APPLICATION OF EMPIRICAL AND MECHANISTIC-EMPIRICAL PAVEMENT DESIGN PROCEDURES TO Mn/ROAD CONCRETE PAVEMENT TEST SECTIONS

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ABSTRACT

Current pavement design procedures are based principally on empirical approaches. The introduction of new materials and the significant increase in traffic volumes have brought uncertainty to their prediction of pavement behavior. The current trend toward developing more mechanistic-empirical type pavement design methods led Minnesota to develop the Minnesota Road Research Project (Mn/ROAD). The project consists of 40 heavily instrumented test sections, 14 of which are jointed plain concrete (JPC) designs.

The predicted lives of the Mn/ROAD mainline concrete test sections were determined using design and as-built data applied to three currently accepted concrete pavement design methods: Minnesota Department of Transportation's (Mn/DOT) rigid pavement design guidelines, *AASHTO Guide for Design of Pavement Structures 1993*, and the *PCA Thickness Design for Concrete Highway and Street Pavements (1984)*. The analysis began with determination of the applicable as-built parameter values for each respective design method. Application of the as-built parameters into the three methods resulted in widely varied predictions of pavement life. For the 1993 AASHTO design method, reliability levels of 50% and 95% were applied for comparison. An experimental procedure for converting PCA method fatigue and erosion results to AASHTO type CESALs demonstrated unsuitability. Validation of the predictions presented will occur as the test cells reach their terminal serviceability.

BACKGROUND

Existing pavement design procedures are principally based on either empirical or mechanistic-empirical approaches. An empirical approach is based strictly on observed performance, without consideration of theoretical behavior. Conversely, a mechanistic-empirical design approach ties together the theoretical behavior of a pavement with observed performance.

Three current pavement design procedures were assessed in this study:

- Minnesota Department of Transportation's, (Mn/DOT) rigid pavement design guidelines[1], (based on modified 1981 *AASHTO Interim Guide for Design of Pavement Structures* [2]).
- *AASHTO Guide for Design of Pavement Structures (1993)* [3].
- *PCA Thickness Design for Concrete Highway and Street Pavements (1984)* .[4]

Mn/DOT's rigid pavement design procedure is "an empirical method which is based on a combination of the modified 1981 AASHTO pavement design procedure and the knowledge gained from performance of rigid pavements in Minnesota.[1]" The 1993 AASHTO concrete pavement design guide, also an empirically based method, adds consideration for reliability, environmental effects, and behavior with tied concrete shoulders. Finally, the 1984 PCA (Portland Cement Association) pavement design method is mechanistic-empirical based. It combines slab behavior theories and finite element analyses with experimental pavement testing results from facilities such as the AASHO Road Test.

The data used in this study came from the Minnesota Road Research Project (Mn/ROAD). Located in Otsego, Minnesota, Mn/ROAD is test cells are grouped into three different periods of expected service life, and receive two different traffic loading volumes and a cold regions pavement test facility consisting of 40 heavily instrumented test sections or "cells" of various materials and layer thicknesses. The types. The three groups are:

1) 5 year design "mainline" cells, which receive live high volume interstate (I-94) traffic loads,
2) 10 year design "mainline" cells, which receive live high volume interstate (I-94) traffic loads,
3) 3 year design "low volume" cells, which receive loading from one calibrated truck driven around a closed loop configuration.

Of the 40 test cells, 14 are portland cement concrete surfaced, 22 are bituminous surfaced, and 4 are aggregate surfaced.

Each Mn/ROAD test cell was designed using current Mn/DOT pavement design guidelines. Designs were checked for reasonableness using the *AASHTO Guide for Design of Pavement Structures (1986)*[5], which was current at that time.

This study intended to address a portion of Mn/ROAD's long term Research Objective #1-C, titled "Verification of Empirical Design Models for New Rigid Pavements.[6]" That research objective seeks to determine the effect recent traffic characteristic changes have on existing pavement design methods. This study, however, only addressed the effect current materials and construction practices have on different design procedures.

OBJECTIVES

The objectives of this study included:

1) Verify parameters and assumptions used in original Mn/ROAD concrete test cell design calculations.
2) Determine applicable pavement design method parameters based on available as-built data collected up to December 1996.
3) Determine the predicted service lives of the Mn/ROAD project's concrete test sections using two empirical and one mechanistic-empirical pavement design method.

SCOPE

This study addressed the properties and behavior of the following Mn/ROAD concrete pavement test cells:

1) "Mainline" 5-year design life cells: # 5 - 9.
2) "Mainline" 10-year design life cells: #10-13.

