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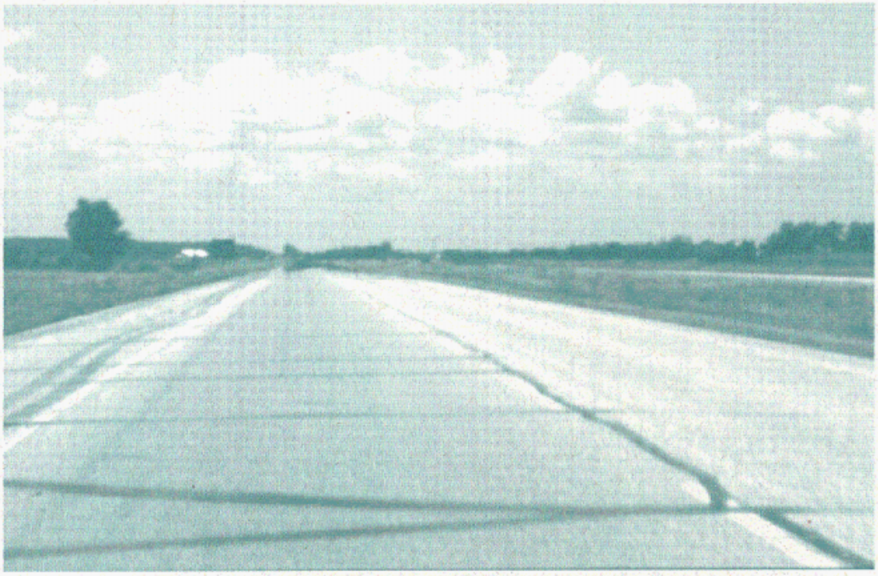

Performance of a Thirty-Two Year Old Concrete Pavement

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Final Report

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16. Abstract (Limit: 200 words)

This report reviews pavement performance testing results on an experimental concrete pavement built on Minnesota T.H. 36 in 1958 that contains variations in joint spacing, reinforcement, dowels, and transverse joint fillers. South Dakota Profile Serviceability Rating (PSR), Minnesota Structural Rating (SR), and Concrete Pavement Evaluation System (COPES) surveys conducted in 1990 revealed that the best performing sections were the 15 foot (4.6 m) and the 20 foot (6.1 m) sections with bituminous coated or rust inhibitor painted dowels. The longer sections, 33 foot (10 m) and 65 foot (20 m), and the panels with sleeved dowels performed poorly. All transverse joint fillers, which included "Presstite 77" and rubber asphalt Minnesota Spec. 3723, failed within three years.

Researchers previously studied the sections from 1959-1969, and this report references several memos and letters on the pavement's performance. The four basic pavement sections include: 15 foot (4.6 m) and 20 foot (6.1 m) unreinforced sections with one undoweled and three different dowel segments, and the 33 foot (10 m) and 65 foot (20 m) reinforced sections with three types of mesh and three different doweled segments.

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Executive Summary

A pavement evaluation study was performed on a thirty-two year old concrete pavement on Minnesota T.H. 36 to evaluate panel length, dowel types, reinforcement, and transverse joint fillers.

The panel lengths consist of 15 foot (4.6 m) and 20 foot (6.1 m) unreinforced, and 33 foot (10 m) and 65 foot (20 m) reinforced concrete pavement. The dowel sections include painted, sleeved, bituminous coated, and undoweled panels.

The conclusions from the 1990 survey and the previous evaluations of the pavement include the following:

* The 15 foot (4.6 m) and 20 foot (6.1 m) panels performed significantly better than the 33 foot (10 m) and 65 foot (20 m) panels.

* The bituminous and rust inhibitor painted dowels performed well, while the sleeved dowels performed poorly.

* Joint opening increases with panel length, and was widest for the sleeved dowels.

* All transverse joint fillers failed within three years.

