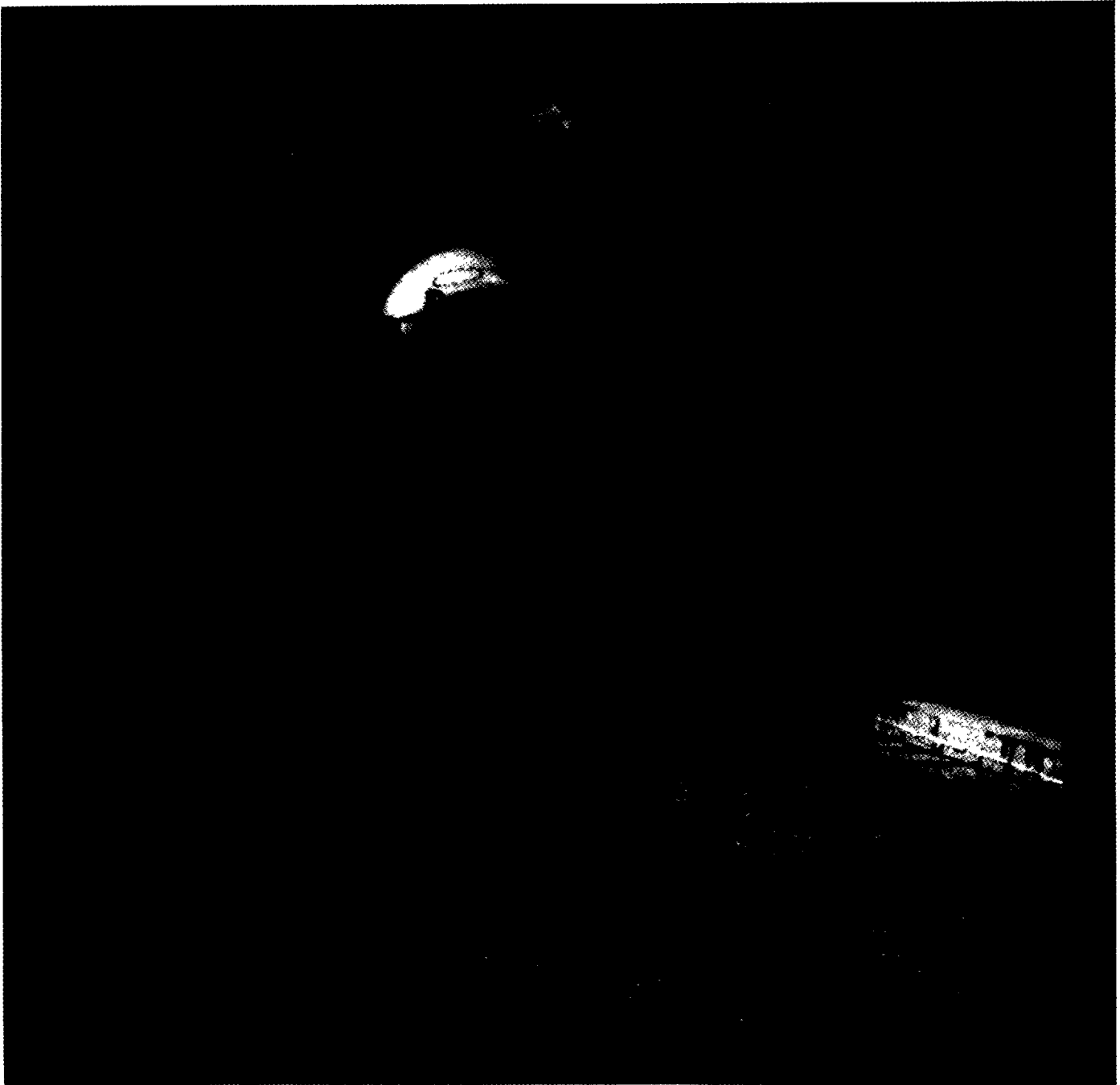


# CONCRETE PAVEMENTS



Compilation 30

American Concrete Institute

# Concrete Pavements

## ACI Compilation 30

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## Preface

ACI Compilations combine material previously published in Institute periodicals to provide compact and ready reference on specific topics. The Material in a compilation does not necessarily represent the opinion of an ACI technical committee — only the opinions of the individual authors. However, the information presented here is considered to be a valuable resource for readers interested in the subject.

Terry W. Sherman  
Chairman, ACI Committee 325  
Concrete Pavements

**On the cover:** Fast track techniques are a relatively new innovation in the concrete paving industry, now in its second century. This method allows traffic to use pavement that was placed only 12 hours earlier; economical concrete mixes that provide high strength in less than 24 hours have made this possible. Photo was taken during a recent paving project in Michigan.



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# COE Design of Cement Stabilized Base Courses for Airfield Pavements

by William N. Brabston and Raymond S. Rollings

**T**he U.S. Army Corps of Engineers (COE) is the primary Department of Defense agency responsible for the design and construction of Army and Air Force airfields. In this role COE develops design criteria, guide specifications, and other technical guidance information that are used for pavement design and contract specifications preparation.

In the past few years, COE has made some changes to and introduced new concepts in its approach to the design of pavements with cement stabilized base courses.

## Design manuals

Four technical manuals (TMs) are applicable in the design of cement stabilized base courses:

- TM 5-822-4 Soil Stabilization for Pavements
- TM 5-825-2 Flexible Pavement Design for Airfields
- TM 5-825-3 Rigid Pavements for Airfields
- TM 5-818-2 Pavement Design for Seasonal Frost Conditions

## Design cement content

TM 5-822-4 provides guidance on selection of design cement content. Included are gradation requirements, initial cement content selection criteria, and strength and durability criteria. This manual is currently undergoing revisions that are included herein. COE gradation requirements for cement stabilized base courses are shown in Fig 1. These criteria are basically a relaxation of the conventional unbound

base course criteria. For comparison, the Portland Cement Association (PCA) gradation requirements for a cement-treated aggregate base (CTAB) are also shown in Fig 1.

Soil classification is based on ASTM D 2487. A further stipulation is a maximum plasticity index between 20 and 30, the specific value depending on the fines content (percent finer than the No. 200 sieve).

Once it has been determined that a base course material is a candidate for cement stabilization, an initial design cement content is selected based on the soil classifica-

tion. Recommended initial design cement content values for various soil types are shown in Table 1.

Soil is then prepared for laboratory compaction tests at the initial estimated cement content. Moisture density tests are conducted following ASTM D 1557. Specimens are then molded at the maximum dry density or appropriate percentage thereof and at optimum water content or appropriate design field water content for strength and durability tests.

The strength of the specimens is determined by unconfined compres-

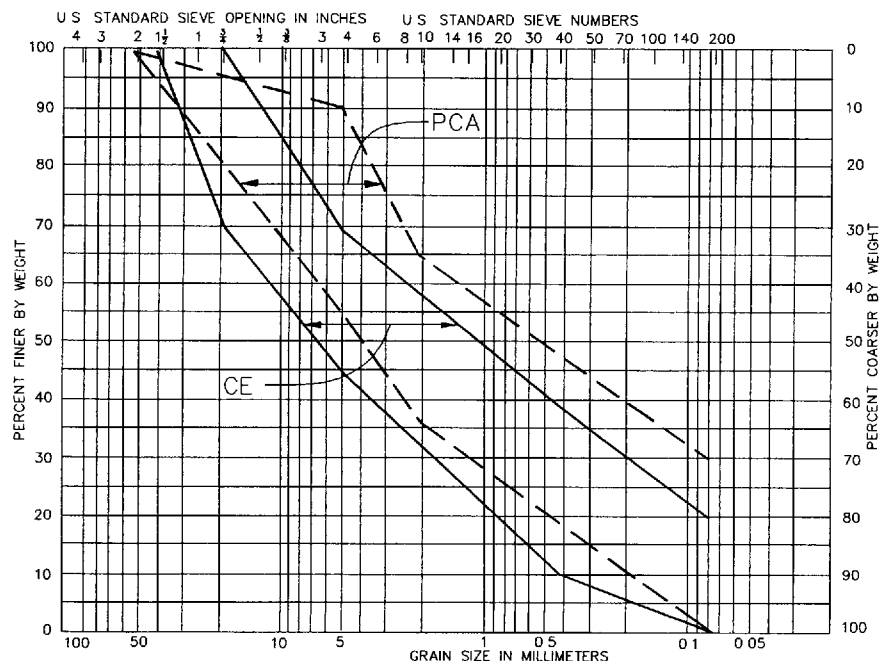


Fig. 1 — CE and PCA gradation requirements for cement stabilized base courses.

**Table 1 — Estimated cement requirement for various soil types**

| Soil classification                                          | Initial estimated cement content (percent dry weight) |
|--------------------------------------------------------------|-------------------------------------------------------|
| GW, SW                                                       | 5                                                     |
| GP, GW-GC, GW-GM, SW-SC, SW-SM                               | 6                                                     |
| GC, GM, GP-GC, GP-GM, GM-GC, SC, SM, SP-SC, SP-SM, SM-SC, SP | 7                                                     |

sive strength tests. Durability is determined by wet-dry or freeze-thaw tests (ASTM D 559 or D 560) as appropriate. For both the strength and durability tests, specimens are prepared in triplicate at the initial design cement content and at cement contents two percent above and two percent below that value. Thus a total of 18 specimens must be prepared. Before testing all specimens are moist cured in a humid room for 7 days. Results of the strength tests are then compared to the criteria for minimum unconfined compressive strength for a cement stabilized base course. The strength must be at least 750 psi for a flexible pavement and at least 500 psi for a rigid pavement. Durability tests consist of subjecting the specimens to 12 cycles of wetting and drying or freezing and thawing depending on which type of test is conducted. In areas where frost design is a consideration the freeze-thaw test would be appropriate, whereas the wet-dry test might be run in non-frost areas.

In the wet-dry test, each cycle consists of a 48 hour period during which the specimen is submerged in tap water for 5 hours and then dried in an oven at 71 C (160 F) for 42 hours. It is then cleaned with a wire brush to remove loose material that may have become unbonded. After 12 cycles (24 days) the total amount of weight loss is calculated and compared to the weight loss criteria

**Table 2 — Requirements after 12 cycles of durability tests**

| Type of soil stabilized | Allowable weight loss (percent of initial weight) |
|-------------------------|---------------------------------------------------|
| Granular, PI < 10       | 11                                                |
| Granular, PI > 10       | 8                                                 |

in Table 2. This table indicates the maximum allowable weight that can be lost from a specimen after 12 cycles of either the wet-dry or freeze thaw test.

In the freeze-thaw test cycle, each specimen is placed in an environmental chamber at a constant temperature of not more than -23 C (-10 F) for 24 hours, thawed in a humid room at 21 C (70 F) for 23 hours, and then brushed. These tests are considered to be a measure of the durability of a cement stabilized material when it is subjected to similar climatic conditions in a pavement structure.

To qualify as a cement stabilized base course, the material must meet both strength and durability criteria. The final design cement content is the lowest value of specimens meeting both criteria.

### Flexible pavements

TM 5-825-2 provides guidance on the design of flexible airfield pavements. Designing a cement stabilized base course involves first designing a conventional flexible pavement with an unbound granular base course and then applying a reduction factor to the unbound base thickness to determine the thickness of the stabilized base. Equivalency factors for cement stabilized base courses are indicated in Table 3.

For example, if a pavement design calls for 11.5 in. (290 mm) of

**Table 3 — Equivalency factors for cement stabilized base courses**

| Material stabilized | Equivalency factor |
|---------------------|--------------------|
| GW, GP, SW, SP      | 1.15               |
| GC, GM              | 1.00               |

unbound base, then 10.0 in. (250 mm) of cement stabilized material may be substituted for the unbound aggregate. This table as currently presented in TM 5-825-2 does not include equivalency factors for soils classified as SC or SM or for those soils having a double classification symbol, i.e. GW-GC. However, this deficiency will be addressed in the next revision to the manual. The revisions will present the following equivalency factors for these soil types:

- 1.15 for GW-GC, GW-GM, SW-SC, and SW-SM
- 1.00 for GP-GC, GP-GM, GM-GC, SC, SM, SP-SC, SP-SM, SM-SC

As shown, only about half of the soil types qualify for an actual reduction factor (1.15). The factor for the remaining materials is 1.00 indicating that the materials can be used in a base course if they meet strength and durability criteria but no thickness reduction is allowed. Therefore, a locally available and more economical material that does not meet conventional base course criteria may be used in the base course if it is properly stabilized.'