See Figures 1 and 2 for test cell cross section details. The base and subbase materials used in the concrete test cells consist of following materials:

Class 3 Special: Well-graded natural sand and gravel, 8 - 15% passing the 75 μm (No. 200) sieve.
Class 4 Special: Well-graded natural sand and gravel, 5 - 10% passing the 75 μm (No. 200) sieve.
Class 5 Special: Well-graded natural sand and gravel, 10 - 15% crushed particles required.
Class 6 Special: Well graded material, 100% crushed particles.

The pavement design parameters considered in this study included:

- Panel length and width
- Presence of dowel bars
- Modulus of subgrade reaction (k-value)
- Concrete modulus of rupture
- Concrete modulus of elasticity
- Joint load transfer effectiveness
- Pavement serviceability (ride quality)
- Drainage coefficient
- Equivalent single axle load (ESALs) applications
- Pavement layer thickness.

As-built design parameter values were determined from concrete core measurements, soil test results, and falling weight deflectometer (FWD) test results.

APPROACH

This study began with the assembly and summarization of design and as-built information obtained during and following the construction of the Mn/ROAD project. Traffic loading and volumes from the on-site weigh-in-motion (WIM) equipment were also gathered for comparison to original traffic forecasts.

Once the necessary information was gathered, it was applied to the three pavement design methods considered in this study. To expedite the analysis, the following computer program versions of each of the design methods were utilized:

1) Mn/DOT method : "PAVE" program[7]
2) 1986 AASHTO method: "DNPS86/PC™" program[8]
3) 1993 AASHTO method: "DARWin™" program[9]
4) 1984 PCA method: PCAPAV program[10].

The analysis process began with the application of original design parameter values to the Mn/DOT design method. This served to highlight the original assumed values, and to verify the original design life predictions. Next, the results of that analysis were compared to those found by applying the same values to the 1986 AASHTO design method, which was current at the time of design. As-built parameter values were next input into all three methods under consideration. This served to determine the effect construction had on each design method's service life predictions.

The final results presented for each design method include:

1) Total CESAL (concrete equivalent single axle load) applications to terminal serviceability predicted for each test cell, based on as-built material and section properties.
2) Predicted serviceability life for each test cell based on data gathered from August 1994 to December 1996.

DESIGN PARAMETERS

The three concrete pavement design methods applied in this study utilize several common input parameters. The original assumed values, together with as-built values as determined by various test methods, are outlined in the following sections. It should be noted that all Mn/ROAD concrete test cells consist of plain jointed concrete (JPC) slabs.

Mn/DOT Concrete Pavement Design Method Parameters

Tables 1 and 2 summarize many of the Mn/ROAD original and as-built design parameter values used for this design method.

Concrete Modulus of Rupture

The concrete modulus of rupture value used for the design of all concrete test cells was 3.450 MPa (500 psi). This came from the specified application of a safety factor of 1.33 to a state (of Minnesota) historical average modulus of rupture value of 4.655 MPa (675 psi)[1]. The as-built values for each test cell were determined from samples taken during construction. All values are based on 28 day third point loading beam tests[11] (ASTM C 78-84). A safety factor of 1.33 was applied to these values for a valid comparison.

Concrete Modulus of Elasticity

The concrete modulus of elasticity value used for the design of all concrete test cells was the Mn/DOT standard value of 28960 MPa (4,200,000 psi). This parameter is rarely tested for in practice, since it has little effect on the final pavement design thickness. The as-built values used in this study came from tests on 28 day concrete core samples[11] (ASTM C 469-87a).

Modulus of Subgrade Reaction

The Mn/DOT design method utilizes a correlation equation which equates subgrade R-values to modulus of subgrade reaction (k-value) values. The correlation equation is as follows:

$$k = -1.17 + 63\sqrt{R} \qquad (1)$$

where k = modulus of subgrade reaction, psi/in, and R is the R-value determined for the subgrade[12]. The R-value test method utilized is a modified AASHTO specification T-190.

Two types of subgrade material were used under the concrete test cells on the Mn/ROAD project. Twelve of the cells (including all of the mainline test cells) have a silty clay subgrade with a design R-value of 12. The other two cells (located on the low volume road loop) have a select granular subgrade material with a design R-value of 70.