1.0 Introduction

Experimental concrete pavement sections containing variations in joint spacing, reinforcement, transverse joint fillers, and dowel assemblies were placed on T.H. 36 in 1957 and 1958. The purpose of that study was to determine:

* the width of joint openings as a function of panel length and dowel type,
* joint seal effectiveness,
* and the effect of variable panel length and reinforcement on the formation of transverse cracks.

The results of this study should be approached with some discretion, as the load transfer systems were placed adjacent to each other, and this may have affected the adjacent panel performance; the doweled sections had joints that alternated between bituminous coated, rust inhibitor painted, and sleeved dowels. Appendix A gives a listing, by location, of the panels with their characteristic length, dowel type, and reinforcement.

No formal report was published from the earlier investigations. However, data from memos and letters outlining earlier results are included in this report. The original panel lengths were 15 feet (4.6 m), 20 feet (6.1 m), 33 feet 4 inch (10 m), and 65 feet 4 inch (20 m). The roadway under went concrete rehabilitation in 1983. The 33 foot (10 m) and 65 foot (20 m) panels were sawed into panels of approximately 11 feet (3.4 m) and 13 feet (4.0 m) respectively. Now the 65 foot (20 m) sections have five segments and the 33 foot (10 m) sections have three segments.

Three different pavement surveys were performed on the sections: a COPES study, a PSR, and an SR. The PSR and SR were then used to calculate a Pavement Quality Index (PQI).

2.0 Background

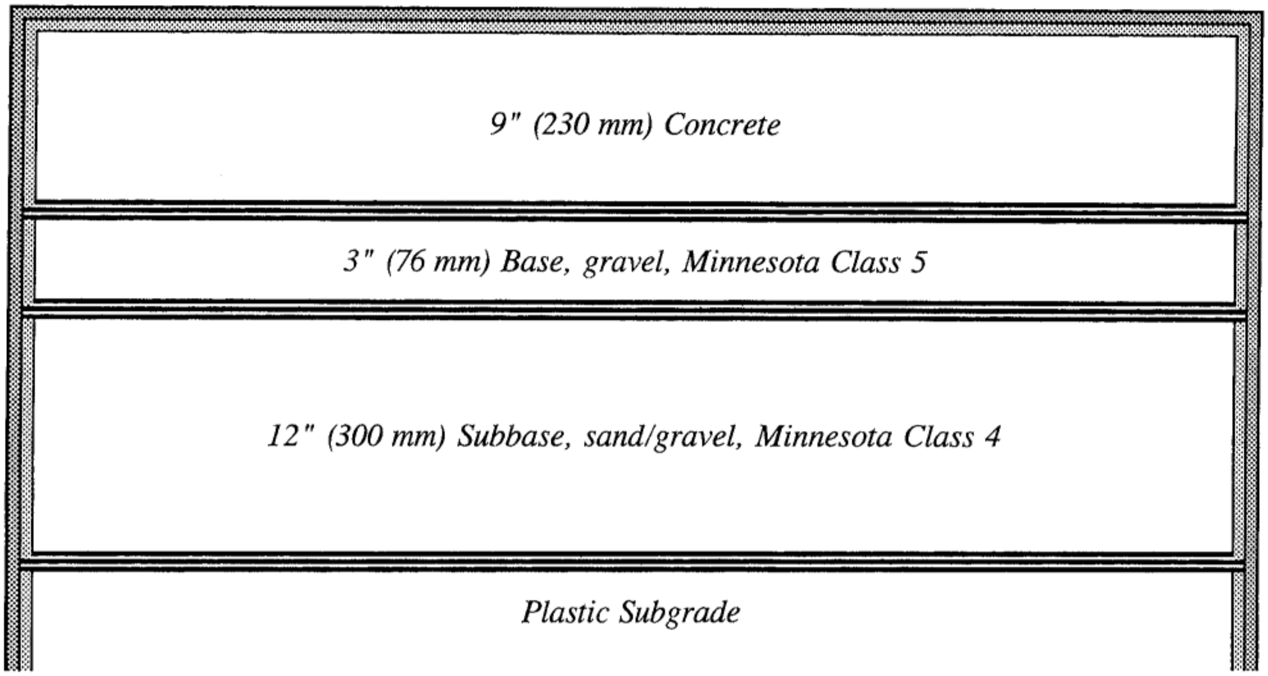
2.1 Typical Sections

Two different bases were used. In the W.B. section STA. 71+00 to 91+37, the subbase was 12 inches (300 mm) of sand-gravel (Minnesota Class 4), with 3 inches (76 mm) of gravel base (Minnesota Class 5). It has a plastic soil subgrade.