The use of equivalency factors is an artifice to accommodate theoretical limitations of the COE design method in TM 5-825-2. This design approach uses Boussinesq theory (homogenous elastic half-space) and is unable to account for layered structures with significantly differ-

ent stiffness characteristics. Consequently, equivalency factors provide a simple usable design method that, however, is not without theoretical drawbacks.

### Rigid pavements

TM 5-825-3 provides guidance for the design of rigid pavements. Background information for these design procedures may be found in References 2 and 3. Design procedures for five types of concrete pavements are addressed: plain, reinforced, fibrous, continuously reinforced, and prestressed. In all of the design procedures, the thickness of the stabilized base course is a selected value (6 in. [150 mm] minimum) and the slab thickness is determined as a function of the base thickness, the modulus of elasticity of the stabilized material, and other design parameters. Thus the design procedures may involve iteration between slab thickness and base thickness since the elastic modulus is essentially a fixed value determined by the quality of the stabilized material.

For plain, reinforced, fibrous, and continuously reinforced concrete design, a stabilized base is treated as a low-strength pavement and the concrete slab is considered as an overlay. Thickness design of the slab involves a modified, partially bonded, rigid-overlay-equation that theoretically allows a reduction in the slab thickness due to

the structural support provided by the stabilized base layer. In actuality, a significant thickness reduction is achieved only if the base course has a high elastic modulus value ( $>2,000,000$  psi [ $14,000,000$  kPa]) as would be the case for a lean concrete base material. Use of the overlay equation for the design of plain concrete is presented below. The overlay equation is applied in a similar fashion for thickness design of reinforced, fibrous, or continuously reinforced concrete on a stabilized base course.

In this procedure, an initial design thickness is first developed for a plain concrete slab directly on an unstabilized subgrade. This thickness value is then used in the overlay equation to determine a final thickness based on a slab on a stabilized base. Design parameters used to develop the initial thickness value are: concrete flexural strength  $R$ ; modulus of soil reaction  $k$ ; and aircraft load factors such as gross weight pass level and pavement traffic area. A typical set of design curves for an Air Force modified heavy-load pavement is shown in Fig. 2. These curves represent spe-

cific aircraft types and load factors.

Next the modified, partially bonded rigid overlay equation is used to develop a final thickness design value. This equation is:

$$h_o = \sqrt[4]{h_d^4 - \left( \sqrt[3]{\frac{E_b}{E_c}} h_b \right)^4}$$

where:

$h_o$  = thickness of plain concrete slab on stabilized base course

$h_d$  = initial thickness design of slab on unstabilized subgrade

$E_b$  = modulus of elasticity of base material

$E_c$  = modulus of elasticity of concrete, usually taken as  $4 \times 10^6$  psi

$h_b$  = thickness of stabilized base course

For example, the design thickness for a concrete slab with a flexural strength of 760 psi (5240 kPa) on a subgrade modulus of 100 pci (2.8 kg/m<sup>3</sup>), Type D traffic area, is 10.0 in. Assuming that design calls for a cement stabilized base course 10 in. thick having a modulus of elasticity of 400,000 psi (2,800,000 kPa), the

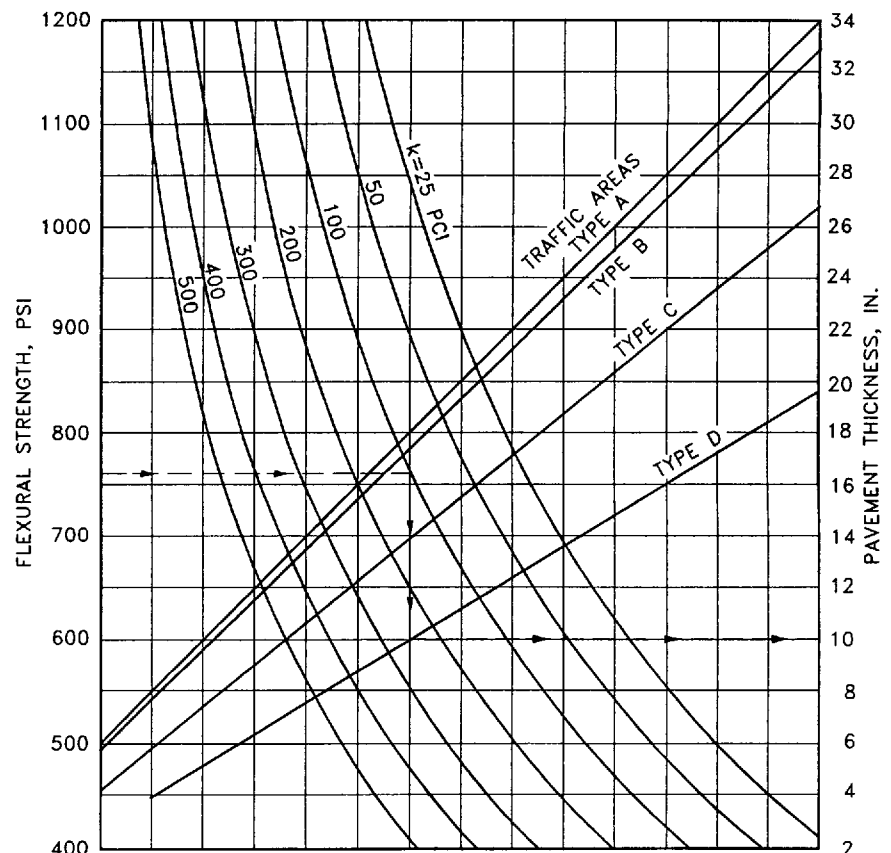


Fig. 2 — Plain concrete design curves for modified heavy load pavement.

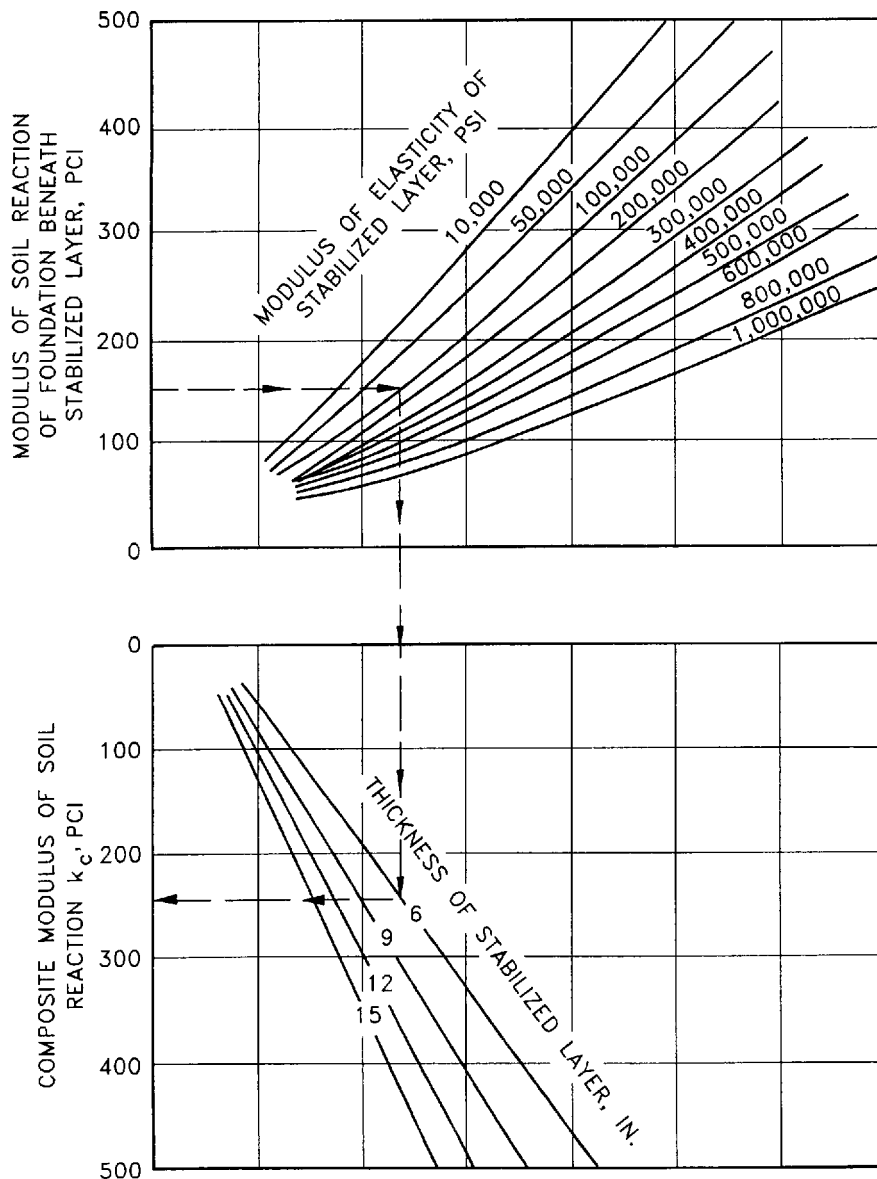


Fig. 3 — Composite modulus of soil reaction.

equation is entered and the final design thickness is determined to be 9.7 in. (246 mm). Thus there is no significant reduction in design thickness. (If the base were a lean concrete of equal thickness and a modulus of 2,000,000 psi [13,800,000 kPa], then the final design thickness based on the overlay equation would be 9.4 in. [239 mm].)

The basic COE concepts for rigid pavement design were developed in the 1940s and 1950s when the best available analytical model was the Westergaard edge loaded model represented by an elastic plate supported on springs. However, the model could not accurately represent a layered structure such as a concrete pavement over a stabilized

base and a subgrade. Consequently, the initial design approach for stabilized bases converted the stabilized base and the subgrade into an "equivalent" single spring constant  $k$  or a composite modulus of elasticity. This approach is still used with continuously reinforced and prestressed concrete pavements. When increasingly strong and stiff cement stabilized bases ("econocrete," lean concrete bases, roller-compacted concrete bases, dry-rolled concrete bases, etc.) became more widely used the modified overlay equation was introduced. These various design subterfuges were necessary because of the design limitations of the Westergaard model. More recent work with lay-

ered elastic and finite element theory offers a more theoretically sound method of examining the effect of cement stabilized bases under rigid pavements.

The design of prestressed concrete pavement is very complicated and requires several iterative procedures. When a cement stabilized base course is involved in pavement design, the structural contribution of the base is included by use of a composite modulus of soil reaction. This value is determined graphically based on the modulus of soil reaction of the subgrade below the stabilized layer, modulus of elasticity of the stabilized layer, and thickness of the stabilized layer which is a selected value. The graphical procedure is presented in Fig. 3.

For example, if it is desired to use a cement stabilized base course having a thickness of 6 in. (150 mm) and a modulus of elasticity of 100,000 psi (690,000 kPa) over a subgrade having a modulus of soil reaction of 160 pci (4.4 kg/m<sup>3</sup>), the composite modulus of soil reaction as determined from Fig. 3 would be 240 pci (6.6 kg/m<sup>3</sup>). This composite modulus value is used in the iterative design equations to determine a design thickness.

### Frost design

TM 5-818-2 provides guidance on design of pavements for frost conditions. Chapter 6 is directed towards the use of stabilized materials. Two items in the manual are of particular interest. First, stabilized base courses may not be used directly under a bituminous paving course. This limitation was placed because of previous experience with reflective cracking. Secondly, the freeze-thaw test (ASTM D 560) is required in areas where frost design is a consideration.

### Future work

Much of the past work with cement stabilized materials has emphasized the strength of the material and often the durability of the cement stabilized base has received only cursory attention. Cement stabilized bases have often been prescribed as a panacea for preventing pumping under rigid pavements but they have proven to be susceptible to erosion from pumping in some cases.