While there are various gravel and asphalt-stabilized base layers over the subgrade layers, their contribution to the design k-value is typically neglected in the Mn/DOT pavement design procedure. However, in an effort to better predict the true behavior of the test cells, the designers attempted to account for the increased stiffness provided by the various base layers. This was accomplished by determining each base layer's R-value based on granular equivalency, and then adding it to the subgrade R-value. This procedure utilized Mn/DOT's Bituminous Pavement Design Chart (Aggregate Base), Figure 5-3.6 in reference 1. Final R-values were then correlated to k-values using equation 1 above.

As-built subgrade soil R-values were determined from testing soil samples taken during the construction of Mn/ROAD. The same R-value base layer modification procedure as described above was applied.

Load Transfer Coefficient

Load transfer coefficient values (J-factors) used in the Mn/DOT design method were taken directly from AASHTO recommendations. Table 1 lists the values used in the original design of each test cell. The Mn/ROAD 5 year design concrete test cells were constructed with a driving lane width of 4.2 m (14 ft), which was considered to be an extended edge or tied concrete shoulder design. The 10 year design concrete test cells have a standard 3.6 m (12 ft) lane width. Except for test cells 8 and 9, the concrete test cells at Mn/ROAD have bituminous shoulders on both sides. Cells 8 and 9 have a tied 4.0 m (13 ft) concrete shoulder attached to the passing lane and a bituminous shoulder adjacent to the driving lane.

Traffic loading

An important parameter was the estimated number of AASHTO 18-kip equivalent single-axle loads (ESALs) to be applied before the serviceability level of each test cell would reach a terminal value of 2.5. Since the 5 and 10 year design test cells receive traffic diverted off the existing Interstate Highway 94, original traffic volumes were estimated in 1987 based on historical data available for that location. Following the 1989 installation of a weigh-in-motion (WIM) device (just preceding the entrance to the project), data was collected and analyzed to validate the original forecast. The design concrete ESALs (CESALs) were as follows:

1) 5 year design test cells (#5-9): 5,262,400
2) 10 year design test cells (#10-13): 11,225,270.

The Mn/DOT design method recommends multiplying estimated ESALs by 0.93 to account for the difference in severity and duration of winter conditions between Ottawa, Illinois (AASHO Road test) and the state of Minnesota. This correction was however not utilized in the design of Mn/ROAD test sections.

Pavement Thickness

Design pavement thicknesses were determined by inserting all of the necessary parameters into the Mn/DOT concrete pavement design equation. To simplify the installation of the load response instrumentation and the paving of the test cells, consistent design thicknesses were chosen for the two different design life segments. Design thicknesses were as follows:

1) 5 year design life cells: 190 mm (7.5 in)
2) 10 year design life cells: 240 mm (9.5 in).

As-built pavement thicknesses were determined from core samples taken after construction (Table 2).

1993 AASHTO Concrete Pavement Design Method Parameters

During the original design of the tests cells, the Mn/DOT design method results were checked for reasonableness by using the 1986 AASHTO concrete pavement design method. Due to the small difference between the 1986 AASHTO design method and the 1993 AASHTO design method, this study uses the former for verification of the original design results and the latter for comparison of the as-built design results. Tables 3 and 4 summarize the original and as-built design parameter values used for these two design methods.

Concrete Modulus of Rupture

A concrete modulus of rupture value of 4.655 Mpa (675 psi) was used for all mainline test cells in the original design verification following the 1986 AASHTO design method. This value was based on the Minnesota state historical average modulus of rupture value reported earlier in this report. The as-built values used in the 1993 AASHTO design method application were the same as those used in the Mn/DOT as-built design analysis (Table 2), without application of the 1.33 safety factor.

Concrete Modulus of Elasticity

For the 1986 AASHTO design method application, a concrete modulus of elasticity value of 28960 MPa (4,200,000 psi) was used for all mainline test cells. For the 1993 AASHTO method application, as-built values were the same as those used in the Mn/DOT as-built design analysis (Table 2).

Modulus of Subgrade Reaction

In the Mn/DOT design check using the 1986 AASHTO design method, k-values for the 5 and 10 year test cells were calculated using assumed seasonal resilient modulus values applied to a worksheet in the "DNPS86/PC™" computer program.

For the 1993 AASHTO design method application, the k-values were determined following the "AREA" procedure as outlined in section 5.6.5 of the design guide[3]. Data was gathered from center of panel falling weight deflectometer (FWD) tests conducted from 1993 through 1996. To insure reasonable contact between slab and base or subgrade, a slab temperature gradient analysis was conducted and only FWD tests conducted during negative or slightly positive gradients were utilized.

The loss of support factor for the design and as-built analysis was taken to be 0.0 for all test cells. This assumption is reasonable, since recent research[14] has reported the use of this factor results in over designed pavement sections.