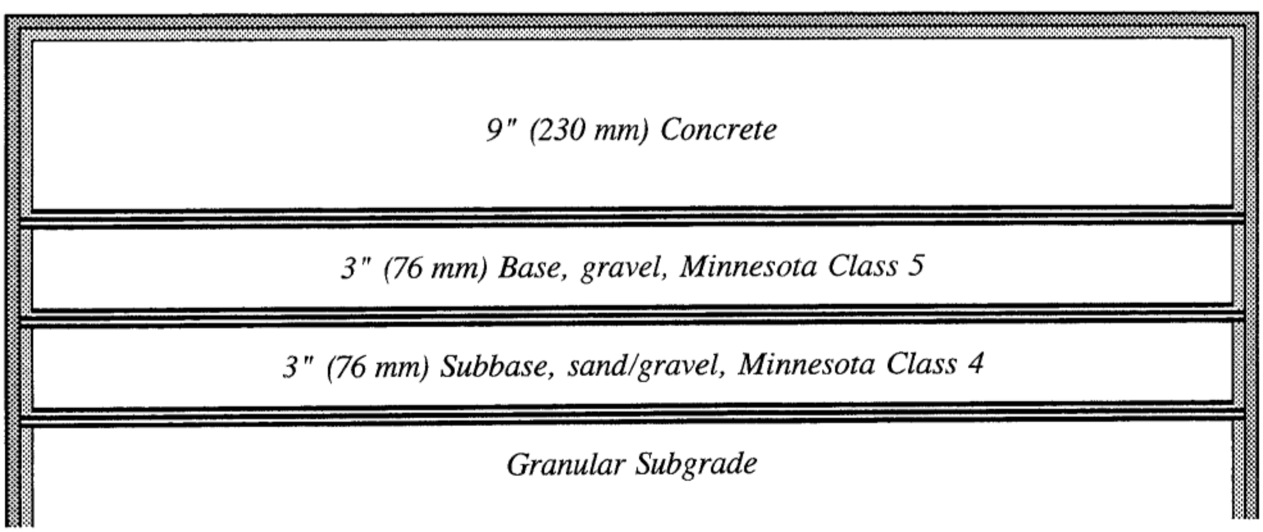
In the W.B. & E.B. sections STA. 182+50 to 202+80, the subbase was 3 inches (76 mm) of sand-gravel (Class 4), with a 3 inch (75 mm) gravel base (Class 5). They have granular soil subgrades.

All sections have a concrete pavement depth of 9 inches (230 mm). Typical sections are shown in Figure 1. The gradations of the Class 4 and 5 aggregates are located in Appendix B.

Figure 1 - Typical Sections



W.B. Station 71+00 - 91+37



E.B. & W.B. Station 182+50 - 202+80

2.2 Traffic

Table 1 gives both the total cumulative ESAL's (Equivalent Single Axel Loads) for 1958-1990, and the 1990 yearly ESAL's for each test section. The ESAL's were calculated for the design lane and one direction of traffic. Yearly ESAL's for each section are approximately 220,000, while accumulative ESAL's are approximately 4 million.

Table 1 - Total and Cumulative ESAL's

Location	**Cumulative ESAL's (1958-1990)**	**Yearly ESAL's (1990)**
W.B. STA. 71-91	3,900,000	220,000
W.B. & E.B. STA. 182-202	4,100,000	220,000

2.3 Steel in JRCP Sections

The percent steel per area of concrete for the sections was 0.10%, 0.15%, and 0.18% for the 612-55, 612-24, and 612-06 steel fabric respectively. The mesh was made of smooth steel fabric. The 33' (10 m) sections had 10 or 15% steel, and the 65' (20 m) sections had 15 or 18% steel.