A dramatic example of the erodibility of cement stabilized bases recently occurred during the accelerated traffic tests at Beerburum, Australia.<sup>5,6</sup> A cement stabilized base was placed in three lifts, surfaced with a seal coat, and trafficked with an accelerated load facility (ALF). Water accumulated in the base's vertical shrinkage cracks and severe erosion occurred along these cracks and along the interfaces between lifts. This led to premature failure of the pavement test section.

The current COE design and mix proportioning methods for cement stabilized bases emphasizes strength and more work is needed to determine how durability should be included with the strength requirement. Reflective cracking from shrinkage cracking also remains a problem and better guidance is needed in this area.

There have been reports of chemical attack of sulfates on lime stabilized materials. Although the sulfate attack of lime stabilized materials has been relatively rare, repairs

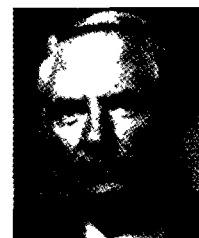
have been very costly. The potential for such problems for cement stabilized materials needs to be addressed.

## References

1. Rollings, R. S., "Substandard Materials for Pavement Construction," *Miscellaneous Paper GL-88-30*, USAE Waterways Experiment Station, Vicksburg, Mississippi, 1988.
2. Rollings, R. S., "Corps of Engineers Rigid Airfield Design Procedures," Second International Conference on Concrete Pavement Design and Rehabilitation, Purdue University, Indiana, 1981.
3. Rollings, R. S., "Developments in the Corps of Engineers Rigid Airfield Design Procedures," Fourth International Conference on Concrete Pavement Design and Rehabilitation, Purdue University, Indiana, 1989.
4. Ames, W. H., "Concrete Pavement Design and Rehabilitation in California," Third International Conference on Concrete Pavement Design and Rehabilitation, Purdue University, Indiana, 1985.
5. Kadar, P., "Experimental Program and Findings of the Beerburum ALF Trail," Main Roads Department, Queensland, Australia, 1987.
6. Howard, M. D., "Erosion of Cement Treated Pavement," 19th Australian Road Research Board Conference, Vol. 14, Part 7, Canberra, Australia, 1985.

Selected for reader interest by the editors.

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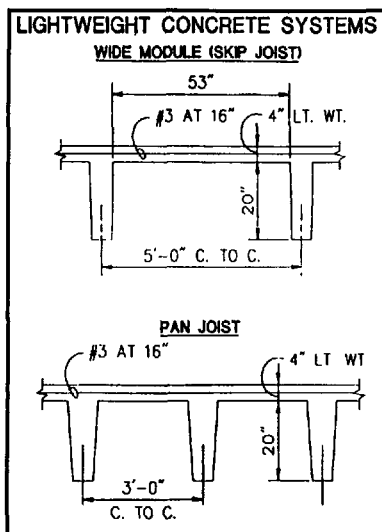


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CONCRETE PAVEMENTS

# Interlocking Concrete Airfield Pavements

by Perry M. King and David R. Smith

**I**nterlocking concrete pavements, also known as "concrete pavers," have been in use in streets and sidewalks for more than 35 years in Europe. The pavement system features low maintenance, ease of access to underground utilities, and an esthetic surface. Concrete pavers have been used in port and industrial applications subject to off-highway loads for more than 15 years in Europe.<sup>1</sup> The first application of concrete pavers in airfields subject to commercial aircraft began at Luton International Airport in Luton, England, a moderate sized city north of London.

Pavers were introduced there initially as a rehabilitative inlay for deteriorating asphalt pavements at aircraft gate parking areas. The asphalt in these areas deteriorated from the combined effect of hydraulic oils, freeze-thaw, and indentations from jacks used to lift landing gear for tire changes. Plate bearing tests by Emery<sup>2,3</sup> on these trial areas demonstrated an improvement in the structural load bearing capacity after replacement of the milled asphalt with 3½ in. (80 mm) thick pavers and 2 in. (50 mm) of bedding sand. After the success of the trials, the turning circles at the ends of the main runway were inlaid with concrete pavers in 1983. Other commercial and military airports have since used concrete pavers in the United Kingdom (Table 1). Concrete pavers are used in German and Israeli airfields, too.

In the early 1970s, a team of professional engineers developed airfield pavement standards for Dallas Fort Worth International Airport (DFW) using FAA design procedures. The result was the DFW "Airfield Pavement Design Man-

ual."<sup>4</sup> Pavement design was based on a 20 year service life. Airfield cross sections typically are 17 in. (430 mm) of jointed reinforced concrete (JRC) constructed on 9 in. (225 mm) of cement treated base (CTB) over 9 to 18 in. (225 to 460 mm) of lime treated subgrade (LTS). Rigid pavements were preferred over flexible pavements, partially due to flexible pavement's anticipated long term maintenance problems.

DFW recently initiated a 10 year, \$3.5 billion capital improvements program. Its goal is to increase capacity from the current 2050 air operations per day to 4000 per day by the year 2010. Passenger traffic is projected to increase from 52 million to 104 million passengers per year in and out of DFW by that time. The first \$27 million project of the expansion program was the construction of Taxiways B and C, forming part of the "West Side Development Plan." The pavements were to be constructed with a typical rigid pavement. Construction of the cross taxiways would have required a 60 day closure of the adjacent runway. Runway closings have a significant impact on air traffic, causing delays in both air and ground operations.

To reduce these delays, DFW staff reviewed an alternative rigid pavement section comprised of 21 in. (530 mm) of JRC pavement on recompacted natural subgrade. This cross section included pressure injected lime/fly ash treatment of the subgrade and an alternative cement. The design removed several of the work items, allowing the work done at night (during off peak airline times) to reduce runway closure times. However, the cross taxi-

way work was still forecast to take 114 nights with 14-hour nightly closures. The contractor also expressed concern about producing satisfactory concrete quality on such a tight schedule and about opening the adjacent runway on time at the end of each closure period.

The DFW Planning and Engineering Department continued to investigate alternative construction methods to reduce the 14-hour runway closures. One option they looked at was the use of interlocking concrete pavements at European airports and seaports. Following initial research and evaluation, a visit by the airport, the Air Transport Association, and airline representatives to airfields in the United Kingdom confirmed the success of interlocking concrete pavements. DFW Planning and Engineering forwarded the results of this investigation to the contractor with the suggestion that this alternative be considered along with others proposed by the contractor.

After engaging specialists and consulting engineers, the contractor proposed an alternative solution using 3½ in. (80 mm) thick concrete pavers placed on 1¼ in. (30 mm) of bedding sand on top of a 27 in. (685 mm) cement treated base (650 psi [4.5 MPa] at 7 days) all over a pressure injected lime/fly ash injected subgrade (Fig. 1).

Concrete pavers have proven their ability to withstand heavy loads and aggressive environments in ports for years. The Luton project had enabled airfield-related problems to be resolved and applied to other sites in the United Kingdom. The investigation of several United Kingdom projects confirmed the suitability of the pro-

posed system. The DFW Airport Board then decided to proceed with the first interlocking concrete airfield pavement application in North America.

In the summer of 1990 a consultant experienced with the pavers designed the project. A second pavement consultant reviewed and accepted the design and detail solutions. Construction of three taxiway crossovers totalling 261,000 ft<sup>2</sup> (23,500 m<sup>2</sup>) began in September 1990 and was completed in November 1990 (Fig. 2). The cost of these areas was about \$1.8 million.

Concrete pavers provide a surface of individual, small precast concrete units locked together by sand vibrated into the joints through compaction. The factory produced blocks are a consistent, high-quality product. There is no curing once the materials are on site, so the pavements can be immediately trafficked.

For this project, the Air Transport Association (ATA) urged the airport to close the runway for less than 14 hours each night during construction. The construction with concrete pavers was amenable to a 12-hour closure period. According to the ATA, this saved an estimated \$37,130 per day in delays to the airlines — \$4,232,820 over the 114-night construction period. The ATA calculations\* made in September 1989 are low because they do not take into account the fuel cost increases in 1990.

Concrete pavers had an additional benefit when construction was unexpectedly stopped: all laborers, material, and equipment



could be removed within 30 minutes of notification from airport operations. When the cloud ceiling dropped to below 1000 ft (325 m), airport operations required that all construction cease and that the closed runway be opened for traffic. Interlocking concrete pavement reduced costs to the airlines from construction closure delays and delays to the entire air transport system tied to DFW. Installation costs were comparable to typical rigid pavement sections at DFW and maintenance costs are expected to be lower.

### Design

The design method used for the taxiway pavement is a modification of the Federal Aviation Administration's (FAA) Advisory Circular, "Airport Pavement Design and Evaluation."<sup>5</sup> The FAA publication recommends flexible pavements from 4 to 5 in. (100 to 125 mm) of asphalt concrete over CTB. For DFW the asphalt layer was replaced by 3 1/8 in. (80 mm) thick concrete pavers and a 1 1/2 in. (38 mm) layer of sand. Testing has shown structural equivalency between asphalt

and the paver/sand layer. The subgrade requirements (sub-base and base thicknesses, materials, and construction quality) are the same as that required for conventional flexible pavement construction for airports.

The FAA concurred with the basic design approach.<sup>6</sup> They stated that each use of concrete pavers should be approved case-by-case. They are cautious about the location of the installation and concerned about the effects of aircraft speed, the ability of the system to withstand snow removal equipment, and problems associated with jet blast and propwash. The design and quality of construction at DFW addresses these concerns.

The taxiway pavement design is based on the predicted air traffic using the airport over 20 years. It assumes an annual average of approximately 950,000 aircraft visits. About 15 percent exceed 300,000 lb (136,000 kg) gross weight. Table 2 shows typical aircraft type, gross weight, and wheel loads.

The airport conducted field and laboratory soil California bearing ratio (CBR) testing. The average

\*Personal correspondence dated Nov. 27, 1990, with Victor Nartz, Air Transport Association, Fort Worth Texas.

**Table 1 — Airfield interlocking concrete pavements in the United Kingdom\***

| Location <sup>1</sup> | Where used                                           | Approx. area<br>Sq. Ft. |
|-----------------------|------------------------------------------------------|-------------------------|
| Abingdon (m)          | Aircraft parking                                     | 5,000                   |
| Blackpool (c)         | Helicopter pad and runway ends                       | 50,000                  |
| Dunsfold (m)          | Runway end                                           | 10,000                  |
| Gatwick (c)           | Aircraft safety areas                                | 50,000                  |
| Heathrow (c)          | Taxiway                                              | 50,000                  |
| Luton (c)             | Aircraft parking and Turning circles                 | 300,000                 |
| Lynham (m)            | Aircraft parking taxiway                             | 35,000                  |
| Northolt (m)          | Aircraft parking                                     | 30,000                  |
| Stanstead (c)         | Aircraft maintenance areas<br>(747s) & service roads | 350,000                 |
| Wood Vale (m)         | Aircraft parking                                     | 50,000                  |
| Glasgow (c)           | Aircraft parking                                     | 250,000                 |
| Vale (m)              | Aircraft parking                                     | 200,000                 |
| Total UK              |                                                      | 1,380,000               |

\*Personal correspondence dated May 26, 1989 from Mark Smallridge, Director, Nigel Nixon and Partners, London, England.