Load Transfer Coefficient

Load transfer coefficient values (J-factors) used both in the 1986 AASHTO and the 1993 AASHTO method analyses were taken to be the same as in Table 1.

Serviceability Factors

For the 1986 AASHTO design method, the initial and terminal serviceability factors were taken to be 4.5 and 2.5 (PSR) respectively. For the 1993 AASHTO design method application, as-built initial serviceability values were determined through correlation to an International Roughness Index (IRI) number based on measurements gathered utilizing the South Dakota profiler technique. The terminal serviceability factor remained at 2.5.

Drainage Coefficients

Drainage coefficient values for both the 1986 AASHTO and the 1993 AASHTO design method applications can be found in Table 3. Based on AASHTO recommendations, the design values were chosen assuming the pavement structure is exposed to moisture levels approaching saturation between 5 and 25 percent of the time. Investigations into the actual soil moisture conditions are currently underway, but were not considered for this study.

Reliability Level

For the 1986 AASHTO method, a reliability level of 95% was used for the mainline test cells. For the 1993 AASHTO design method application, reliability levels of both 50% and 95% were used for each of the test cells.

The standard deviation value assumed for both applications was 0.39, as recommended for rigid pavements by the 1986/1993 AASHTO design methods.

Traffic loading

Traffic volumes used for the 1986 AASHTO design method analysis were the same as for the Mn/DOT design method analysis.

Pavement Thickness

Mn/DOT method pavement design thicknesses were checked for reasonableness by inserting all of the applicable parameters into the DNPS86/PC™ program. For the 5 year design cells, the resulting thicknesses were generally less than that found using the Mn/DOT method. For the 10 year design cells, the thicknesses were slightly higher than those found with the Mn/DOT method. See Tables 1 and 3. As-built pavement thicknesses were taken to be the same as in the Mn/DOT as-built analysis (Table 2).

1984 PCA Concrete Pavement Design Method Parameters

The PCA concrete pavement design method was not used in the design of Mn/ROAD concrete test cells. In this study, however, as-built data was applied to this method to provide a comparison between mechanistic-empirical (PCA) and purely empirical (AASHTO) pavement design approaches. The design procedure is different from the AASHTO approach in that several axle load categories are analyzed for their contribution toward fatigue stress or erosion damage. Table 5 summarizes the two unique parameters used in the 1984 PCA design method application.

Concrete Modulus of Rupture

The as-built values used in this method were the same as those used in the Mn/DOT as-built design analysis (Table 2), without application of the 1.33 safety factor.

Modulus of Subgrade Reaction

Rather than utilizing the correlation chart provided in the PCA design manual, this study used the same as-built k-values as those determined in the 1993 AASHTO design method (Table 4).

Shoulder and Joint Type

Table 5 shows the shoulder and joint types used for this analysis. This design method only requires general descriptive information for these two parameters.

Pavement Thickness

The same as-built pavement thicknesses that were used in the previous two methods were applied.

Load Safety Factor

This was chosen to be 1.2, as recommended by the PCA design guide for interstate traffic loadings.

Axle Load Distribution and Volumes

Traffic load and volume information for this design method was provided by Mn/ROAD's on-site weigh-in-motion equipment. For each axle load category, the total truck axle counts per 1000 trucks were determined for the month of October 1994 (shortly after construction completed). Single and tandem axle group loadings were considered. Table 6 shows a typical axle load and count breakdown.

TEST CELL SERVICE LIFE ANALYSIS

For the Mn/DOT and 1993 AASHTO design analyses, two applications of the design parameters were carried out. The first application used original design parameters, the second used as-built data. For the PCA design method, only as-built data was applied. Table 7 summarizes the predicted concrete ESAL applications to terminal serviceability found from each method application. Below are general observations noted during the application of data to each method.

Mn/DOT Concrete Pavement Design Method

When the as-built design parameters were applied to this method, slight to moderate decreases in predicted pavement service life were found for the 5 year design life cells, while slight increases were found for the 10 year cells. Several factors account for these differences. By far the greatest contribution came from applying the as-built values for the modulus of rupture. Even though the concrete mixture design was the same for all of the mainline concrete test cells, the 28 day average concrete modulus of rupture values varied (after applying the 1.33 safety factor) from 2.64 MPa (385 psi) to 3.73 MPa (540 psi), with a standard deviation of 0.34 MPa (50 psi). Test cells 11 and 13 were the only mainline cells with 28 day values greater than the original design value of 3.45 MPa (500 psi).

