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Light-Traffic Roads Of Concrete

By
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Synopsis: Knowledge gained from slipforming heavy-duty concrete airport and primary road pavements has been applied to slipforming thin-concrete pavements for secondary and county roads carrying low volumes and light weights of traffic. Studies show that at low volumes of traffic there are few heavy multiaxle trucks in the traffic stream. Several thickness-design procedures are compared, and the serviceability index design model is discussed. Jointing and construction practices are summarized, noting that transverse joint intervals in light-traffic pavements vary from 15 to 20 ft (4.57, 6.10 m) up to 40 ft (12.19 m). A major survey shows that performance of thin-concrete county and secondary road pavement is good.

Keywords: axle loads; concrete construction; concrete pavement; concrete; highways; joints (junctions); performance tests; research; serviceability; slip-form construction; structural desigh.

2 pavement design

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INTRODUCTION

Progress through knowledge is slow but never ending. It took years of learning and development to provide today's highly efficient paving equipment and know-how for economically slipforming 18-in. to 24-in.-thick (45.7, 61.0 cm) heavy-duty concrete airport pavements. Many miles of 8-in., 9-in., and 10-in.-thick (20.3, 22.9, 25.4 cm) concrete pavements are built yearly to carry heavy (volume and weight) traffic on the Interstate and primary highway systems. Knowledge gained in these areas is being applied to build concrete pavements thinner-- 6 and 7 in. (15.2, 17.8 cm) thick--for the more lightly traveled secondary and county rural roads.

Presented here for engineers concerned with concrete design and performance are: background information on thin pavements carrying light traffic; a discussion of traffic patterns on these roads; some thickness-design comparisons, including comments on the serviceability index design model; brief summaries of jointing and construction practices; and the results of a major survey on thin-concrete pavement performance.

RESEARCH

There has been very little research on pavement for light-traffic rural roads. The emphasis on most highway research programs is on major highways carrying large volumes of heavy-weight traffic. However, two projects conducted in the United States have helped to establish design guidelines and document the excellent performance of concrete for light-traffic roads.

The first project, known as the AASHO Road Test, was conducted by the American Association of State Highway Officials* in 1958-1961 and reported by the Highway Research Board in 1962 (1). Concrete pavement thicknesses from 2-1/2 to 12-1/2 in. (6.4, 31.8 cm) were tested under axle loads from 2000 lb. (907 kg) on a single axle to

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*Now the American Association of State Highway and Transportation Officials

48,000 lb. (21,773 kg) on a tandem axle. The 1.1 million axle loads of test vehicles probably subjected the test pavement to as many loads over a period of two years as a normal rural road will carry in 25 to 30 years.

The quality of performance of the various pavement designs at the AASHO Road Test was determined from serviceability measurements at various intervals throughout the test. Figs. 1, 2, and 3 present the performance histories of the 3-1/2-in., 5-in., and 6-1/2-in. (8.9, 12.7, 16.5 cm) concrete test sections, respectively, with the serviceability index plotted at various numbers of axle load applications. These results show the excellent performance of the 5-in. and 6-1/2-in. (12.7, 16.5 cm) pavements for the lighter axle loads under the conditions prevailing at the Road Test, i.e. the soil and climate of central Illinois. There was no significant difference in the performance of the pavements, whether plain or reinforced, with or without subbase (a granular subbase of 3, 6, or 9 in.--7.6, 15.2, 22.9 cm). These results are evidence that 8-in. or 9-in. (20.3, 22.9 cm) concrete pavement is not required on many miles of light-traffic roads.

The second project, of equal interest, was an experimental road built by Greene County, Iowa, in 1951. It consisted of 2 miles of 4-1/2 in., 5-in., and 5-1/2-in. (11.4, 12.7, 14.0 cm) concrete slabs. After 15 years the county reported: "There is strong evidence that thin concrete pavements, when based on realistic design loads and built with modern techniques, are both economical and desirable for secondary road systems." (2) The performance of all three designs was excellent. In fact, even after 21 years, there is no substantial difference in their performance. There is also no major performance difference between the plain and the reinforced pavements designed for this project.

THE IOWA STORY

The state of Iowa provides the most striking example of concrete for light-traffic rural roads. It was in Iowa that the first slipform paver was used. The Iowa State Highway Commission developed it for use on the state's secondary system (3).

Iowa has over 90,000 miles (144,810 km) of rural secondary roads --and soils that are excellent for farming but notoriously poor for highway foundations. Most Iowa counties had attempted to provide all-weather surfaces through the use of gravel. However, diminishing supplies of gravel; degradation of the surfacing from thawing of subgrades in the spring after deep frost penetration in the severe Iowa winters; the need for limiting loads in the spring; and the dust problem in the summer--all indicated the need for a more practical solution.

Thus, the slipform paver was developed in the late 1940's. Slipform paving is a low-cost method of building concrete pavement, with a minimum of labor, on a narrow right-of-way with deep side ditches. It was used on two projects--a 1-mile (1.6 km) section and a 1/2-mile (0.8 km) section of 6-in. (15.2 cm) pavement--in 1949. The success of these projects, plus the experimental road in Greene County already mentioned, led to the acceptance of slipformed 6-in. (15.2 cm) plain concrete pavements by most Iowa counties.