<sup>1</sup>c = civilian, m = military

**Table 2 — Aircraft characteristics**

| Aircraft type | Gross weight | Wheel load |
|---------------|--------------|------------|
| Boeing 727    | 198,000      | 48,800 lb  |
| Boeing 737    | 150,500      | 35,800 lb  |
| MD-80         | 141,000      | 35,700 lb  |
| DC-10         | 583,000      | 54,700 lb  |
| L1011         | 498,000      | 57,500 lb  |
| Boeing 747    | 836,000      | 50,000 lb  |
| Boeing 767    | 388,000      | 47,000 lb  |

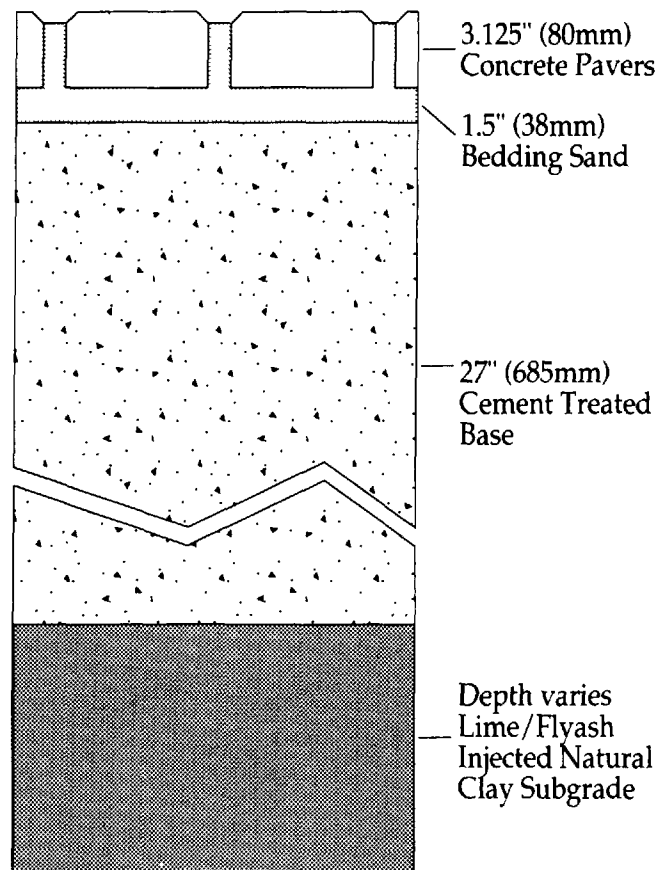


Fig. 1 — Flexible airfield pavement with interlocking concrete pavers.

CBR value of the natural, untreated soil subgrade was 1.5 percent. After injection with lime/fly ash, this increased to an average of 28 percent. The minimum design CBR for the injected subgrade was 7 percent.

Aircraft pavements demand the highest performance criteria of all pavement applications. They include durability, strength, stability, skid resistance, ride quality, water dissipation, maintenance requirements, and resistance to thermal shock, fuel and oil spills, and deicing and anti-icing agents. Interlocking concrete pavements meet these criteria because they are modular and made from high-strength, high-density concrete.

### Bedding sand

The project specifications included precise requirements for sand grading and cleanliness in order to obtain stability and long term performance.<sup>7</sup> Natural river sand provided bedding for the pavers. It was subjected to and passed a degradation test to ensure durability under loads. A high-quality, finely graded

sand keeps each unit about two to three millimeters apart. The sand in the joints enables loads placed on units to be transferred (by shear) to neighboring units, thereby reducing stress on the base.

### Concrete pavers

The paving units were rectangular, with a nominal size of 4 x 8 x 3 1/8 in. (100 x 200 x 80 mm) thick. Dimensional tolerances were  $\pm 1/16$  in. (1.5 mm) on length and width and 1/8 in. (3.0 mm) on thickness. A 45 deg herringbone laying pattern offered the best resistance to turning and braking forces.

Enhancements were made to the requirements of ASTM C 936, "Standard Specification for Solid Interlocking Concrete Paving Units."<sup>8</sup> The project specifications had precise requirements for aggregate type, compressive strengths and tensile splitting strength to ensure superior performance. The compressive strength requirement of the samples at 28 days was identical with ASTM C 936: the average not less than 8000 psi (55 MPa) with no individual unit less than 7200 psi (50

MPa). A tensile splitting strength requirement included a 28 day strength of not less than 650 psi (4.5 MPa). This test was conducted according to ISO 4108.<sup>9</sup>

To increase the durability of the pavers, absorption and freeze-thaw resistance requirements were also increased above the ASTM minimum. Absorption was no greater than an average of 5 percent with no individual unit greater than 6 percent. Seven percent is the maximum for absorption of individual units per ASTM. Freeze-thaw durability requirements followed Canadian Specification Association, CAN3-A231.2-M85, which exceeds the freeze-thaw requirements of ASTM C 936.<sup>10</sup>

### Construction

After placing and compacting the CTB, sand was spread and screeded to specified elevations. The pavers were brought to the site and placed in the 45 deg herringbone pattern. The specifications included requirements for edge cutting with masonry saws. Toward the end of each night's work, the units were

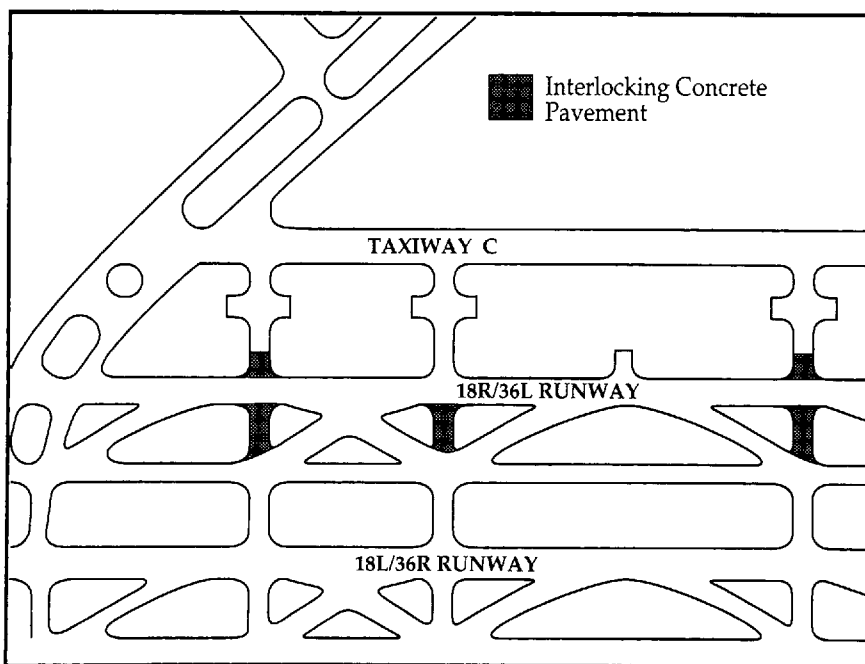


Fig. 2 — Project location with paved cross taxiways marked in grey.

brated with a hand operated plate compactor. The joints were filled with a fine sand and final compaction operations were carried out using a vibratory plate and 8 to 10 ton vibratory, rubber-coated drum roller. These ensured total filling of the joints as well as final seating of the units. A specialized clear, flexible, polymer-sealant spray was applied to the surface after filling the joints with sand and vibrating the units. Sealing eliminated engine ingestion of joint sand.

The three taxiways surfaced with concrete pavers have received occasional aircraft traffic including an errant MD-82 passenger aircraft during construction. The taxiways opened in April 1991 when the remainder of the taxiway project was completed. The taxiways are currently subject to extensive traffic from heavy commercial aircraft. DFW Airport is monitoring the performance of the pavement during its initial life.

#### References

1. For a comprehensive collection of technical papers on concrete block paving, see the following proceedings:

First International Conference on Concrete Block Paving, University of Newcastle, England, 1980.

Second International Conference on Concrete Block Paving, Technical University of Delft, the Netherlands, 1984.

Third International Conference on Concrete Block Paving, Pavitalia, Rome, Italy, 1988 (The Fourth International Conference on Concrete Block Paving will be held at the University of Auckland, New Zealand, Feb. 1992).

2. Emery, J. A., "Concrete Pavers for Aircraft Pavement Surfaces," *Journal of Transportation Engineering*, ASCE, V. 112, No. 6, Nov. 1986, pp. 1-15.

3. Emery, J. A., "Evaluation of the Performance of Concrete Blocks on Aircraft Pavements at Luton Airport," *Proceedings*, Third International Conference of Concrete Block Paving, Pavitalia, Rome, 1988, pp. 340-344.

4. *Airfield Pavement Design Manual*, Dallas Fort Worth International Airport, Paving and Engineering Division, Texas, 1971.

5. *Airport Pavement Design and Evaluation*, AC 150/53206C, Federal Aviation Administration, U. S. Department of Transportation, Washington, D.C., 1978.

6. Knapton, J., and Emery, J. A., *Airfield Pavement Design with Concrete Pavers*, Concrete Paver Institute, Herndon, Virginia, Apr. 1989.

7. Nigel Nixon and Partners, "Specification for Area 'A' Flexible Pavement Design at Dallas/Fort Worth International Airport," *Contract No. 8001255*, London, England, June 1990.

8. "Standard Specification for Solid Interlocking Concrete Paving Units," (C936-82) (Reapproved 1988), *1989 Annual Book of ASTM Standards*, V. 4.05, ASTM, Philadelphia, 1989, pp. 573-574.

9. "Concrete—Determination of Tensile Splitting Strength of Test Specimens," ISO-4108-1980(E), International Organization for Standards, Switzerland, 1980.

10. "Precast Concrete Pavers," (CAN3-A231.2-M85), Canadian Standards Association, Rexdale, Ontario, Apr. 1985.

Selected for reader interest by the editors.

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## Point of View

# Performance Specifications

by James M. Shilstone, Sr.

**P**ressure is mounting on public agencies and the paving industry to implement innovative practices and use performance specifications. The need is especially critical for public agencies, many of which are losing experienced personnel and facing mounting claims, while working with reduced staff levels.

Materials and construction technology are too complex to be managed using past practices. Many current standards and practices that have been in use for many years led to the problems cited in a National Research Council report titled, "Concrete Durability — A Multi-Billion Dollar Opportunity."

The recently published Transportation Research Board report, "Construction Research Needs," cites that the number-one priority research item is performance-related specifications. This was discussed by a select group of public agency, professional, education, association, and industry personnel during a December 1990 meeting in which it was projected that \$27 million are needed for research to evaluate alternative programs. Clearly, change is coming and the concrete

industry must be prepared to meet future needs. We need to look at the reasons for current problems and suggest a method for developing performance specifications.

### The problem

The problem is simple. There is no single answer to a very important question: "What are the characteristics of the portland cement concrete portion of a pavement that will provide a 30 to 40 year durability under a certain E18 use when cast on a sound, engineered subgrade and base and that has properly installed joints?" To be meaningful, the answer must be in the form of a detailed, technical description of the concrete composite.

The description should include objectives for the paste, including entrained air, spacing factor, and the amount of trapped air; aggregate size and qualities including geological types with shape and texture limitations and particle distribution; in-place strength (after at least 90 days) in both flexural and compressive terms; relative density; permeability; and surface conditions.

Today, primary attention is given to researching empirical formulas to facilitate pavement design, but nothing is done to determine the specific details of the mixture itself. Where studies are done, they are generally in the form of failure analysis rather than success analysis.

According to the FHWA report, "Relationship of Consolidation to Performance of Concrete Pavements," "Presently, quality control specifications exist to assure a quality product through all phases of construction up to delivery of

concrete at a site. However, there are no direct specifications available to monitor concrete quality after the concrete is placed in front of the paver." Translated literally, this means there are no standards dividing a good from a poorly performing pavement. Specimens cast from a mixture may test adequately in the laboratory, but that mixture may not respond well to the vibrator, so the in-place quality may be poor. In such a case, the laboratory test is meaningless.

### The need

A modern concrete paving spread is a manufacturing process that leaves its product in-place. In other industries, manufacturers are expected to control their product design, materials, labor, and production processes. If they have a quality product, they prosper. If they fail to maintain an acceptable level of control, they pay the penalties and fail. However, these benefits and concurrent responsibilities elude the paving contractor because others prescribe his materials and methods. If performance were specified instead, he could meet those objectives at the least cost.

Darrell W. Harp, Assistant Commissioner, Office of Legal Affairs, New York State DOT<sup>2</sup> commented, "The contractor can't use his own initiative because he has little option when he is told precisely what he must do, what type of materials he must incorporate and exactly how it is to be put in place. Innovation is stymied. Another drawback is that the improvement of the product will be very slight and it is doubtful that you will see a reduction in overall cost. If we were to live forever with materials and

#### POINT OF VIEW

This article was selected for reader interest by the editors; however, the opinions expressed by the author are not necessarily those of the American Concrete Institute. The editors invite comments from readers about the personal views given in this article.

# for Concrete Pavements

methods specifications, I suppose we would still be driving around in Model T's."

From the earliest days of the proverbial "master builder," an engineer has been in charge of design and construction. Early master builders were expert not only in design but in materials and construction methods. They left their marks on the terrain for us to know something of their times — when design details were not so complex, materials were limited, tools were simple, workers were skilled, and time was not a factor.