3.0 Data

3.1 Former Data

3.11 1962

Memo from K.V. Benthin (Concrete Eng.) to C.K. Preus (Materials and Research Eng.) 3/5/62.

Joint filler material used was rubber asphalt type meeting M.H.D. Specification 3723 (1947). "Presstite 77" was used in some joints, which were subsequently resealed with rubber asphalt.

3.12 1964

Memo from P.A. Jensen (Research Eng.) to C.K. Preus (Materials & Research Eng.) 1/30/64

The sleeved dowel assembly allowed relatively unimpeded movement, whereas the bituminous coated and rust inhibitor painted dowels caused some restraint and therefore a substantial decrease in movement. Table 2 shows the joint openings for various dowel sizes, dowel types, and panel lengths. The longer panels had wider joint openings. The sleeved dowels had wider openings than the bituminous coated, rust inhibitor painted, and non-doweled sections.

Table 2 - Average Joint Opening for Various Panel Lengths and Dowel Types at 40⁰ F.

Panel Length	Dowel Diameter	Dowel Type	Opening Width
65' (20 m)	1.25" (32 mm)	Sleeved	0.33" (8.4 mm)
65' (20 m)	1.25" (32 mm)	Bituminous	0.19" (4.8 mm)
65' (20 m)	1.25" (32 mm)	Painted	0.23" (5.8 mm)
49' (15 m)	1.25" (32 mm)	Sleeved	0.23" (5.8 mm)
49' (15 m)	1.25" (32 mm)	Bituminous	0.14" (3.6 mm)
49' (15 m)	1.25" (32 mm)	Painted	0.13" (3.3 mm)
49' (15 m)	1" (25 mm)	Sleeved	0.19" (4.8 mm)
49' (15 m)	1" (25 mm)	Bituminous	0.14" (3.6 mm)
49' (15 m)	1" (25 mm)	Painted	0.14" (3.6 mm)
33' (10 m)	1.25" (32 mm)	Sleeved	0.18" (4.6 mm)
33' (10 m)	1.25" (32 mm)	Bituminous	0.09" (2.3 mm)
33' (10 m)	1.25" (32 mm)	Painted	0.11" (2.8 mm)
33' (10 m)	1" (25 mm)	Sleeved	0.20" (5.1 mm)
33' (10 m)	1" (25 mm)	Bituminous	0.10" (2.5 mm)
33' (10 m)	1" (25 mm)	Painted	0.09" (2.3 mm)
20' (6.1 m)	1.25" (32 mm)	Sleeved	0.09" (2.3 mm)
20' (6.1 m)	1.25" (32 mm)	Bituminous	0.06" (1.5 mm)
20' (6.1 m)	1.25" (32 mm)	Painted	0.07" (1.8 mm)
20' (6.1 m)	1" (25 mm)	Sleeved	0.10" (2.5 mm)
20' (6.1 m)	1" (25 mm)	Bituminous	0.08" (2.0 mm)
20' (6.1 m)	1" (25 mm)	Painted	0.05" (1.3 mm)
20' (6.1 m)	NONE	NONE	0.08" (2.0 mm)
15' (4.6 m)	1.25" (32 mm)	Sleeved	0.13" (3.3 mm)
15' (4.6 m)	1.25" (32 mm)	Bituminous	0.03" (0.8 mm)
15' (4.6 m)	1.25" (32 mm)	Painted	0.04" (1.0 mm)
15' (4.6 m)	1" (25 mm)	Sleeved	0.09" (2.3 mm)
15' (4.6 m)	1" (25 mm)	Bituminous	0.04" (1.0 mm)
15' (4.6 m)	1" (25 mm)	Painted	0.05" (1.3 mm)
15' (4.6 m)	None	NONE	0.08" (2.0 mm)

