RESEARCH 88-2

AND DEVELOPMENT

"Implementing research findings"
Effect of Concrete Shoulders, Lane Widening and Frozen Subgrade on Concrete Pavement Performance

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This is the fourth and final report of a study to determine the effect of concrete shoulders, lane widening and frozen subgrade on concrete pavement performance. In this portion of the study, Falling Weight Deflectometer tests were conducted seasonally over a two-year period to determine the seasonal variation in pavement deflection. Tests were also conducted to determine the change in pavement deflection throughout the day. An analysis was run to verify earlier results determined by the Construction Technologies Laboratory of the Portland Cement Association.
FOREWORD

This is the fourth and final report issued as part of a project to determine the effect of concrete shoulders, lane widening and frozen subgrade on the performance of concrete pavements. The earlier portions of the project were conducted and reported on by Construction Technologies Laboratories, a division of the Portland Cement Association.

The contribution of three co-workers in the Physical Research Section who conducted the Falling Weight Deflectometer tests and assisted in the data reduction is gratefully acknowledged: Daniel Bubalo, David Bullock, and Gerald Teig.

This project was done in conjunction with the FHWA's Highway Planning and Research Program.
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INTRODUCTION

Concrete shoulders have been used adjacent to mainline concrete pavements in the United States for almost twenty years. More recently it has been noted that the use of tied shoulders has improved the performance of concrete pavements. Similarly, the use of widened lanes has also resulted in improved pavement performance. The improved performance is due to reduced edge strains, reduced edge and corner deflections, and reduced water infiltration along the pavement edges.

Currently used thickness design methods for concrete pavements do not consider the contribution of tied shoulders and widened lanes. Use of these design methods results in the same thickness requirements for concrete pavements with or without tied shoulders, or lane widening. However, both tied shoulders and widened lanes contribute to improved pavement performance. Therefore, it should be possible to use a thinner mainline pavement and obtain the same pavement performance as that of a thicker pavement without tied shoulders or lane widening.

In 1977, the Minnesota Department of Transportation (Mn/DOT) sponsored a study to evaluate the effect of tied concrete shoulders and widened lanes. The study was conducted by the Construction Technology Laboratories, a division of Portland Cement Association (PCA), and consisted of load testing of several newly-constructed concrete pavement sections with and without tied shoulders and widening. The study showed significant reductions in pavement strains and deflections for pavements with tied shoulders and lane widening\(^{(1)}\). However,
results from the study were not implemented because of concerns that sufficient performance data gathered over a period of time were not available.

To alleviate these concerns and to obtain further field data to quantify the beneficial effects of using tied concrete shoulder and lane widening, a follow-up field testing study was conducted. Two additional objectives of the follow-up study were to evaluate the effects of frozen support and tridems on strain and deflection responses of concrete pavement.

PCA measured strain and deflection responses in the fall of 1982 and the winter of 1983. Mn/DOT conducted Falling Weight Deflectometer (FWD) tests concurrently with the PCA tests, and also, each season through the summer of 1984. The primary purpose of the FWD tests was to determine the seasonal variation in deflection values.

The work done by PCA has previously been reported\(^2\),\(^3\),\(^4\). This report covers the results of the FWD tests conducted by Mn/DOT.

**DESCRIPTION OF TEST SITES**

Field measurements were taken on five projects located in the southeastern portion of Minnesota, as shown in Figure 1. Projects 1 through 3 had been included in the 1976 field study on concrete shoulders and lane widening\(^1\). A brief description of each project follows:

PROJECT 1 is a four-lane divided highway located on I-90 just east of Blue Earth in southern Minnesota. It has 27-foot wide roadways consisting of 15-foot wide inside lanes and 12-foot wide outside lanes with 10-foot wide...
Figure 1. Test site locations
outside tied, keyed concrete shoulders. Shoulders are tied at 30-inch spacing using 30-inch long No. 5 tie bars. Shoulder thickness is 6 inches. The pavement is 9-inch thick plain concrete slabs with skewed joints at a repeated random spacing of 13, 16, 14, and 19 feet. Subgrade at the site was classified as silty clay to clay loam and had a 5-inch thick gravel subbase over it. Dowel bars were placed only in the 12-foot wide outside traffic lanes. Dowels are No. 8 round bars, spaced 12 inches on center with the first dowel located 6 inches inward from the pavement edge. Construction was completed in October of 1976 and opened to traffic the same month. By the end of June 1988, the accumulated number of equivalent standard axle loads (ESALs) had reached 2.2 million. The 1986 serviceability rating was 3.4. Panels selected for testing are located in the eastbound roadway at Station 538+65 and Station 540+10.