Those conditions do not exist today. Past practices are not adaptable to present user needs, engineering design, materials, construction equipment, worker skills, and construction economics. Today, there is no single point for control of responsibility.

The current system creates problems and predictable results. In today's complex construction industry, it is not possible to produce a set of documents covering hundreds of variables, each having a broad range of tolerances, and expect the outcome to meet a predetermined level of quality. Engineers seem to believe the contractor should conform to the intent and take the best of all options. Unfortunately, intent is not a part of the contract and the contractor is forced by the system to use the lowest priced solutions if he is to get the job.

Disagreements frequently are resolved in the courts, with public agencies paying contractor claims based upon inaccuracies and inconsistencies in contract documents. Agencies have a small chance of winning, as the contractor is protected by the U.S. Supreme Court's

1918 decision in the case of the U.S. versus Spearin.

Under Spearin, an owner warrants that the plans and specifications will achieve the results the owner intends. The contractor is not responsible if he complies with those plans and specifications but the project does not work as the owner intended. The contractor is not bound to use the best of all options — only to do that which falls within the broad limits of the documents. If the documents incorporate tolerances which, under the project conditions, can be combined to produce an unacceptable product, the owner — not the contractor — is responsible. The Spearin case should be taught at engineering schools.

To their credit, most contractors do everything they can to avoid having their lawyers invoke Spearin. Most want to do a good job but cannot afford to lose money. As a result, field engineers may hear the contractor take the position that "I'm just a contractor trying to follow what's in your recipe book." In the majority of those cases, that contractor is at the end of what he feels he can do within his budget and is preparing to make a claim. Field engineers who tell the contractor what to do will probably never hear that their action led to a claim that was settled in court at a very high cost.

## The performance contract

Engineers often claim that current documents are of the performance type, but this is not borne out by the fact that it takes a book like a state highway manual or 30 pages to describe the materials and methods to be used in the work. Those spec-

ifications often contain more specific detail than recipes for baking a cake.

Construction specifications cite broad materials tolerances, allow use of different products, accept wide variations in construction equipment and practices, and fail to consider construction economics. Under the unit price system used in the past, the project engineer could do what he wanted and the agency paid the bill. The practice of lump-sum bids forces attention to price at each level of the supply/construction process. Some jobs are good; others are defective. The system cannot logically produce consistent products, and the ultimate loser is the taxpayer.

Two contracting arrangements do apply the principles of performance standards. We feel the first can be applied following a simple, less than \$27 million, research program. The second is the more extreme and might be referred to as innovative in the paving industry, though these practices are common in the buildings segment of the construction industry. The two alternatives are:

1. The engineer, on behalf of the owner, prepares detailed engineering plans for the project and describes "what" and "where" but not the "how." The documents avoid detailed instructions concerning materials and methods for other than basic qualities. Most attention is given to in-place quality, quality management, and performance-related incentives and disincentives.

2. The second alternative would reinstitute the philosophy of the master builder who responds to an owner's design and construction needs. Under this system, the owner

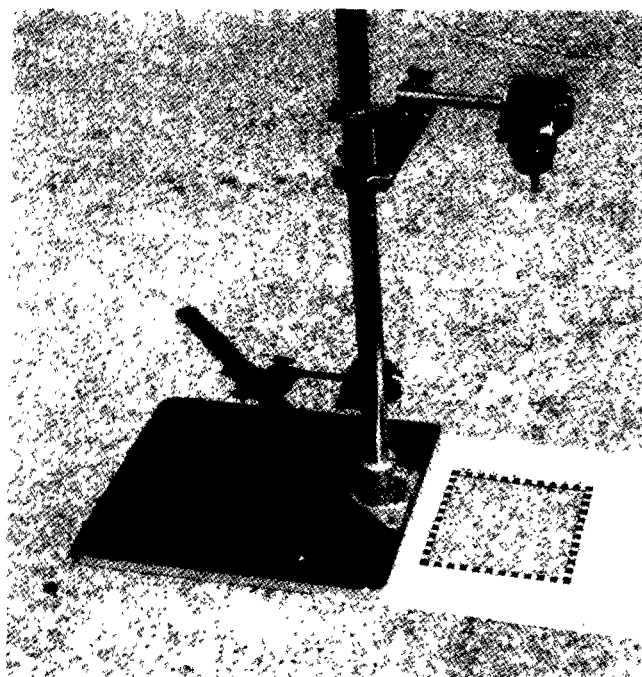


Fig. 1 — Photographic study setup.

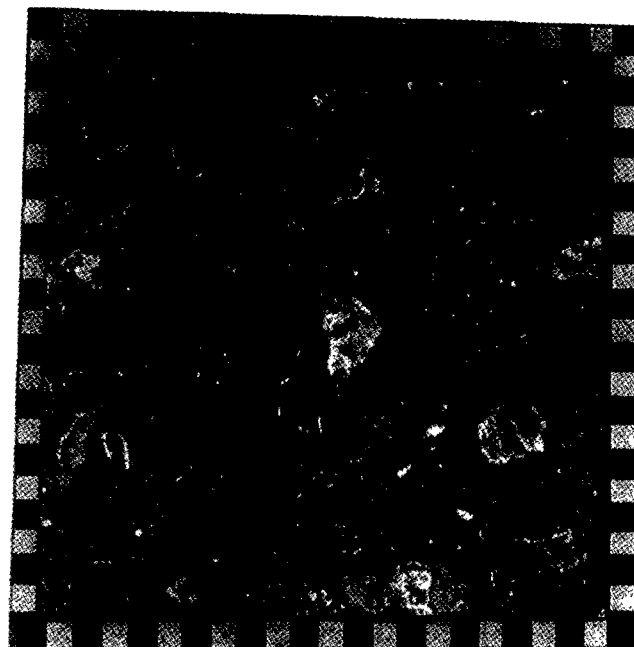


Fig. 2 — Concrete pavement cast in 1922 showing high incidence of coarse sand particles ( $\frac{3}{8}$  in. to No. 16).

would develop a master plan and engineer/contractor teams would submit bids with their solutions to the plan. The supporting data for the master plan would include sufficient geotechnical and right-of-way information so that all bidders could proceed with design and construction plans without having to research a site. Award would be to the lowest responsible bidder.

While Option 2 would be the most traumatic for both engineers and contractors, it could lead to the best product at the lowest cost. Project bidding would require research and imagination. Cost would be low because design details would be subject to creative use of the most economical materials and equipment at bid time. Design and construction team members would have to work together for the common good. The owner would not have Spearin-based claims because the responsibilities would be unified. Option 1 will be discussed here because performance specifications are our subject.

### Defining objectives

The difference between good and poorly performing pavements must be defined in physical terms and not by reference to specifications, materials standards, equipment, or contractor personality. Once the

differences are established, objectives can be translated into the terms of a model. The study must include surface examinations; in-place density tests using nuclear gages; coring for compressive strength, split-core strength, and density; boil (or other) test for permeability; evaluation of aggregate type, shape, and distribution; water-cement ratio approximation; entrained-air point count; and general condition. From that analysis, a profile of the composite will emerge and be used as the basis for the model.

The findings should be factors that can be monitored during production and measured on completion. The measurements should be ones that can be translated into incentives or penalties.

The first step is to determine which in-place characteristics are needed to project long-term performance. Studies should be undertaken to determine why different projects constructed under the same specifications using the same or similar materials performed differently. What made the best ones perform well and what caused the others to deteriorate prematurely? Carefully researched studies of good concrete will reveal the reasons for its high performance. Even the traditional means of petrographic study do not adequately describe

the aggregate characteristics. The study must be innovative.

In the majority of cases, the high performers will be found to exceed minimum strength standards. An initial reaction may be that minimum standards are not high enough and should be increased, but such a response can be counterproductive. The 28-day strength is an engineer's guide to assess a minimum level of quality for load-carrying ability, not its potential long-term durability.<sup>3</sup>

Studies of old concretes that have performed well frequently indicate strengths ranging from 8000 to 10,000 psi (55 to 70 MPa). When cast, these mixtures probably produced strengths no greater than 3000 psi (20 MPa). We need to find out what has made the difference over the intervening years and how comparable results can be replicated using current resources. Investigators must consider the materials of the time, the age, and how that concrete matured through the years in place. The answers will provide the key to performance standards.

The second step should be a detailed study to develop a model. A limited-scope study performed for the City of Dallas can provide insight into methods. The results of that study are supported by ACI documents and other technical papers.<sup>4,8</sup> Because of the mild climate

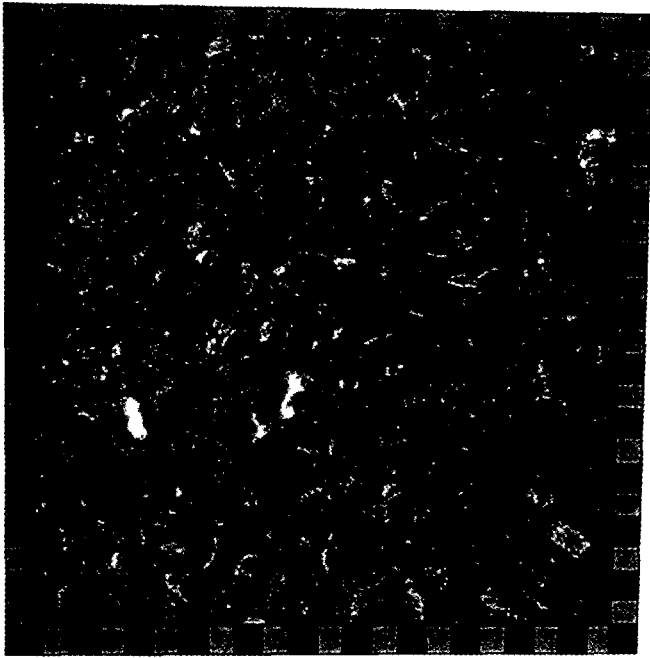


Fig. 3 — Gap-graded mixture showing heavy wear. This sample and Fig. 2 are shown in the Shilstone Grid.

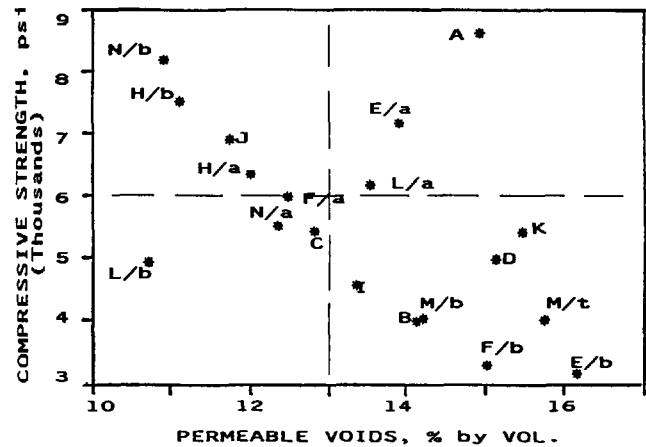


Fig. 4 — Strength versus permeability, Dallas study.

and use of non-alkali-reactive aggregates in Dallas, the study did not consider entrained air, D-cracking, sulfate attack, or deicing salts.

Many streets were studied to identify both old and new, good and bad pavements with differing concrete-related performance histories. The study was done without concern for base or similar external failures. Knowledge of poor drainage can be helpful because that condition can accentuate permeability problems. Pavements cast under the same contract that exhibited different results were ideal for the study.

The study involved traveling throughout the city to assess surface conditions. To record surface conditions for comparison, photographs were made of surface wear within an 8 in. (200 mm) square opening in a template inscribed with  $\frac{3}{8}$  in. (10 mm) hash marks along the edges (Fig. 1). Fig. 2 shows the surface appearance at one location and Fig. 3 shows a portion of the project cast under the same contract, in the same traffic lane at a point less than 100 ft (30 m) distant, but separated by a construction joint. Traffic along that pavement is very heavy.

Typical conditions were identified and cores taken for compressive strength, permeability, and specialized petrographic analysis.