As shown in Table 3, no cracks were found in the 15 foot (4.6 m) and 20 foot (6.1 m) panels. The 33 foot (10 m) panels were reinforced with two different steel mesh styles. The panels with 0.15% steel mesh were adequately reinforced since only 9% of the panels had cracks, while those with 0.10% mesh allowed cracking of 25% of the 33 foot (10 m) panels. The 49 foot (15 m) and 65 foot (20 m) panels containing 0.15% steel mesh had cracking at rates of 57% and 65% respectively. The 65 foot (20 m) panels with 0.18% steel mesh, had crack occurrences of 47%. There was no obvious faulting on this roadway, and the highway rode smoothly throughout its length.

Table 3 - 1963 Panel Cracking Survey T.H. 36

Section	% of Panels Cracked
15' (4.6 m)	0
20' (6.1 m)	0
33' (10 m) (0.10% Steel)	25
33' (10 m) (0.15% Steel)	9
49' (15 m) (0.15% Steel)	57
65' (20 m) (0.15% Steel)	65
65' (20 m) (0.18% Steel)	47

All the joint sealants had failed by February 1961. Maintenance was advised to reseal the joints as necessary. This completed the sealant portion of the research.

3.13 1968

Memo from E.C. Carsberg (Concrete Engineer) to F.C. Fredrickson (Materials Engineer) 8/20/68

The Experimental sections of the project were surveyed in 1968 to determine the extent of joint spalling, panel cracking, and joint faulting. A portion of the 1958 standard 49 foot (15 m) paving section was also surveyed. None of the doweled joints showed any appreciable faulting. The undoweled 15' (4.6 m) panels had 2.4% and the undoweled 20' (6.1 m) panels had 10.8% of their joints faulted at least 0.1 inch (2.5 mm).

The crack survey showed an increase in transverse cracking with an increase in panel length. The cracking increased sharply in panels longer than 20 feet (6.1 m). In this survey, cracks open one eighth inch (3 mm) or more were considered to have mesh failure. The 15 foot (4.6 m) and 20 foot (6.1 m) panels (non-reinforced) had 3.5 (2.2) and 2.6 (1.6) cracks per mile (km) respectively. The 33 foot (10 m), 49 foot (15 m), and 65 foot (20 m) panels had 21 (13), 28 (17), and 23 (14) cracks per mile (km) respectively. The "standard" paving section, 49 foot (15 m) with 0.15% steel mesh, had a total of 19 (12) cracks and 5.8 (3.6) mesh failures per mile (km). The standard paving section also showed diagonal and transverse cracking (See Table 4).

Table 4 - 1968 Panel Cracking Survey T.H. 36

Section	Transverse Cracks/Mile (km)	Mesh Failures/Mile (km)
15' (4.6 m)	3.5 (2.2)	---
20' (6.1 m)	2.6 (1.6)	---
33' (10 m)	21 (13)	2.7 (1.7)
49' (15 m)	28 (17)	3.7 (2.3)
65' (20 m)	23 (14)	1.4 (0.9)
Standard 49' (15 m) Mesh Reinforced	19 (12)	5.8 (3.6)

The joint spalling survey indicated an increase in spalling with an increase in panel length. Only 24 (15)/mile (km) of the 15 foot (4.6 m) panels and 12 (7.5)/mile (km) of the 20 foot (6.1 m) panels had joint spalling of 0.1 ft^2 (0.01 m^2), and none as high as 1.0 ft^2 (0.1 m^2) of spall area. The spalling increased to 36 (22), 41 (25), and 59 (37)/mile (km) of the joints spalled 0.1 ft^2 (0.01 m^2) or more for the 33 foot (10 m), 49 foot (15 m), and 65 foot (20 m) panels respectively, and many joints had a spalled area greater than 0.1 ft^2 (0.01 m^2). A survey of the "standard" paving section, 49 foot (15 m), showed that 26 (16) joints/mile (km) were spalled 0.1 ft^2 (0.01 m^2) or more (See Table 5).