The second significant parameter was the as-built slab thicknesses. Measured thicknesses after construction were high enough that in many cases they compensated for low concrete modulus of rupture values. The increase was particularly noticeable in the 10 year design life test cells, where pavement thicknesses were as much as 20 mm (0.8 in) thicker than design. These results are not unexpected, since a recent report[13] pointed out that several state DOTs routinely measure as-built slab thicknesses greater than design. While many times this is caused by disincentives to contractors for paving too thin, in the case of construction of the Mn/ROAD test cells, heavily instrumented areas caused several starts and stops for the slip-form paving equipment. Interrupted paver progress often leads not only to inconsistent pavement thicknesses, but a deterioration of the pavement surface ride quality, which was clearly experienced at Mn/ROAD.

1993 AASHTO Concrete Pavement Design Method

For this method, the predicted test cell service lives depended greatly on the reliability level chosen. Choosing a reliability level of 95%, as recommended by AASHTO for the design of interstate pavements, resulted in predicted service lives of less than 50% of the original design assumptions. However, choosing a reliability level of 50% resulted in predicted service lives close to design for the 5 year design cells, but over 100% greater than the design life for many 10 year cells.

As in the Mn/DOT method analysis, one of the important parameters affecting the results was the modulus of rupture. The assumed design value of 4.655 MPa (675 psi) was generally greater than most of the 28 day as-built values found through material testing.

During this analysis, a major difference was noticed between the k-values determined for the various design methods. The values found using the "AREA" method were approximately 50% less than the values found using the modified R-value correlation procedure in the Mn/DOT method. They were also up to 79% less than the design values found using the originally assumed resilient modulus values in the 1986 AASHTO design method. See Tables 1, 3, and 4 for comparison. Such large differences, as demonstrated by this comparison, clearly indicate the limitations and assumptions involved in determining a representative k-value.

This design method was significantly affected by the low values measured for the initial serviceability factor. While very well constructed concrete pavements might have an initial serviceability factor exceeding 4.0, Mn/ROAD concrete test cells had an average value near 3.5. These significantly lower values essentially "used up" much of available service life CESALs predicted by this method.

1984 PCA Concrete Pavement Design Method

Using the design life prediction procedure outlined later in this section, the pavement service lives predicted by this method were lower than design for the 5 year cells, and extremely higher than design for the 10 year cells. The major aspect causing the disparity between the two was the mode of failure predicted. For the 5 year design cells, the fatigue stress failure mode dominated the analysis. For the 10 year cells, the base layer erosion damage was controlling. Comments given in the PCA method indicate this to be the normal failure modes for medium and heavy trafficked pavements, respectively.

The process used to determine the axle repetitions (CESALs) to failure was as follows:

1) Axle load counts (for one month) for both single and tandem axles were broken into 10 load categories each, and normalized to the number of axle events per 1000 trucks.
2) As-built parameters were input into the PCAPAV™ program.
3) The average daily truck traffic (ADTT) value was altered until either the total flexural stress fatigue or erosion damage was predicted to be 100%.
4) For each axle load category which contributed toward the controlling damage mode, the expected repetitions were converted to CESALs using AASHTO axle load equivalency factors (ALEF) for rigid pavements, with a terminal serviceability of 2.5 (Ref. 3, Table D.14).
5) Calculated CESALs were combined from both single and tandem axles to find the predicted CESALs to terminal serviceability.

The PCAPAV™ program does not accommodate a traffic growth input. Therefore the design versus predicted CESAL analysis was carried out assuming a zero traffic growth rate for all test cells. Design CESAL values were compensated accordingly during comparisons.

Test Cell Service Life Prediction Summary

Due to the uncertainty in predicting future traffic levels and growth, the original traffic growth rate of 2.5% (compounded annually) was used to forecast the service lives given by each design method in this study. Recent data indicates the mainline test cells received approximately 2.2 million CESALs from August 1994 to November 1996. Therefore, the first year assumption of 1,000,000 CESALs was a good estimate. Table 8 shows the predicted service life for each test cell based on as-built data applied to the three design methods.

SUMMARY AND DISCUSSION

Empirical design methods have served pavement engineers very effectively over the past several decades. However, with significant increases in traffic loads and volumes on the interstate highway system recently, a review of the results of applying those methods seemed timely. The Minnesota Department of Transportation constructed the Mn/ROAD project to evaluate several pavement sections designed using current pavement design methods.