The following is a summary of the study conclusions:

1. Permeability and ultimate compressive strength are key factors affecting durability. Fig. 4 is a regression analysis comparing permeability as determined by the boil test (ASTM C 642) and core compressive strengths. Pavements having compressive strengths in excess of 6000 psi (40 MPa) and permeabilities of less than 13 percent are performing well; those with lower strengths and higher permeabilities are not. The pavements in the other two quadrants performed better than the poor performers, but had deficiencies. These results support the ACI 210 recommendation<sup>5</sup> that the ultimate compressive strength of the concrete subject to abrasion or erosion should be greater than 6000 psi (40 MPa).

2. Mixtures with well graded aggregates performed better than poorly graded mixtures and this factor was one of the surface conditions used to determine core locations. The benefits of using well graded aggregates, which reduces the need for water and thereby increases strength, has been described.<sup>3,9,10</sup> There are other benefits, such as the increased durability that results from a reduced water-cement ratio, which we believe accrue as a result of water reduction. The benefits of well graded aggregates

are almost as important for concrete as for asphalt.

There are logical reasons why old concretes are often more durable than new castings. Neville,<sup>7</sup> Munro,<sup>8</sup> and others have described the effects of changes in cement quality. Earlier cements contributed to long-term strength gain, often exceeding 30 percent after the 28-day test. Today, the strength gain may be as little as 5 percent. During the Dallas study, a 1922 cast pavement (Point A in Fig. 3) produced a core compressive strength test result of 8550 psi (60 MPa), while a two-year-old, poorly performing pavement tested slightly higher than the specified 3000 psi (20 MPa).

Though the specified 28-day strengths may be the same today as those specified 30 years ago, the ultimate in-place strength will be less. Durability of concrete exposed to an aggressive environment is based upon its long-term strength.<sup>3</sup> Engineers have failed to recognize the adverse effect of the changes in cementitious materials chemistry. Thus, the ultimate quality of an in-place pavement cast today may be considerably less than that specified to produce the same 28-day strength and cast 30 years ago.

Since durability analysis is based upon compressive strength, cylinder tests should be used to evaluate durability, though test beams and

# Concrete Pavement Model

## Project

(Describe and locate)

The contractor shall prepare a construction plan and submit it to the engineer for approval. The plan shall include a description of all materials, mixtures, equipment, and methods to be used in the work.

## Concrete mixture

Portland cement concrete shall consist of portland cement, natural sand, crushed or natural gravel coarse aggregate, water, water-reducing or water-reducing set-retarding admixture, air content equal to 5 percent ( $\pm 1$  percent) of the volume, and water shall be potable. Fly ash shall be used as an additive to aid long-term strength gain.

Aggregates shall meet the requirements of ASTM C 33 except be nominal 1 in. and uniformly graded with a combined gradation similar to that projected by the 0.45 power chart used for asphalt but with a deviation to trace below the chart from the No. 16

sieve and down. Produce the mixture by blending at least three sizes of aggregate with one being predominately  $\frac{3}{8}$  in. to #16 sieve. Material passing the  $\frac{3}{8}$  in. sieve shall be predominately fine gravel or coarse sand or hard durable crushed stone as approved by the engineer.

Water content shall be the lowest possible to produce the needed mix cohesiveness and workability at a water-cement ratio no greater than 0.45.

Minimum flexural strength shall be 650 psi. The minimum 28-day compressive strength shall be 5000 psi and be projected, based upon local materials history and/or tests, to produce a one year strength of at least 6000 psi. The means of attaining the strength gain shall be subject to the approval of the engineer.

## Mixing, delivery, placement, compaction, finishing & curing

The concrete shall be mixed to assure uniform distribution of ingredients

and delivered in such condition that minimal cement hydration has occurred in transit. The consistency shall be such that it can be worked into the intricacies of the corners and around dowel bar baskets if that alternative is used at control joints.

The vibration and compaction system shall be selected to be compatible with the mixture to assure the concrete is thoroughly compacted and trapped air expelled. Compaction shall be uniform through the thickness to produce a wet density at any point in the pavement of no less than 98 percent of the wet unit weight of the concrete. The hardened concrete shall have less than 12 percent permeable voids in any 1 in. thickness in an 8 in. diameter sample.

Use a curing system to prevent rapid moisture loss. If a membrane-forming curing compound is used, the concrete shall be cured to assure a loss of less than 0.30 grams of water per square meter.

Install control and construction joints to prevent cracking at other

flexural strength are used to verify load-carrying capacity. However, strength alone should not be the means for determining acceptability as it may be produced using methods which do not improve in-place durability.

Other related studies indicate that:

1. The greater the density of hard, inert particles of aggregate on the surface, the lesser the potential for water and deleterious materials to penetrate into the mortar below and contribute to deterioration.<sup>4,5</sup>

2. Optimized, uniformly graded mixtures reduce the need for water.<sup>4,5</sup> Such mixtures require less paste (approximately 2 to 3 percent by volume of concrete), thus allowing either a lower water-cement ratio for a constant cement content or a reduced paste content for a constant water-cement ratio.

3. Old concrete generally has a higher incidence of  $\frac{3}{8}$  in. to #8 sieve size particles because in 1923 ASTM C 33 specified "the sand shall be predominately coarse particles."

The importance of consolidation is discussed Reference 1. The primary conclusions of that report are:

1. The degree of consolidation affects pavement service life as it effects flexural strength and may lead to premature pavement failure.

2. Permeability increases with a decrease in percent consolidation. There are significant variations based upon aggregate type and level of air entrainment and where consolidation is less than 96 percent.

3. The projected service life of a concrete pavement can be described as a function of degree of consolidation. At 95 percent, the pavement life of a 20-year-life project can be cut in half and a 90 percent consolidation can reduce life to but 5.4 years. (The latter is a calculated factor extending beyond the norm of the data and thus may not be actual.)

## Research for a model

Before the performance specification can be written, the characteristics of the required pavements must be established. A thorough study program should proceed as follows:

1. Identify old and new, good and bad pavements for study. As much detailed information as is

available should be assembled. The details should include sources of materials and actual test data collected throughout the work, mixture proportions and adjustments, mixer types, placement methods, consolidation equipment and methods, reinforcing details, joint details and practices, finishing methods, curing, and climatological conditions at time of casting. Data must be specific, not a reference to compliance with a certain document. While contract documents may be helpful, they do not supply the needed detail.

2. Inspect representative construction, observing not only overall performance but also detailed conditions. Identify pavement conditions based upon factors other than the concrete mixture. These should be considered but not be allowed to interfere with the study of the concrete element alone. Identify the effects of such influences as scaling, D-cracking, aggregate reactivity, abrasion, erosion, or other concrete deterioration from surface conditions. Photograph the overall and detailed conditions. The close-ups should be the area within an

than the joint locations. Texture the surface to produce a non-slip finish and a ride, as measured by profilograph, of not more than 7 in. per mile.

### Quality control

Establish a quality control organization, separate from the operations staff, to verify that the work is performed in accordance with the approved contractor's construction plan using proven industry practices and to conform with the requirements of the contract. Inspection shall include verification of placing, finishing, and compacting procedures. The qualifications of the quality control personnel and their plan for testing and inspection of work in progress shall be submitted to the engineer for approval.

### Owner's quality verification

The owner will, as a minimum, perform the following tests to verify compliance with the contract:

± 8 in. (200 mm) border cut in card stock with  $\frac{3}{8}$  in. (10 mm) hash marks around the interior border. Give special attention to variations in quality of work done under the same contract.

3. Correlate the data and photographs and attempt to define a pattern from the preliminary study. From that study, select representative locations for detailed evaluation.

4. At each selected sample site: (a) Drill 1 in. (25 mm) holes and use a nuclear density gage to measure variations in pavement density from the bottom to the top at 1 in. intervals. Cut 8 in. (200 mm) diameter cores tangent to the 1 in. hole and include the concrete evaluated by the nuclear gage. (b) Take sufficient 4 to 6 in. (100 to 150 mm) cores to measure compressive strength and permeability by the boil or chloride penetration test and for petrographic studies.

5. Cut the 8 in. (200 mm) core into 1 in. (25 mm) plates and evaluate each plate petrographically and by other means to determine relative density and trapped and entrained air.

1. Take and test samples of the aggregates delivered to the project.

2. Take and test samples of the concrete incorporated in the work.

3. Use nuclear gages to test freshly placed and hardened concrete to determine relative density.

4. Core the hardened concrete to determine thickness, compressive strength, aggregate particle distribution, relative density of 1 in. thick layers, entrained air, permeability, and such other tests or petrographic analysis procedures deemed necessary to verify the quality of the in-place concrete.

### Incentives and penalties

The contractor will be awarded incentive pay for achieving the following:

1. For every increase of \_\_\_\_\_ psi in flexural strength, add \_\_\_\_\_ percent up to a total of \_\_\_\_\_ percent.

2. For a ride of less than \_\_\_\_\_ in. per mile, add \_\_\_\_\_ percent per in.

6. Determine compressive strength and permeability of the other cores.

7. In the petrographic studies, assess not only the quality of the paste and mortar, but also identify the presence of reactive aggregates which may or may not have contributed to problems. Describe the aggregate particle shape, texture, and distribution by individual sieve sizes to determine the combined gradation.

8. Analyze and report the data.

The result should provide a picture of the difference between the good and poorly performing pavements. Develop performance specifications around those that performed well and avoid the others.

### The performance specification

The specification should be brief, define objectives, and not prescribe how the work is to be done. Requirements should be in terms of the composite, including mixture characteristics, reinforcement, degree of consolidation, jointing, surface finish and condition, curing, and ride. Clearly state detailed

3. For  $\frac{1}{4}$  in. over thickness, add \_\_\_\_\_ percent and for  $\frac{1}{2}$  in. add \_\_\_\_\_ percent.

4. Density exceeding \_\_\_\_\_ percent.

5. Permeability less than \_\_\_\_\_ percent.

The contractor shall be penalized in pay based upon the following:

1. For a decrease in flexural strength, deduct \_\_\_\_\_ percent for every psi and remove and replace if strength is less than \_\_\_\_\_ psi.

2. For a ride more than 7 in. per mile, deduct \_\_\_\_\_ percent per in. up to \_\_\_\_\_ in. Take corrective action by grinding beyond \_\_\_\_\_ inches.

3. For  $\frac{1}{4}$  in. under thickness, deduct \_\_\_\_\_ percent. Remove and replace when thickness is  $\frac{1}{2}$  in. or more less than that specified.

4. Density equal to or less than \_\_\_\_\_ percent.

5. Permeability equal to or more than \_\_\_\_\_ percent.

quality management requirements. Only the organization performing the work can control the quality. That function must include in-process controls and in-place verification of quality.

The contractor will then have to develop and use technical skills to assemble materials, equipment, and labor to organize a construction process<sup>11,12</sup> to comply with the model. This practice will assure that primary attention is given to results rather than resources. Since the contractor will not have to labor under constraints of the prescriptive requirements, he will have maximum latitude to produce the pavement at the lowest cost.

Current state manuals must be put aside. It is not possible to change results while keeping the recipe the same. A key to innovation is the proper identification of objectives and verification methods. The following performance objectives offer an outline of what to be included in the specification:

**Engineering** — Strength, thickness, and joints

**Construction** — Compacted density, surface texture, and ride

**Durability** — Entrained air, sulfate resistance and/or D-crack controls, abrasion and/or erosion resistance, and permeability

**Quality** — Materials, equipment, methods, personnel, and quality control practices

**Verification**—Owner methods

**Other**—Incentives and disincentives

## Agency responsibilities

Performance specifications require an agency to undertake its work from a new perspective. Agency officials will have to review submittals and judge their adequacy to meet both short- and long-term objectives. Performance warranties probably will not exceed 5 years, though the objective may be 40-year durability. Agency officials must be prepared to protect the public against those who will try to find ways to design and construct pavements which hold up for 5 to 10 years but deteriorate rapidly there-

after. The agency also must be protected from political pressures.

Those who review submittals will not be able to rely on formulas like those used for design. Their concern must be for durability and their decisions technically based. For example, a given combination of materials may produce adequate concrete strength to satisfy the requirements for load-carrying capability of the pavement; however, that combination of materials may contribute to potential long-term problems due to poor rheological properties and experience rapid wear in high traffic or turning lanes.