With the development of commercial slipform paving equipment in 1955, use of concrete pavements spread rapidly in Iowa. There are more than 3000 miles (4827 km) of concrete pavements built by the slipform method on county roads in this state. Fig. 4 shows a breakdown of Iowa concrete paving mileage county by county by the end of 1973.

THE STORY IN OTHER STATES

Following Iowa's example, several states are now using plain concrete for light-traffic roads. In Nebraska in 1969 through 1973 over 325 miles (522.9 km) of 6-in. to 8-in.-thick (15.2, 20.3 cm) concrete were paved by counties and the state; most of this is 6-in. to 7-in. (15.2, 17.8 cm) pavement on the secondary road system of the Nebraska Department of Roads. In Minnesota over 40 miles (64.4 km) of 6-in. and 6-1/2-in. (15.2, 16.5 cm) concrete pavement have been constructed on the county road system. Illinois recently revised its design standards to permit 6-in. and 7-in. (15.2, 17.8 cm) plain concrete with no subbase; some 32 miles (51.5 km) were built on Illinois county roads in 1970 to 1973. Other concrete paving projects have been built on light-traffic roads in Michigan, Pennsylvania, North Dakota, and Wisconsin.

TRAFFIC STUDIES

Highway statistics show that local rural roads represent 71 percent of the rural road mileage (some 2.26 million miles--3.64 million km), and these roads carry 24 percent of the traffic. However, most of the published data regarding traffic volumes and weights are for major rural and urban highways. Such information is an essential ingredient in the proper design of highways.

Although traffic data for lightly traveled rural roads are meager, some data are available. Of the 90,000 miles (144,810 km) of rural secondary roads in Iowa, 16,000 miles (25,744 km) carry over 100 vehicles per day, including 5 to 15 percent trucks. Throughout the state, traffic ranges from about 100 to 1060 vehicles per day on the secondary system.

Several traffic studies for Portland Cement Association (PCA)-- one by M. P. Brokaw* in 1965 and the other by this author** in 1968-- show that at low traffic volumes the number of heavy trucks (tractor semitrailers and combinations) diminishes rapidly. In Brokaw's study of Wisconsin traffic, a consistent relationship was found between two-way dual-tired truck volume and tractor semitrailer and combination truck volume (Fig. 5). The basic equation is:

$$\text{Log (DT ADT)} = 0.7830 \text{ Log (TST ADT} + 4) + 0.8296$$

where DT ADT = two-way dual-tired trucks daily

TST ADT = two-way tractor semitrailer and combination trucks daily

My own study summarized the 1968 traffic count data for rural highways in seven states (Table 1). It related total two-way traffic volume to commercial traffic and to the type of trucks in the traffic stream. This study agreed with Brokaw's study that at low traffic volumes there are few multiaxle trucks present.

In order to properly evaluate the effects of heavy commercial vehicles on the pavement and the part they play in the structural design of the slab, PCA helped to develop a computer program that converts data from Federal Highway Administration (FHWA) standard loadometer tables (W-4) to probability constants for use in structural design. These probability constants approximate the number of axles of each load group per 1,000 trucks. However, loadometer data are not generally available for local rural roads and PCA developed general probability constants for them (4). Table 2 gives the results for county rural roads in axles per 1000 trucks--with the minimum, average, and maximum for each load group on single and tandem axles. These traffic data can be used for the thickness design of concrete pavements when more accurate information is not available.

THICKNESS DESIGN

Various thickness-design procedures are used by highway departments. One of them, the PCA method of design (5, 6), is based on influence charts developed from Dr. H. M. Westergaard's equation

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*Unpublished data by M. P. Brokaw, Senior Paving Engineer, Portland Cement Association, Skokie, Illinois, 1965.

**Summary of 1968 traffic data by author in Table 1.

for flexural stress due to a load at the slab edge. Another method, the AASHO interim design guide (7), is based on the results of the AASHO Road Test. Both methods provide a structural design analysis based on subgrade and concrete strengths, design life, and the weights and repetitions of axle loads of traffic.

Table 3 is a design comparison of these two methods (plus the serviceability index design model, discussed below) for various traffic volume levels for one subgrade condition. These values will vary some for different assumed truck traffic volume and weight patterns, subgrades, and concrete strengths.

The Illinois Department of Transportation uses a modified AASHO interim guide procedure with certain minimum requirements (Table 4). Also, the Minnesota Department of Highways has a simplified design table that provides suggested designs for different subgrades and anticipated traffic (Table 5).

A separate empirical design method based on the performance of plain concrete pavements has been developed by M. P. Brokaw of the Portland Cement Association. In 1971-1972 he made an extensive study and analysis (8) of the performance of plain concrete pavements (no mesh or dowels) in service in four Midwestern states. The study covered some 3500 miles (5,632 km) of pavement 6 to 10 in. (15.2, 25.4 cm) thick and with transverse joint spacing of 15 to 20 ft (4.56, 6.10 m). It involved the measurement and analysis of truck traffic, general subgrade conditions, faulting, and age, as well as use of the PCA Road Meter, a device installed in a passenger car to measure the Present Serviceability Index (PSI) of pavements while traveling at a speed of 50 miles (80.5 km) per hour (9). The results of this field investigation of plain concrete pavement performance produced the serviceability index design model.

