showed some correspondence to areas of initial surface roughness.

Under the action of slower-moving, loaded trucks, deterioration tended to be deeper, with loose material confined to damaged areas. Although degradation began more slowly, full-depth damage with up to 2.5-cm (1-in.) ruts developed after passage of 250 loaded trucks. At this point, as CSOGB was paved over, there was no significant infilling or pumping of fines in the ruts. Again there was correlation between the locations of distressed areas and segregation bands. Here, however, the frequency of significant damage was lower, with about 2 percent of the area substantially affected.

One-way construction traffic varied from 74 to 250 trucks over the test section. Performance was characterized as good, with no serious deterioration and no remedial work required before paving.

Medium Cement Content

The test section for medium-cement material began about 5.6 km (3.5 mi) into the northern portion of the project. Although the subgrade was generally dry and stable, there were some soft areas that had been undercut and filled with sand. Again there was minor segregation, surface roughness, and differential compaction.

Damage from 1,800 higher-speed empty trucks was limited to surface erosion. The onset and growth of distress was more gradual than it was with the low-cement material. Loosened material was thrown from raveled areas by the trucks. Deterioration affected about 3 percent of the area and extended to depths of up to 2.5 cm (1 in.). Although not all segregation bands showed distress, surface degradation followed the same pattern. There was little correlation between initial roughness and the development of raveling.

Under 530 loaded trucks, isolated full-depth degradation occurred with 2.5- to 5-cm (1- to 2-in.) ruts over about 2 percent of the total area. There was some infilling of fines, but to a degree that had no appreciable effect on drainability. Loose material was confined to the ruts.

One-way traffic ranged from 1,680 to 1,940 trucks over the test section. Performance was generally good, but there were some isolated areas of more severe distress. These trouble spots were related to poor conditions in the subbase. Damage in these areas was repairable, characterized by dispersion of loose material, cracking, and loss of permeability caused by infill and pumping of fines.

High Cement Content

The test section for high-cement material was located about 6.4 km (4 mi) into the southern portion of the project. Underlying dense-graded material was extremely stable with only isolated soft spots. Segregation and roughness were comparable to the other test sections and there was some differential compaction.

Operation of 2,045 empty trucks caused only minimal aggregate fracture and virtually no erosion of the surface. The only discernible defects were transverse shrinkage cracks at 15- to 30-m (50 to 100-ft) intervals. Operation of up to 1,475 loaded trucks led to only minor deterioration. The only noticeable effects were some aggregate fracture and a limited amount of erosion along some of the shrinkage cracks.

Two-way trucking of 1,250 to 2,060 trucks was sustained over the test section. Performance was excellent. There was some confined full-depth damage directly over a small soft spot in the subgrade.

Auxiliary Observations

Observations of material with varying water contents indicated that, although higher water contents promoted segregation, excessively dry mixes deteriorated faster. This effect became less pronounced as cement content was increased. High-cement content mixes also exhibited increased ability to bridge over soft spots in the subbase. Low-cement content material subjected to extended trucking suffered severe deterioration regardless of water content or subbase support.

A 122-m (400-ft) length of high cement material was left exposed to air cure. When compared with the adjacent material that was covered with plastic for the first 4 days, no significant degradation in truckability was evident.

Factors Influencing Performance

Major factors influencing the performance of the CSOGB were cement content, number of trucks, structural stability of sublayers, and segregation. Surface irregularities played a minor role.

TABLE 4 Performance Index

0 Very poor	Widespread dispersion of material, extensive deep deterioration, and significant infill of fines. Required extensive replacement of material to maintain support and/or permeability.
1 Poor	Extensive dispersion of material, frequent deep deterioration, cracking, and localized infill of fines. Required additional material and regrading.
2 Fair	Some dispersion of material, deep raveling, occasional deep deterioration, and some isolated infill of fines. Required some grading of dispersed material.
3 Good	Isolated dispersion of material, shallow raveling, some deep deterioration, and no appreciable infill of fines. Required only isolated grading of dispersed material.
4 Very good	Minimal raveling , confined deep deterioration with some subsidence, and no infill of fines. Required no significant repairs.
5 Excellent	Deterioration confined to isolated problem areas. Required no significant repairs.

Higher cement content mixes performed better for all subbase conditions. Improvement from medium-to-high cement was markedly greater than that observed from low-to-medium cement in areas with soft support.