Therefore, contractor submittals must be reviewed for not only engineering designs, materials, and mixture proportions, but also construction equipment and processes, quality control, and projected long-term performance. There are no simple formulas for durability, so new guidelines for acceptance and rejection must be published. Current manuals will not provide answers. Though there is a growing void in the technology of the concrete construction process, technical judgment must be applied properly or performance practices can turn into a boondoggle rather than a boon to pavement needs.

Once work is underway, the owner must audit quality control and perform acceptance testing, not only during but after project completion. Until technologies, equipment, and practices are proven, contractors may have to cast trial sections to prove their materials, equipment, and processes.

## Conclusion

Change affects special skills and markets. Large-scale change is difficult in consensus-standards organizations, since those groups are greatly influenced by the resistance of their members whose skills and markets are threatened. Change in perspective will not be a simple matter. There is no KISS (Keep it simple, stupid) method for such an important and technical subject as performance-based specifications.

But performance standards are necessary to cope with the needs of the future. As John Ruskin said, "Quality is never an accident. It is always the result of intelligent effort." Deming supports this com-

ment and adds, "Quality must be built into the work. It cannot be inspected in." Quality will come from knowing and controlling those factors that make performance superior and not just adequate. To serve the needs of the concerned public, a paradigm shift must take place.

## References

1. Whiting, D. A., and Tayabji, S. D., "Relationship of Consolidation to Performance of Concrete Pavements," *Report No. FHWA/RD-87/095*, Federal Highway Administration, McLean, Feb. 1988, 135 pp.
2. Harp, Darrell W., "Innovative Contracting Practices — The New Way to Undertake Public Works Projects," *Hot Mix Asphalt Technology*, New York State Department of Transportation, Winter 1990.
3. Shilstone, James M., "A Hard Look at Concrete," *Civil Engineering*, Jan. 1989.
4. ACI Committee 201, "Guide to Durable Concrete" (ACI 201.2R-77) (reapproved 1982), American Concrete Institute, Detroit, 1977, 37 pp.
5. ACI Committee 210, "Erosion of Concrete in Hydraulic Structures" (ACI 210R-87), American Concrete Institute, Detroit, 1987, 22 pp.
6. ACI Committee 224, "Control of Cracking in Concrete Structures" (ACI 224R-89), American Concrete Institute, Detroit, 1989, 43 pp.
7. Neville, A., "Why We Have Concrete Durability Problems," *Concrete Durability—Katharine & Bryant Mather International Conference*, SP-100, American Concrete Institute, Detroit, 1987, V. 1, pp. 21-30.
8. Munro, E. V., "Concrete Durability in a Free Market System," *Concrete International: Design & Construction*, V. 8, No. 10, Oct. 1986, pp. 30-31.
9. Shilstone, James M., "Concrete Mixture Optimization," *Concrete International: Design & Construction*, V. 12, No. 6, June 1990, pp. 33-39.
10. "Doing More with Less: Optimizing Concrete Mix," *Better Roads*, V. 60, No. 8, Aug. 1990, pp. 18-25.
11. Shilstone, James M., Sr., and Shilstone, James M., Jr., "Mixture Proportions for Construction Needs," *Concrete International: Design & Construction*, V. 11, No. 12, Dec. 1989, pp. 53-57.
12. Shilstone, James M., "Concrete Construction—Making the Process Work," *ACI JOURNAL, Proceedings* V. 74, No. 12, Dec. 1977, pp. N11-N14.

Selected for reader interest by the editors.

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# Investigations into Improving Field-Molded Pavement Joint Sealant Field Performance

by Larry N. Lynch

In 1988, the U.S. Army Engineer Waterways Experiment Station (WES) completed a two-part investigation of field-molded pavement joint sealants. The investigation consisted of a laboratory evaluation and a field performance survey conducted at the request of the Air Force Civil Engineering Support Agency and the Headquarters, U.S. Army Corps of Engineers. The main objective of this investigation was to explain the unsatisfactory field performance of field-molded joint sealants that supposedly conformed to and were installed according to specification.

A three-phase approach was used to accomplish the objective. The first phase of the investigation was to compile laboratory results of field-molded joint sealant specification testing conducted by the Pavement Systems Division (PSD), Geotechnical Laboratory, WES. The sealants tested by the PSD were submitted for specification conformance testing by military installations.

## Sealant specification

The sealants that were submitted were manufactured to meet the requirements of one of three federal specifications: Federal Specification SS-S-1401, SS-S-1614, or SS-S-200. Sealants manufactured to meet the requirements of Federal Specification SS-S-1401 are hot-applied, asphalt-based, non-jet-fuel-resistant (non-JFR) materials generally specified for use in rigid or flexible pavements. Sealants manufactured to meet Federal Specification SS-S-1614 are hot-applied, coal tar-based, jet-fuel-resistant (JFR) materials specified for use in rigid pavements. Sealants manufactured to meet the requirements of Federal

Table 1 — Joint Sealant Specification Tests

| Test*                         | SS-S<br>1401 | D<br>3405 | SS-S<br>1614 | D<br>3581 | SS-S<br>200 |
|-------------------------------|--------------|-----------|--------------|-----------|-------------|
| Nonimmersed penetration       | **           | **        | **           | **        | N/A         |
| Fuel-immersed penetration     | N/A          | N/A       | **           | **        | N/A         |
| Flow                          | **           | **        | **           | **        | **          |
| Nonimmersed bond              | **           | **        | **           | **        | **          |
| Water-immersed bond           | **           | N/A       | **           | **        | **          |
| Fuel-immersed bond            | N/A          | N/A       | **           | **        | **          |
| Unaged resilience             | **           | **        | **           | **        | **          |
| Aged resilience               | **           | N/A       | **           | **        | **          |
| Solubility (change in weight) | N/A          | N/A       | **           | **        | **          |
| Artificial weathering         | N/A          | N/A       | N/A          | N/A       | **          |

\*Not all tests for each specification are listed. The test procedures and requirements are not identical between the specifications.  
\*\*Test is applicable to the specification.

Specification SS-S-200 are two-component, cold-applied materials that are resistant to the solvent action of jet fuels and the effects of prolonged exposure to aircraft exhaust.

Federal Specifications SS-S-1401 and SS-S-1614 are similar to ASTM D 3405 and ASTM D 3581 respectively. There is not an ASTM specification that is similar to Federal Specification SS-S-200. Table 1 provides some of the tests required for the different specifications.

The goal of the data compilation was to determine if there was one or two predominant modes of non-conformance. The second and third phases were field evaluations of in-place joint sealants and of the construction procedures used by contractors on joint and crack sealing projects. The goals of the in-place sealant evaluations were to determine the modes of failure experienced in the field, compare these failure modes to the ones experienced in the laboratory evaluation, and to obtain a better understanding of what user agencies considered unsatisfactory performance. The goal of the construction proce-

dures evaluations was to determine if project specifications and the joint sealant manufacturer's recommendations for joint preparation and sealant application were being followed.

## Laboratory data

A summary of the compiled laboratory data is provided in Table 2. The summary includes data that was obtained from 1980 to 1990. The data indicate that approximately one third of the sealants tested did not conform to the appropriate specification. The predominant areas of non-conformance were associated with bond testing, material resiliency, and penetration testing. Also the seal-

Table 2 — Laboratory specification testing summary

| Sealant Type | Number tested | Number failed | % failed |
|--------------|---------------|---------------|----------|
| SS-S-1401    | 54            | 19            | 35       |
| SS-S-1614    | 91            | 15            | 16       |
| SS-S-200     | 149           | 62            | 42       |
| Total        | 294           | 96            | 33       |

ants that did not conform to specification requirements often failed more than one test.

Each of the specifications have several requirements that must be met, failure of any one of the requirements constitutes specification non-conformance. For example, there are 22 individual requirements that a sealant manufactured to meet Federal Specification SS-S-200 must meet to conform to the specification. If there is a 1 percent probability that a sample will fail to meet each of the 22 requirements, there is approximately a 20 percent probability that the sealant will fail Federal Specification SS-S-200. Likewise, there is approximately an 8 percent probability that a sealant tested against Federal Specification SS-S-1401 or Federal Specification SS-S-1614 will not meet all of the respective requirements.

These are unweighted approximations, that is, they assume that each one of the requirements has equal weight and equal probability. A statistical analysis on the compiled laboratory data has not been completed. Therefore, based upon the laboratory data, one can only state that if a user agency does not require specification conformance testing then they have a 33 percent probability of using a non-conforming sealant. This statement assumes that the small sample population collected by the PSD is representative of all sealant materials produced and that specification testing does not produce false positives.

## Field procedures

The second and third phases of the study indicated potential problems associated with inspection and construction procedures.

Most inspection problems noted during the study involved lack of time, lack of emphasis, or both. The lack of time came from having several ongoing projects which reduced the amount of time the inspector could spend at any one project. The lack of emphasis normally was caused by the fact that the actual cost of the joint sealing portion of a contract was very small when compared to the overall construction contract.

Another problem noted with the inspection procedures was the fact

that the sealants used for a project were often not tested by an independent laboratory for specification conformance verification.

Conformance to a material specification does not ensure adequate field performance because of the dependence of field performance on construction procedures including joint preparation, sealant installation, sealant shape factor, and the environmental conditions at the time of installation. But specification conformance does provide the user agency with the physical material properties of the sealant and can be used as a quality control tool for the sealant. Even though specification conformance does not necessarily imply field performance and sealants that do not conform to specification requirements should not be used on sealing projects; it was interesting to note that the predominant sealant failures observed in the field were related to bond failure or stiffening of the sealant; i.e. the same modes predominant in laboratory testing.

Similar equipment was used by the contractors at the various joint sealing projects visited during the study. The contractors would use a joint plow or concrete saw to remove the existing joint sealant, sandblasting or high pressure water equipment to remove residual debris from the joint, and compressed air to remove sand or dust that was remaining in the joint.

The major difference in joint preparation between the various contractors was their definition of a "clean" joint. The definition of a clean joint ranged from simply removing the sealant from the reservoir without regard to the residual sealant on the joint walls to "hospital clean" where all foreign debris and residual joint sealant were removed. The actual amount of joint preparation required for satisfactory performance of a particular sealant material will normally be closer to the hospital clean end of the spectra, but how clean is clean is still under constant debate.

## Survey conclusions

The overall conclusions of the laboratory evaluation and field performance survey were:

- There was no single factor that could explain the unsatisfactory

field performance of the field-molded sealants.

- There was not a general consensus of what actually defines unsatisfactory field performance.
- The field performance failures could not be directly related to material or project specifications.

The main reasons for the lack of correlation between field performance and material or project specifications are that materials are generally not tested for specification conformance and project specifications are not rigidly enforced. Also, long term sealant field performance data for projects in which "everything was done correctly" are limited. Therefore, the accusations concerning the poor field performance of field-molded pavement joint sealants that conformed to specifications were invalid.

The conclusions concerning the critical nature of joint preparation and sealant installation procedures were not new. Previous studies and investigations have concluded that many sealant failures in the field are caused by poor quality materials or inadequate construction procedures caused by either poor workmanship or defective project specifications. Based on the conclusions and recommendations from the investigation conducted by WES and the above referenced studies, two research projects were initiated. The first project concentrated on the improvement of the material properties of hot-applied joint sealants and the second concerns the collection of realistic life cycle data for field molded sealants.

The first project was a collaborative effort between WES and Crafcro, Incorporated, a joint sealant manufacturer. The project was conducted under the auspices of the Construction Productivity Advancement Research (CPAR) program which was established by the Water Resources Development Act of 1988, P.L. 100-676, Section 7, and the Stevenson-Wydler Technology Innovation Act of 1980, as amended, 15 U.S.C. 3710a et seq. This legislation allows the Secretary of the Army to utilize U.S. Army Corps of Engineers laboratories and research centers in cost-shared research and development with the construction industry.