This study examined the results from the application of Mn/ROAD design and as-built pavement design parameters to three common concrete pavement design methods. The differences between the design and as-built parameters were also highlighted during the analysis process.

The following observations were made with regard to as-built parameter values:

1) As-built 28 day concrete modulus of rupture values were generally lower than assumed in design.
2) As-built modulus of subgrade reaction values were very close to design assumptions for the Mn/DOT method, but were about 40% lower than design for the 1993 AASHTO method (different methods were used to calculate each).
3) Generally, as-built pavement thicknesses were over 2% higher than design.
4) Initial serviceability factors were much lower than expected for new concrete pavement construction. The presence of load response instrumentation most likely had detrimental effects on the slip-form paving operation.

The predicted test cell life (to terminal serviceability) varied widely depending on the design life, pavement design method, and reliability level. The following observations were made:

1) As-built information applied to the Mn/DOT design method resulted in test cell life predictions ranging from 2.4 to 5.8 years for the 5 year design cells, and from 12.0 to 13.1 years for the 10 year design cells.
2) For a reliability level of 95%, as-built information applied to the 1993 AASHTO design method resulted in test cell life predictions ranging from 0.8 to 2.3 years for the 5 year design cells, and from 3 to 5.3 years for the 10 year design cells. For a reliability level of 50%, test cell life predictions were somewhat closer to design values, but still varied widely.
3) With the exceptions of test cells 6 and 8, the 1984 PCA design method predicted pavement fatigue stress and erosion damage to be less than 15% for the original design lives of the mainline test cells. The procedure outlined in this study for converting PCA method fatigue and erosion results to AASHTO CESALs demonstrated unsuitability. The need exists for a reliable procedure which would correlate fatigue and erosion damage to AASHTO serviceability criteria (ride quality).

The focus of this study was to examine, through comparison of current concrete pavement design procedures, the effects current materials and construction practices have on predicted pavement service life. While many as-built input parameters could be measured or calculated, several others were not addressed. Two such parameters are the load transfer coefficient (J-factor) and the drainage coefficient. Future research will focus on determination of suitable values for these and other factors related to concrete pavement behavior.

The significantly different test cell life predictions that were found in this study demonstrate the disagreement on how to best predict concrete pavement life. It also highlights the limitations caused by the assumptions for each method, and the extent to which the original AASHO Road Test results have been extrapolated beyond their intended application. The results clearly justify the need for a more rational design method, taking into account modern day traffic loads, materials, and construction practices.

With the age of Mn/ROAD test cells currently at 2.5 years, and CESAL applications at approximately 2.2 million, there is very little visual evidence of surface distress or measurable deterioration of ride quality since construction was complete. Results from this study therefore indicate some discrepancies between field performance and the empirical design methods currently being applied.

The predictions found in this study will be monitored as the Mn/ROAD test cells continue to age. Validation of the predictions presented here will occur as the test cells reach terminal serviceability.

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Figure 1. Mn/ROAD 5-Year Mainline Concrete Test Sections