Table 5 - 1968 Joint Spalling T.H. 36

	Joints Spalled/Mile (km) - ft^2/Joint (m^2/joint)				
Section	**0.1 (0.01)**	**1.0 (0.1)**	**2.0 (0.2)**	**3.0 (0.3)**	**4.0 (0.4)**
15' (4.6 m)	24 (15)	0	0	0	0
20' (6.1 m)	12 (7.5)	0	0	0	0
33' (10 m)	36 (22)	26 (16)	15 (9.3)	15 (9.3)	5.1 (3.2)
49' (15 m)	41 (25)	33 (21)	17 (11)	8.3 (5.2)	0
65' (20 m)	59 (37)	51 (32)	37 (23)	32 (20)	32 (20)
Standard 49' (15 m) Mesh Reinforced	26 (16)	17.6 (11)	9.1 (5.7)	5.8 (3.6)	4.1 (2.5)

3.14 1969

Memo from E.C. Carsberg (Concrete Engineer) to F.C. Fredrickson (Materials Engineer) 3/12/69

In January of 1969, cores were taken from 14 joints. The cores were taken directly through the contraction joints at the dowel bar locations about 6 inches (150 mm) from the north edge of the pavement on the W.B. roadway.

Six cores were taken from successive contraction joints in the 33 foot (10 m) and 65 foot (20 m) panels. Two cores were from each of the three types: dowels covered with metal sleeves, dowels painted with rust inhibitor, and dowels coated with bituminous. In addition, two cores were taken from joints in the 49 foot (15 m) standard panel design where the dowels were coated with both the paint and the bituminous material. Examination of the dowels by groups indicates that the dowels coated with rust inhibitor paint or with bituminous material had about the same degree of corrosion. The dowels coated with both the rust inhibitor paint and the bituminous material had less rust than those coated with only one material. Three of the four dowels covered with metal sleeves had no trace of rust. The forth dowel that was removed with a sleeve was rusted quite extensively on the bottom portion of the dowel, but there was no rust on the top. Apparently, water was able to seep in between the sleeve and caused the rusting on the bottom portion of the dowel.

3.2 1990 Data

Three pavement evaluations were performed on the test sections. They were a Structural Rating (SR), a Profile Surface Rating (PSR), and a COPES evaluation. Background information on these tests is located in Appendix C.

3.21 Structural Rating

Minnesota's Structural Ratings range from zero to four, with a grade of four being the best rating.

The PQI (Pavement Quality Index) is used by Mn/DOT to assess pavements for rehabilitation. It is calculated by using the following formula:

$$PQI = (SR \times PSR)^{1/2}$$

The following values are then used to evaluate the pavements:

PQI	**Status**
2.7	Programmed for Rehabilitation
2.5	Terminal Surface

The 15 foot (4.6 m) and 20 foot (6.1 m) sections had the highest Structural Ratings. The 15 foot

(4.6 m) non-doweled section had an SR of 4.0, while the other three, the 15 foot (4.6 m) doweled, 20 foot (6.1 m) doweled, and 20 foot (6.1 m) undoweled had an SR of 3.6. The Structural Ratings for the 33 feet (10 m) and 65 feet (20 m) sections were lower. The 33 foot (10 m) (0.10% steel), 33 foot (10 m) (0.15% steel), 65 foot (20 m) (0.15% steel), and 65 foot (20 m) (0.18% steel) had ratings of 3.3, 3.4, 3.5, and 3.4 respectively. The highest rated location was E.B. STA. 182-202, and the lowest rated was W.B. STA 71-91. Appendices D-1 through D-3 give a summary of the SR defects in each of the three roadway sections. Appendix D-4 summarizes these defects from the three sections.