The model equations are:

For A-1, 2, 3 subgrades,

$$PSI = 5.41 - 1.8 \text{ Log } [1014/10^{0.56P_o} + 1.94TA^2/D^{5.47} + (A+1)^{0.58} - 1] - 0.01A + 0.65 \text{ Log } D - 0.62$$

For A-4, 5, 6, 7 subgrades,

$$PSI = 5.41 - 1.8 \text{ Log } [1014/10^{0.56P_o} + 1.11TA^2/D^{4.60} + (A+1)^{0.70} - 1] - 0.01A + 0.65 \text{ Log } D - 0.62$$

where PSI = serviceability index following years of service (A) after construction

P_o = serviceability index constructed
T = two-way average daily traffic of tractor semitrailer and combination vehicles during years of service (A)
A = years of service after construction until reaching PSI
D = thickness of pavement in inches

Note that Table 3 includes thickness design values for a given set of conditions using the model.

The import of the serviceability index design model is two-fold:

1. The advantages of plain concrete pavement can be extended to major truck routes by increasing the pavement thickness without using dowels and distributed reinforcement.

2. Because plain thin-concrete pavements have a greater capacity for truck traffic than previously predicted, they are especially suited for use on the secondary and county highway systems.

JOINTING

Jointing details vary from state to state. The plain (unreinforced) pavements have transverse construction joints sawed at various intervals. For example, in Iowa the joints are sawed at 40-ft (12.19 m) intervals; in Illinois, at 20-ft (6.10 m) intervals. Nebraska uses joints skewed and sawed at 15-ft (4.57 m) intervals; Minnesota at 20-ft (6.10 m) intervals.

On most projects the only subbase provided under concrete pavements is the old or existing gravel surface bladed into shape for the proper cross section. These pavements usually are somewhat narrower than primary and Interstate pavements; i.e., they have a width of 20 or 22 ft (6.10, 6.71 m) rather than the 24-ft (7.32 m) width generally used on major roads.

The only steel used is in the 1/2-in.-diameter (1.3 cm) tiebars across the longitudinal centerline joint. Most projects have a 2-in. (5.1 cm) crown to facilitate drainage and use a slightly lower cement factor (470 to 517 lb. of cement per cubic yard - approx. 279,307 kg/m^3) than used on primary highways. All use air-entrained concrete.

CONSTRUCTION

In recent years concrete light-traffic roads have been built almost entirely by the slipform paver. Generally the slipform paver is preceded by some type of electronically controlled automatic fine grader that scarifies, levels, and cuts the subgrade to full width. Most such fine graders now take both horizontal and vertical guidance from a preset string line. In Iowa, where the right-of-way is narrow and the side ditches quite deep, a special belt conveyor is mounted on the fine grader to carry the central-mixed concrete over the fine grader and deposit it on the grade just ahead of the slipform paver.

The slipform paver performs all operations of spreading, consolidating, and finishing the concrete; only a minimum of hand-finishing is required. The final surface texture is obtained with a burlap drag and the pavement is cured with white-pigmented membrane.

PERFORMANCE

The performance of the relatively thin, plain concrete pavements on county roads in Iowa is well documented. In 1968 and 1969 a performance evaluation (10) was made of 2044 miles (3289 km) of concrete pavement on the Iowa secondary road system--95 percent of all mileage built since 1955. Of the roads surveyed, 90 percent were 6 in. (15. 2 cm) thick; about 8. 5 percent, 7 in. (17. 8 cm); and 1. 5 percent, 8 in. (20. 3 cm). They had traffic counts from about 100 to as much as 2000 vehicles per day.

The survey was conducted by using the PCA Road Meter (9) to measure the Present Serviceability Index (PSI). The weighted average of current PSI value for each year's construction ranged from 3. 26 in 1955 to 4. 15 in 1969 (Fig. 6). The average PSI for the total 2044 miles (3289 km) in the study was 3. 91.

Comparison of the PSI in Fig. 6 with the road roughness plot in Fig. 7, which is based on the Bureau of Public Roads* roughometer, shows that the lower PSI of the old projects is only partially accounted for by loss of PSI due to age. Much of the difference is due to improvements in both equipment and construction techniques during this period.

It is gratifying that the average PSI value for pavements up to 13 and 14 years old was 3. 26 or better. In other words, the 2044 miles

*BPR, which is now the FHWA

(3289 km) of rural county concrete roads surveyed had a serviceability rating in the good category (PSI of 3.00 or better) after 2 to 14 years of service.

SUMMARY

Knowledge of the traffic characteristics, design, construction and performance of major highways has been modified and adapted for the design of thin-concrete pavements carrying light traffic. Traffic studies show that at low traffic volumes there are few heavy multi-axle trucks in the traffic stream. Although various thickness-design procedures are used, the performance of thin-concrete pavement on county and secondary roads is good.

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