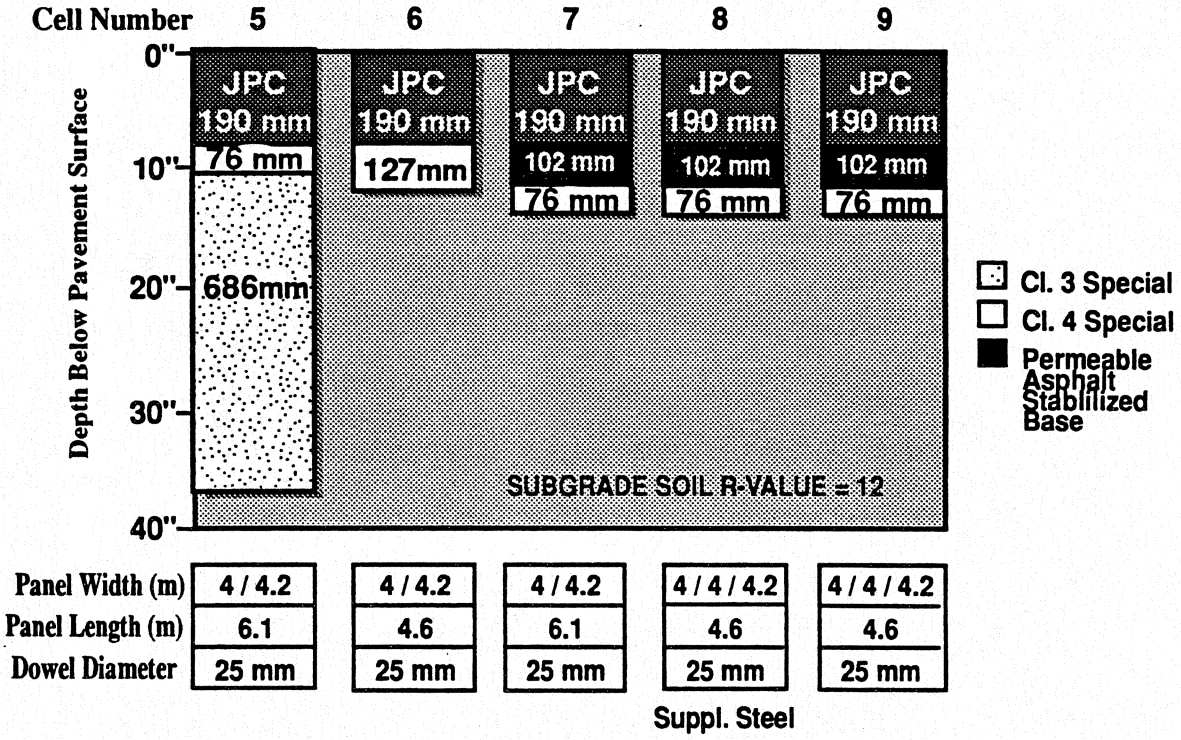


Figure 2. Mn/ROAD 10-Year Mainline Concrete Test Sections

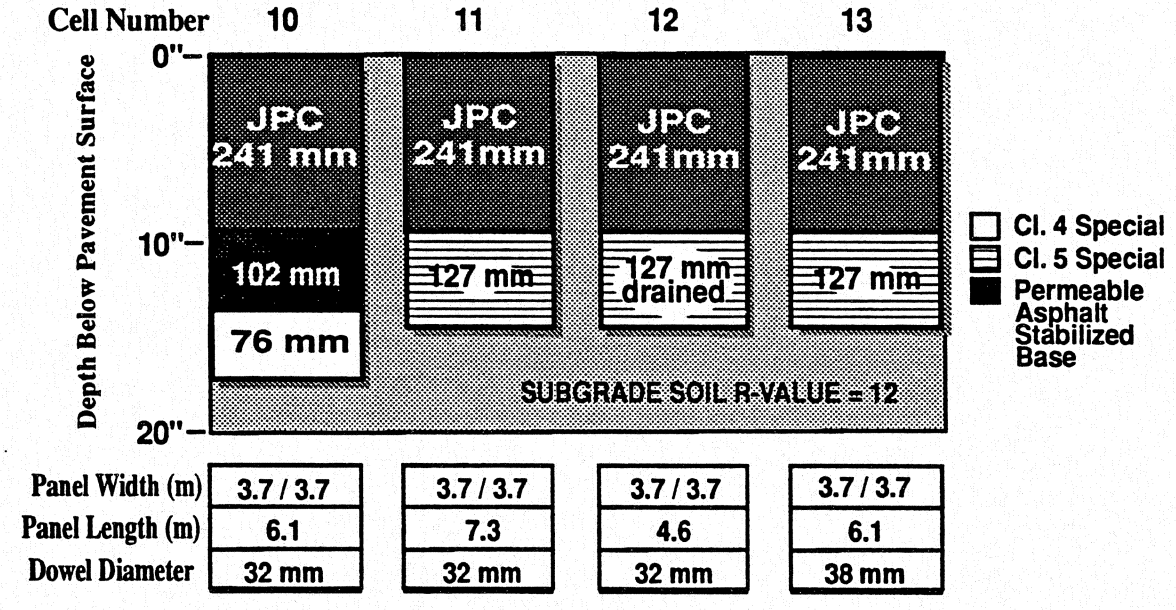


TABLE 1 Mn/ROAD Original Design Parameters for Mn/DOT Concrete Pavement Design Method

Test Cell #	Mod. of Subgrade Reaction (kPa/cm)	Load Transfer Coefficient (assumed)	Pavement Thickness[a] (mm)
5	1420	2.6	178
6	720	2.6	193
7	795	2.6	190
8	795	2.6	190
9	795	2.6	190
10	795	3.2	246
11	720	3.2	246
12	720	3.2	246
13	720	3.2	246

[a] Determined using Mn/DOT's PAVE computer program[7].