PROJECT 2 is located only about 0.3 miles west of Project 1. It is identical to Project 1 except it has a slab thickness of 8 inches and a 6-inch thick subgrade. The modulus of subgrade reaction was reported to be 270 pci. Construction was completed in October of 1976 and opened to traffic the same month. By the end of June 1988, the accumulated ESALs had reached 2.2 million. The 1986 serviceability rating was 3.4. Panels selected for testing are located in the eastbound roadway at Station 520+55 and Station 521+81.

PROJECT 3 is on I-90 several miles east of Project 1. It has 27-foot wide roadways with 15-foot wide inside lanes and 12-foot wide outside lanes. The pavement is 9-inch thick reinforced concrete with skewed joints at a spacing of 27 feet. Subgrade at the site was classified as clay loam to silty clay loam to sandy clay loam. A 5-inch thick gravel subbase was used. Dowel bars were placed only in the 12-foot mainline pavement portion of both traffic
lanes. Dowels are No. 8 round bars, spaced 12 inches on center. Construction was completed in October of 1976 and opened to traffic the same month. By the end of June 1988, the accumulated ESALs had reached 2.2 million. The 1986 serviceability rating was 3.2. Panels selected for testing are located in the eastbound roadway at Station 985+53 and Station 987+11.

PROJECT 4 is on I-90 just east of Fairmont. The 24-foot wide roadways have 12-foot inside and 12-foot outside lanes. The pavement is 9-inch thick reinforced concrete with skewed joints at a spacing of 27 feet. Subgrade at the site was clay loam with an AASHTO classification of A-6. Modulus of subgrade reaction was reported to be 300 pci. A 6-inch thick gravel subbase was used. Dowel bars were placed in both lanes. Dowels are No. 8 round bars spaced 12 inches on center. Construction was completed in October of 1975. By the end of June 1988, the accumulated ESALs had reached 2.4 million. The 1986 serviceability rating was 3.3. Panels selected for testing are located in the eastbound roadway at Station 1329+52 and Station 1330+59.

PROJECT 5 is on I-94 southeast of St. Cloud. It has 24-foot wide roadways with 12-foot wide inside lanes and 12-foot wide outside lanes. The pavement is 9-inch thick reinforced concrete with skewed joints at a spacing of 27 feet. Subgrade at the site is coarse sand with an AASHTO classification of A-1-b. Modulus of subgrade reaction was reported to be 700 pci. A 5-inch thick gravel subbase was used. Dowel bars were placed in both lanes. Dowels are No. 8 round bars, spaced 12 inches on center. Construction was completed in October of 1976 and opened to traffic that same month. By the end of June 1988, the accumulated ESALs had reached 8.2 million. The 1986 serviceability rating was 3.7. Panels selected for testing are located in the westbound roadway at Station 507+93 and Station 509+28.
The findings and conclusions from the strain and deflection tests conducted by PCA can be summarized as follows:

1. Deflections along a tied-shoulder joint can be conservatively taken as 85 percent of those along a free edge.

2. For application to the AASHTO thickness design procedure, only one-half of the design 18-kip equivalent single axle loads need to be considered for concrete pavements with a tied-concrete shoulder. This results in a one-inch reduction in the required mainline thickness.

3. A tridem-axle load can be considered to be equivalent to a single-axle load weighing 50 percent as much or a tandem-axle load weighing 80 percent as much.

4. Axle loads applied during the winter are only one-seventh as damaging as the same loads applied during fall months.

FALLING WEIGHT DEFLECTOMETER TESTS

Falling Weight Deflectometer tests were conducted eight times at each test site. The first two coincided with the testing conducted by PCA. Subsequently, they were conducted seasonally six additional times over a total period of two years.

Testing was conducted with the device shown in Figure 2. Several drop heights were used so as to simulate tire loads up to approximately eight tons. During
each test period, between two and five tests were run at each location to determine hourly variations.

![Figure 2 Falling Weight Deflectometer](image)

**SEASONAL VARIATION**

The seasonal variation in deflection is shown in Figures 3 and 4 for values taken at the slab corner and slab edge, respectively. Average values from Projects 1 through 4 were plotted as one line; these projects have plastic subgrade soils. Values from Project 5, which has granular subgrade soils, were plotted separately. The results were normalized by dividing the fall, winter and summer deflections by the appropriate spring deflection, as shown in Table 1. These values indicate that there is not a large variation in pcc pavement deflection during the non-frozen times of the year and that deflections taken during the winter are only about one-tenth as large as those taken during the rest of the year.
Figure 3  Seasonal variation in FWD deflection at slab corner
Table 1. FWD deflections normalized to Spring values.