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## Research objectives

The WES/Crafco CPAR project was entitled "Improved Materials and Processes for Sealing and Resealing Joints in Portland Cement Concrete Pavements." The objectives of this project were to:

- Develop specification limits for a hot-applied, JFR sealant with improved performance characteristics as compared to current sealants manufactured to meet the requirements of Federal Specification SS-S-1614A.
- Develop specification limits for a hot-applied, non-JFR sealant with improved low temperature performance characteristics as compared to current sealants which are manufactured to meet the requirements of Federal Specification SS-S-1401C.
- Develop specification limits for a primer system that will minimize the bubbling tendencies associated with hot-applied joint sealants as well as improve the adhesion properties to portland cement concrete (PCC).
- Develop field data to determine if the field performance of hot-applied sealants in PCC pavements can be improved by using an overfill application geometry instead of the current requirements of recessing the sealant  $\frac{1}{8}$  to  $\frac{1}{4}$  in. below the pavement surface.

## Laboratory evaluations

To meet these objectives, commercially available sealants (both non-JFR and JFR types) were purchased and laboratory evaluations conducted to determine their material property limits. The testing included Federal Specification SS-S-1401C testing of the non-JFR sealants and Federal Specification SS-S-1614A testing of the JFR sealants. Additional tests such as bond to concrete at lower temperatures and greater amounts of extension than the procedures specified in the federal specifications, aging of test specimens, and extending the time that the sealants were heated prior to pouring it into specimen molds as well as other tests were also conducted.

A total of 11 hot-applied sealants from three different manufacturers were purchased and evaluated. The laboratory evaluation indicated that improvements in the low temperature characteristics of JFR hot-ap-

plied sealants would be desirable and that non-JFR sealants which were manufactured to meet a modified low-modulus ASTM D 3405 specification should exhibit better field performance in low temperature climates.

## Improved sealants

Based on the laboratory information and laboratory development work conducted at Crafco, Inc., two improved low-modulus, hot-applied sealants, one non-JFR and one JFR, were developed. These sealants were formulated to exhibit better low temperature characteristics and experience less hardening during aging. Draft specifications were developed for these materials and pilot production batches were produced. These sealants were installed at Fairchild Air Force Base (AFB), Washington, for field evaluation.

The bubbling tendencies of hot-applied joint sealants has become an increasing concern for user agencies. Laboratory studies conducted by WES and Crafco, Inc., during the CPAR program indicated that much of the bubbling can be attributed to moisture in the PCC. Bubbles were evident in laboratory specimens in which the PCC blocks contained as little as 0.5 percent moisture. Therefore, a barrier system which would eliminate moisture escaping into the sealant during application, but that would not adversely affect the adhesive properties of the sealant to the PCC joint wall was desired.

A wide variety of potential encapsulating primer formulations were produced in the laboratory and investigated. Results indicated that by using the appropriate primer system, the bubbling of the sealant material could be greatly reduced. The developmental primer system for the non-JFR sealants also increased the adhesion properties of the sealant. A draft specification for this material was developed, a pilot production batch was produced, and it was installed at Fairchild AFB, for field evaluation. The primer systems evaluated for the JFR materials reduced the adhesion properties of the JFR sealants when exposed to fuel and this portion of the study was terminated.

## Field testing

The last phase of the WES/Crafco CPAR program was to evaluate the developed materials in the field and to evaluate the overfill installation geometry. From observations made on various sealing projects, Crafco, Inc., personnel believed that the overfill geometry would improve the field performance of hot-applied sealants. Fairchild AFB in Spokane, Washington, was selected for the site of the field evaluation because of its climate, and the interest and cooperation exhibited by base personnel.

Other manufacturers were provided the option of installing commercially available sealants at the evaluation site. These manufacturers included those whose sealants had been evaluated in the laboratory evaluation as well as the manufacturers of cold-applied sealants. The invitation to other manufacturers was given to allow a head-to-head comparison of the products developed in the CPAR program with as many commercially available sealants as possible.

A total of 13 sealants from four different manufacturers were installed at Fairchild AFB during July, 1991. All of the joints were sawed to reface the joint wall, flushed with high pressure water, allowed to dry, sandblasted using a multiple pass technique, and finally cleaned with compressed air. A backer rod material was placed in all of the joints and the individual manufacturers installed their material. The sealants that were installed included five silicone materials; one, single-component, polysulfide-based sealant; one, two-component, polysulfide-based sealant; three, hot-applied, non-JFR sealants; and three, hot-applied, JFR sealants.

## Field performance

The field performance of the sealants was evaluated in January 1992. This evaluation indicated that no failures had occurred in the silicone sealants, the single-component and two-component, cold-applied polysulfide-based sealants, the JFR sealants, or the non-JFR sealants that had been applied without the use of the CPAR developed primer system. Some surface hardening

and some surface bubbles were noted on some of the materials, but they were not to the extent that would adversely affect field performance.

The sealants that had been installed using the primer system exhibited considerable swelling and bubbling. From additional studies conducted at Crafco, Inc., it is believed that the primer was not completely dry when the sealant was installed into the joint. Therefore, it is possible that the swelling and bubbling was caused by solvent release from the primer system. Attempts will be made to continue evaluations of the in-place sealant materials until all of them have exhibited 80 to 90 percent total failure.

### Ongoing effort

The second project is an on-going effort sponsored by the Federal Aviation Administration (FAA). The objective of the project is to determine realistic life cycle data for field-molded joint sealants in varying climatic regions.

To achieve this objective, five different joint sealant materials which are manufactured to five different specifications will be installed at five different airports in the United States. Construction variables such as material specification conformance, joint preparation, and sealant installation will be minimized using several steps. First the selected sealants were tested for specification conformance before they were purchased, and the same lot number that was tested will be installed at the five airports. The project specifications were prepared using U.S. Army Corps of Engineers and FAA guide specifications and the requirements provided in the project specifications will be enforced through communications with the contractor and 100 percent inspection by WES personnel. Also one contractor will be required to install all five sealants at all five airports to maximize consistency in joint preparation and sealant installation.

Approximately 10,000 linear feet of joints will be sealed at each airport with 5,000 linear feet of these joints located in a taxiway area, and the other 5,000 linear feet located in a parking apron or gate area. The

test sections at each airport will be situated so that they receive similar traffic. The test sections will be evaluated every six months, once during the winter and once during the summer, for three years to monitor the condition of the sealants.

Currently, the five sealants and airports have been selected and sealant installation is scheduled to begin in April or May, 1992. The five airports that were selected are; Orlando International Airport, Metro-Nashville Airport, Chicago-O'Hare International Airport, Reno-Cannon Airport, and Albuquerque International Airport. These airports were selected because they are located in climatic regions that compose approximately 85 percent of the United States. The definitions that were used for the climatic regions are those described by Peterson.

The five sealants that will be installed at the airports include a self-leveling silicone sealant; a self-leveling, single component, polysulfide-based sealant, two hot-applied, coal tar-based sealants, and a two-component, cold-applied, polysulfide-based sealant. The specific sealants that will be used were selected based upon historical laboratory test data at WES, FAA interest concerning specific sealants, and the fact that all of the projects would be rehabilitation activities.

The field performance data gained from the FAA sponsored research project will provide life cycle costs of the sealants and provide performance data as related to a specific amount of joint cleanliness and environmental exposure. The data will allow project engineers to specify the specification type of sealant that performs best in their particular climate much like they now select a particular grade of asphalt cement for use in asphalt pavements.

### Summary

The three studies described in this article provide insight into efforts undertaken to investigate, understand, and improve the field performance of field-molded pavement joint sealants. The first study outlined the areas that are considered by many user agencies as the reasons for unsatisfactory field per-

formance; specifically, inadequate materials, inadequate construction procedures, and inadequate project specifications. Each of these complaints were not justifiable in all circumstances, but they could be a contributing factor.

The WES/Crafco, Inc. CPAR project addressed one of the outlined areas, inadequate materials, from the first study directly and the other two indirectly. The specific goals of the project were to develop hot-applied sealants and specifications that would have an increased field performance over existing materials and to examine a different sealant installation geometry. The results of the field evaluation have not been conclusive to date, but the laboratory data indicate that the performance of the developed materials should in fact be an improvement over existing materials.

The on-going FAA study will directly investigate the last two areas of the first study, inadequate construction procedures and inadequate project specifications. The specifications and construction procedures used at each installation site will be controlled. Therefore, realistic life cycle values for various types of sealants will be determined. Also, defects in procedural methods or specifications should be detectable as the biannual sealant evaluations are conducted.

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# Crack Repairs to Concrete Pavement

by Brock E. Hoskins and B.F. McCullough

**T**he Center for Transportation Research at the University of Texas at Austin and the Texas State Department of Highways and Public Transportation have been working together to develop effective repair techniques for portland cement concrete pavement. Many repair techniques have been investigated over the past several years. This article discusses specific repair techniques used on Interstate Loop 610 in Houston and on U.S. 59 in District 11 about 100 miles north of Houston.

## Interstate Loop 610

In 1980, the Center for Transportation Research assisted the Urban District (now part of District 12) in developing a procedure for repairing extensive longitudinal cracking on I-610 in Houston. Examination of numerous cores revealed that the cracks always occurred above longitudinal bars, apparently because of poor consolidation of concrete below the reinforcing steel (Fig. 1). The cracks had to be sealed to prevent water intrusion.

Polymer concrete (PC) consisting of aggregate with a polymer binder was used to repair the portland cement concrete (PCC). The longitudinal cracks had to be enlarged to allow the PC to be placed, and several methods for enlarging the cracks were investigated. Sawing was not feasible for following the irregular cracks and high pressure water jetting was not feasible since PC does not bond well to wet surfaces and it would have been necessary to allow the cracks to dry before placing the PC.

A single-piston pneumatic crack router was selected as the best available piece of equipment to en-

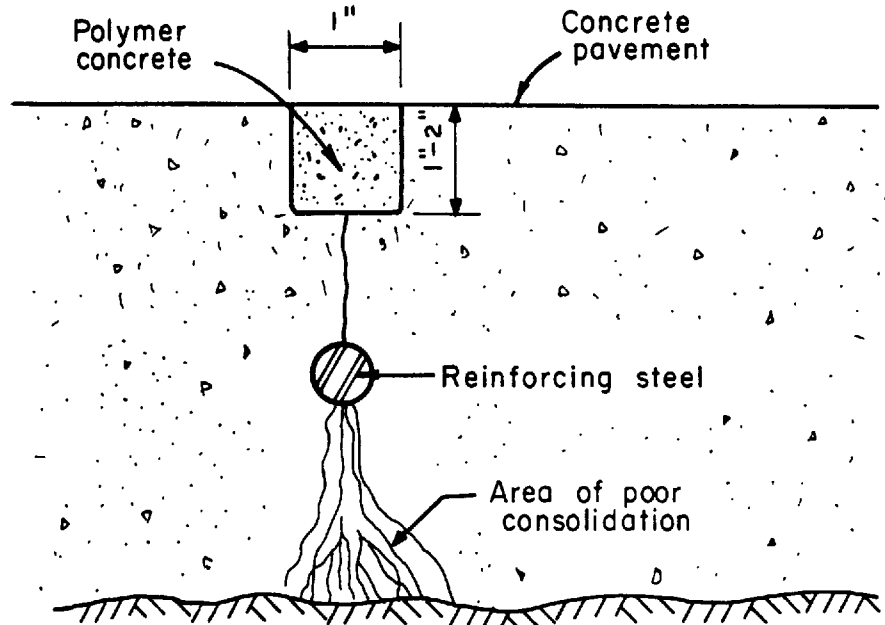


Fig. 1 — Poor concrete consolidation below the reinforcing steel caused cracks to occur above longitudinal bars.

large the cracks. The bit has a 0.75 in. (19 mm) diameter and the crack is usually widened to 1 in. (25 mm) in a single pass (Fig. 2 and 3). The depth varies, but is usually 1 to 2 in. (25 to 51 mm). The polymer concrete was placed by filling the enlarged crack with clean, dry, concrete sand and pouring methyl methacrylate (MMA) monomer system over the sand until it was completely saturated (Fig. 4).

## Monomer system

The monomer system consists of 95 percent MMA and 5 percent trimethylol propane trimethacrylate (TMPTMA). Benzoyl peroxide (BzP) initiator, in dispersion form, is added at a level of about 1 percent (2.5 percent for 40 percent dispersion) and a promoter, dimethylpara-toluidine (DMPT), is added at a level of 0.5 percent, both by



Fig. 2 — A single-piston pneumatic crack router was used to enlarge cracks.