TABLE 2 Mn/ROAD As-built Design Parameters for Mn/DOT Concrete Pavement Design Method

Test Cell #	Concrete Mod. of Rupture[b,c] (MPa)	Concrete Mod. of Elasticity[b] (MPa)	Mod. of Subgrade Reaction (kPa/cm)	Average Pavement Thickness[b] (mm)
5	3.241	25560	1425	189
6	2.929	31325	780	187
7	2.981	27065	950	199
8	2.643	31205	915	194
9	2.929	29450	930	198
10	3.267	21435	950	253
11	3.733	26075	885	244
12	3.447	28455	830	253
13	3.526	27325	830	250

[b] From reference 11. [c] Reduced by safety factor = 1.33.

TABLE 3 Mn/ROAD Original Design Parameters for 1986 AASHTO Concrete Pavement Design Method

Test Cell #	Mod. of Subgrade Reaction (kPa/cm)	Drainage Coefficient (assumed)	Pavement Thickness[d] (mm)
5	2295	1.00	180
6	1368	1.00	196
7	1401	1.15	178
8	1401	1.15	178
9	1401	1.15	178
10	1453	1.15	234
11	1412	1.00	254
12	1412	1.05	246
13	1412	1.00	254

[d] Determined using DNPS86/PC™ computer program[8].

Unit Conversions:
MPa=145psi
kPa/cm=0.369pci
mm=0.0394in

TABLE 4 Mn/ROAD As-built Design Parameters for the 1993 Concrete Pavement Design Method

Test Cell #	Modulus of Subgrade Reaction (kPa/cm)	Initial Serviceability Factor
5	490	3.5
6	450	3.6
7	475	3.8
8	500	3.2
9	500	3.6
10	530	3.5
11	515	3.3
12	530	3.5
13	515	3.7

TABLE 5 Mn/ROAD As-built Design Parameters for the 1984 PCA Concrete Pavement Design Method

Test Cell #	Concrete Shoulder Considered	Joint Type
5	Y	Doweled
6	Y	Doweled
7	Y	Doweled
8	Y	Doweled
9	Y	Doweled
10	N	Doweled
11	N	Doweled
12	N	Doweled
13	N	Doweled

TABLE 6 Mn/ROAD Typical Axle Load and Count Breakdown

Axle Group Weight Range (kN)	Axle Group Count[a]	
	Single Axles	Tandem Axles
214-231		13
196-214		58
178-196		387
160-178		2194
142-160		10162
125-142	8	12114
107-125	52	7517
89-107	708	7607
71-89	4649	8504
53-71	6947	9150
36-53	42185	10922
18-36	15484	4342
0-18	12437	647

[a] Mn/ROAD (I-94) right lane WIM data for month of October 1994.

Unit Conversions:
kPa/cm=0.369pci
kN=0.225kips

TABLE 7 Predicted CESALs to Terminal Serviceability for Mn/ROAD Mainline Concrete Test Cells [a]

Test Cell #	Original Design Volumes	Using As-built Design Parameters			
			1993 AASHTO		
		Mn/DOT	95% Reliability	50% Reliability	PCA
5	5,262,400	6,190,000	1,220,675	5,348,515	2,921,600
6	5,262,400	2,630,000	777,475	3,406,585	637,200
7	5,262,400	4,540,000	2,352,225	10,306,500	2,159,720
8	5,262,400	2,450,000	755,810	3,311,655	514,560
9	5,262,400	4,030,000	1,788,960	7,838,505	1,614,820
10	11,225,270	13,800,000	5,557,275	24,349,755	223,528,890
11	11,225,270	15,260,000	3,138,195	13,750,310	137,017,270
12	11,225,270	13,840,000	4,468,495	19,579,140	220,579,580
13	11,225,270	13,970,000	4,445,615	19,478,900	182,106,130

[a] Terminal serviceability value = 2.5.

TABLE 8 Service Life Predicted for Mn/ROAD Concrete Test Cells Based on 2.5% Traffic Growth [a]

Test Cell Number	Test Cell Life Predicted (years) [b]			
		1993 AASHTO Method		
	Mn/DOT Method	95% Reliability	50% Reliability	1984 PCA Method
5	5.8	1.2	5.1	2.9
6	2.6	0.8	3.3	0.7
7	4.4	2.3	9.3	2.2
8	2.4	0.8	3.2	0.6
9	3.9	1.8	7.2	1.6
10	12.0	5.3	19.2	76.4
11	13.1	3.0	12.0	60.2
12	12.0	4.3	16.1	75.9
13	12.1	4.2	16.1	69.4

[a] Initial year CESALs estimated at 1,000,000.
[b] Based on as-built data gathered as of December 1996.

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