<table>
<thead>
<tr>
<th>Season</th>
<th>Projects 1-4</th>
<th>Project 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 1982</td>
<td>0.99</td>
<td>1.10</td>
</tr>
<tr>
<td>Winter 1983</td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td>Spring 1983</td>
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<td>1.00</td>
</tr>
<tr>
<td>Summer 1983</td>
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<td>Spring 1984</td>
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<td>1.00</td>
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<tr>
<td>Summer 1984</td>
<td>0.93</td>
<td>1.07</td>
</tr>
</tbody>
</table>

TIME OF DAY VERSUS DEFLECTION

During the unfrozen portion of the year, pcc pavement slabs will curl at the edges and corners because of temperature differentials between the top and bottom of the slab. In the morning when the upper surface of the slab is cooler than the lower surface, the edges and corners will be curled up. This causes increased deflection and stress at these locations when subjected to wheel loads. As the top surface warms up, the amount of upward curl decreases, and eventually will curl downward. When this occurs, there is full support for the slab edges and corners (assuming there are no voids) and deflections are reduced at these locations. PCC slabs also have permanent warping. When concrete pavement is curing, drying shrinkage occurs more rapidly at the top of the slab than at the bottom. Also, the bottom of the slab may remain wet because of moisture in the base and subgrade, resulting in less shrinkage at the bottom of the slab. The differential shrinkage between the top and bottom of the slab causes the slab to be permanently warped up at the corners and edges. Curling and warping of pcc pavement slabs tend to be less in Minnesota during the winter because the slabs can be frozen to the
base. Figure 5 shows the relationship between FWD deflection and the difference in temperature between the top and bottom of the concrete slab. Results obtained at the slab corner show a 40 percent reduction in deflection over the temperature range investigated. Results at mid-slab edge were fairly constant.

EFFECT OF CONCRETE SHOULDERS

The effect of tied concrete shoulders was difficult to determine. There were only two test sites with this design: Project 1 with a nine-inch slab, and Project 2 with an eight-inch slab. The average reduction in deflection at the slab edges and corners over the two-year period, which could be attributed to tied-concrete shoulders, was six percent for the nine-inch slab and 30 percent for the eight-inch slab.

EFFECT OF PAVEMENT WIDENING

FWD deflection tests were conducted at one, two, and three feet from the slab edge, and the results compared to the values obtained at the pavement edge. Average percent reduction in deflection for the unfrozen portion of the year were as follows: One foot, 27 percent; two feet, 40 percent; and three feet, 46 percent. When the base and subgrade were frozen, no significant reduction was noted.
Figure 5  Effect of temperature differential on deflection
1. Deflection results taken during the non-frozen portion of the year are quite constant on pcc pavement. This is probably due to fairly constant subgrade moisture conditions.

2. Deflection results taken during the frozen portion of the year are about one-tenth as great as those taken during the non-frozen portion of the year. This finding is consistent with the finding by PCA, from work done on these sections, that axle loads applied during the winter are only one-seventh as damaging as the same loads applied during the fall months.

3. Pavement curl, particularly at the slab corners, can affect deflection quite significantly. This effect undoubtedly varies from project to project, depending on the amount of warp in the pavement and panel length.

4. The reduction in deflection resulting from the use of tied-concrete shoulders was difficult to determine in this study. The 15 percent value determined by PCA seems an appropriate figure.

5. Pavement deflections can be significantly reduced by constructing pavement lanes wider than 12 feet and placing an edge line 12 feet from centerline. The reduction appears to be approximately 27 percent, 40 percent and 46 percent for widenings of one, two and three feet, respectively.
RECOMMENDATIONS

1. Since pavement deflections are greatly reduced during winters in Minnesota, it is recommended that traffic loads applied during these periods be ignored when calculating the design CESALs. For purposes of calculating CESALs, winter can be defined as the period of time beginning when frost penetrates the subgrade to a depth of six inches and ending when the subgrade has thawed to a depth of six inches. In Minnesota, this period is normally about 4-1/3 months.

2. It is recommended that pcc pavements be paved wider than the 12-foot traffic lanes and that edgelines be placed 12 feet from centerline. This will reduce pavement deflections and extend service life. The optimum widening is 1-1/2 to 2 feet. Widenings greater than 2 feet provide little additional benefit in deflection reduction.

IMPLEMENTATION

The Minnesota Department of Transportation has modified its pcc pavement design. The new design calls for a paving width of 27 feet for two-lane roadways. For single roadways with two-way traffic, the paved width is 13-1/2 feet on each side of centerline; for dual roadways, the inside lanes are paved to a width of 13 feet; and the outside lanes (where most of the heavy trucks travel), to a width of 14 feet.
REFERENCES