CSOGB deteriorated with trucking volume. Problems tended to develop quickly in areas with segregation or poor structural support. The severity of distress increased with traffic, but the size of the distressed regions remained fairly constant. Higher volumes also led to more areas of damage, but progression was gradual. Deterioration became widespread only under very high volumes.

Empty trucks running at relatively high speeds, about 72 km/hr (45 mph), caused gradual shallow distress and dispersion of material. Full trucks running at low speeds, often in reverse, led to deep damage characterized by the rapid development of ruts with confined subsidence of loose material. The worst damage occurred when heavily loaded trucks were operated at high speed. This condition prevailed where CSOGB was subjected to two-way hauling over substantial distances. Damage was deeper and characterized by dispersion of material, aggregate fracture, and infilling of fines.

Soft areas in underlying layers caused deterioration of the CSOGB. Each mix performed adequately where the support was good, but in areas with only fair support, all the mixes showed some major deterioration. Material over soft spots tended to break up in chunks, crack, and pump fines from the subbase. Lower-cement content mixes tended toward widespread damage, whereas the high-cement material sustained only isolated damage.

CSOGB is harsh, unworkable, and susceptible to segregation. Excessive mix water caused separation of the paste from the aggregate, resulting in areas where permeability was reduced because of the infilling of paste. Dry mixes had areas of inadequate bonding that were subject to structural deterioration.

During placement, material in the finegrader hopper was pushed by the machine at the center of the roadway and augered to each

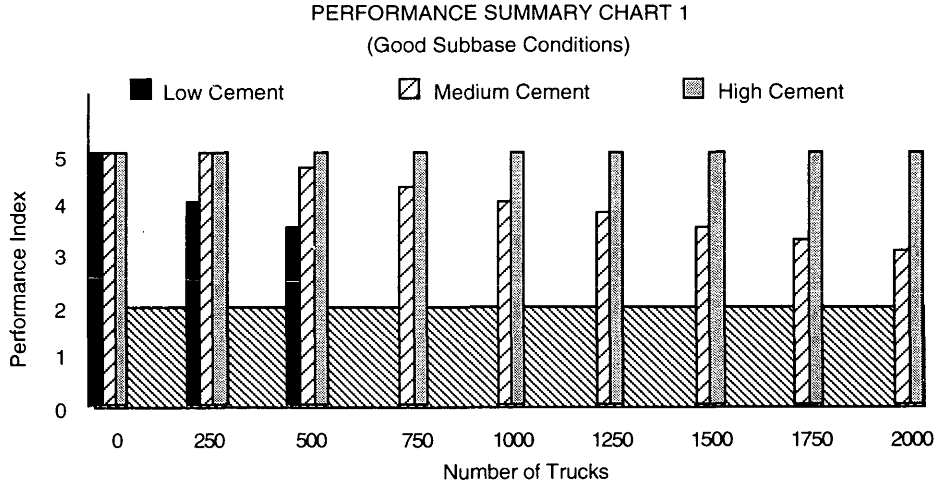

FIGURE 5 Performance over good subbase.

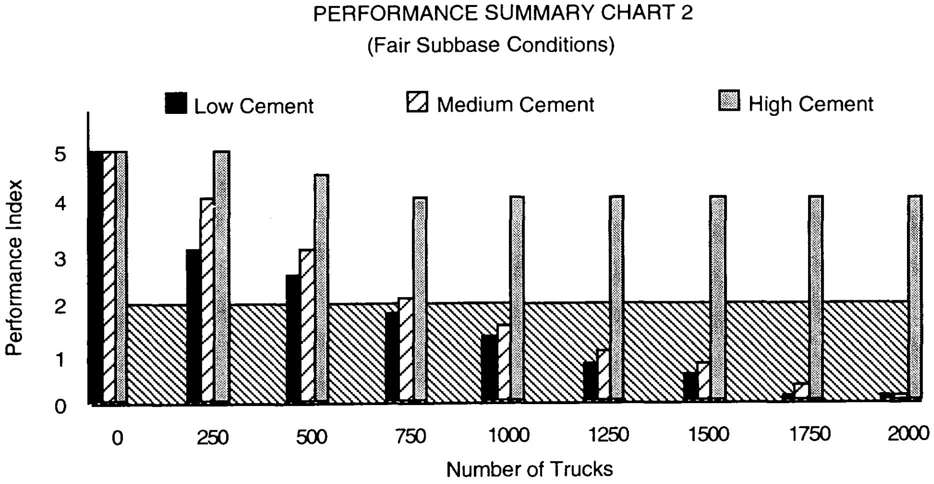

FIGURE 6 Performance over fair subbase.

side. Crescent-shaped areas of wet and dry material were formed as new material was added. These defects persisted throughout the range of water contents tried, but their severity could be limited. Performance was impaired with severe segregation, but was relatively unaffected with minimal segregation.

CSOGB does not respond as a plastic mass in a slump test and there is no other simple field test for workability. Examination of the extent of segregation of material in transit and as laid down can, however, be used to make mix-water adjustments. Visual inspection was sufficient to identify extreme segregation and a touch test was used when segregation was less pronounced. Pastes from wet and dry areas were compared for consistency. If the paste felt grainy and lacked cohesion, water was added. If the paste felt too fluid, less water was used. Using too little water proved to be more detrimental to performance.

Rough areas in the low-cement test section often developed into regions of shallow surface raveling. Roughness was less important in the higher-cement content materials, but poor compaction contributed to increased surface erosion.

Review of Findings

The second major objective of this work was to determine how well CSOGB performs under construction traffic. Results indicate that these materials can function as a haul road without excessive damage to either their structural integrity or their ability to provide adequate drainage.

Performance improved with cement content, but even low-cement mixes demonstrated reasonable durability. Low-cement material gave good performance under one-way trucking of up to a 1.6 km (1 mi) when placed over sound sublayers. Medium-cement material also performed well under one-way trucking of up to 3.2 km (2 mi). Performance was significantly enhanced with high-cement content even under two-way trucking for hauls of up to 8 km (5 mi) although some damage occurred when support was poor. Performance of lower-cement mixes, however, showed marked deterioration when placed over less sound material.

The performance index defined in Table 4 was developed to quantify the relation between performance and cement content. Performance is rated from 0 to 5 in terms of (*a*) dispersion of material, (*b*) depth and nature of deterioration, (*c*) extent of infilling or pumping of fines, (*d*) percentage of suface area significantly affected, and (*e*) extent of remedial work required.

Characterizations of performance presented in Figures 5 and 6 summarize the information collected during observation of construction activities. The cross-hatched region of each chart represents a level of damage that requires significant repair or replacement.

Predicted performance for material is shown in Figure 5. High-cement material gave excellent performance. Medium-cement material showed progressive decay but gave good performance up to passage of 2,000 trucks. Low-cement material held up well under traffic approaching 500 trucks.

Predicted performance for material with fair support is shown in Figure 6. High-cement material bridged over soft areas and gave good performance even after extensive trucking. Low- and medium-cement materials progressively deteriorated with marginal performance by the time volume reached 750 trucks.

CONCLUSIONS AND RECOMMENDATIONS

Physical Testing

1. Compression, split tensile, and bending tests yield meaningful strengths for CSOGB;
2. Cores can be cut and tested for in-place strength and permeability of CSOGB;
3. Four modifications should be made to standard ASTM (*1*) concrete testing methods: (*a*) larger samples should be taken, (*b*) specimens should be tamped rather than rodded, (*c*) specimens should be left in molds and covered until tested, and (*d*) load rates should be reduced;
4. An objective measure of workability should be developed for mix design and quality control; and
5. Relationships among cement content, w/c ratio, and strength should be explored.

Field Performance

1. Performance of CSOGB under trucking traffic depends on cement content, trucking volume, stability of underlying layers, segregation, and surface irregularities. Primary detriments were poor underlying structural support and segregation of the paste from the aggregate;
2. Frequent access should be provided to minimize two-way trucking;
3. Cement content should be tailored to trucking and subbase conditions. Low cement should be restricted to short hauls over stable subbase; medium cement is appropriate for general use and high cement should be used in areas with poor support or heavy trucking;
4. Benefits of covering should be investigated; and
5. Long-term performance should be monitored.

ACKNOWLEDGMENTS

The work presented in this report was funded through the Demonstration Projects Program, Office of Technology Applications, Engineering Applications Division, Federal Highway Administration. FHWA sponsored this research in the interest of information exchange and does not necessarily endorse the author's conclusions and recommendations.

REFERENCES

1. *Annual Book of ASTM Standards,* Vol. 04.02, Concrete and Aggregates. American Society for Testing and Materials, Philadelphia, Pa., 1990.
2. *Standard Specifications for Transportation Materials and Methods of Sampling and Testing,* Part 1, Specifications. American Association of State Highway and Transportation Officials, Washington, D.C., 1986.
3. *Permeability Test for Open-Graded Base Courses.* Wisconsin Department of Transportation, Madison, Wis., 1990.