The most common defects in the sections were slightly and severely spalled joints and cracked panels. Except for the 15 foot (4.6 m) non-doweled, all sections had spalled joints. Three sections had three, three had five, and one section had six spalled joints. One should note that the SR surveys do not count spalling of joints that were earlier repaired and are now in good condition. The percentage of cracked panels was quite high in the 33 foot (10 m) and 65 foot (20 m) sections, and the percentage of cracks seemed to be dependent on the type of steel in the sections. The 33 foot (10 m) and 65 foot (20 m) panels with 0.15% steel mesh had 7% and 33% cracked panels respectively. While the 33 foot (10 m) panels with 0.10% steel mesh and the 65 foot (20 m) panels with 0.18% mesh had 40% and 58% cracked panels.

The average SR for the entire test section was 3.5. The high was 3.7 for E.B. STA. 182-202, and the low was 3.3 for W.B. STA. 71-91, the section with the plastic subgrade. Table 6 shows the Structural Ratings for each panel length and roadway section.

Table 6 - 1990 Structural Rating T.H. 36

Section	W.B. STA 71 - 91 (Plastic Subgrade)	W.B. STA. 182 - 202 (Granular Subgrade)	E.B. STA. 182-202 (Granular Subgrade)	Average
15' (4.6 m) No Dowels	4.0	4.0	4.0	4.0
15' (4.6 m) Doweled	3.7	3.5	3.7	3.6
20' (6.1 m) No Dowels	3.3	3.7	3.7	3.6
20' (6.1 m) Doweled	3.7	3.4	3.8	3.6
33' (10 m) (0.10% Steel)	3.0	3.2	3.6	3.3
33' (10 m) (0.15% Steel)	3.4	3.3	3.4	3.4
65' (20 m) (0.15% Steel)	2.8	3.5	3.7	3.5
65' (20 m) (0.18% Steel)	2.6	3.2	3.7	3.4
Average	**3.3**	**3.5**	**3.7**	**3.5**

3.22 PSR

The results from the South Dakota Profiler test were quite similar to the SR test except for two instances. The 15 foot (4.6 m) non-doweled section, which had the highest SR of 4.0 had the lowest PSR of 2.8. Also, the 33 foot (10 m) (0.15% steel), which had a low SR of 3.4, had the highest profile reading of 3.1. Appendix E shows the raw data, the IRA vs. the PSR for the sections. Table 7 summarizes the PSR data for each section.

One curious result was that the section with highest SR, E.B. STA. 182-202, had the lowest PSR rating.

Table 7 - 1990 PSR Rating Survey T.H. 36

Section	W.B. STA 71 - 91 (Plastic Subgrade)	W.B. STA. 182 - 202 (Granular Subgrade)	E.B. STA. 182-202 (Granular Subgrade)	Average
15' (4.6 m) No Dowels	3.1	2.9	2.3	2.8
15' (4.6 m) Doweled	3.0	3.2	2.9	3.0
20' (6.1 m) No Dowels	3.2	3.0	2.6	2.9
20' (6.1 m) Doweled	3.3	3.1	3.0	3.1
33' (10 m) (0.10% Steel)	2.7	3.3	2.8	2.9
33' (10 m) (0.15% Steel)	3.2	3.0	3.0	3.1
65' (20 m) (0.15% Steel)	3.0	2.8	2.8	2.9
65' (20 m) (0.18% Steel)	3.3	2.8	2.4	2.8
Average	**3.1**	**3.0**	**2.7**	**2.9**

3.23 Pavement Quality Index

The PQI Ratings show that the best pavements are the 15 foot (4.6 m) and 20 foot (6.1 m) sections. Their ratings ranged from 3.2 to 3.4. The best section was the 20 foot (6.1 m) doweled section. The 33 foot (10 m) and 65 foot (20 m) sections had ratings of 3.0 to 3.2. Again, the better performing sections were those with 0.15% steel per area of concrete. Table 8 shows the PQI ratings for each section.

Table 8 - 1990 PQI Rating T.H. 36

Section	W.B. STA 71 - 91 (Plastic Subgrade)	W.B. STA. 182 - 202 (Granular Subgrade)	E.B. STA. 182-202 (Granular Subgrade)	Average
15' (4.6 m) No Dowels	3.5	3.4	3.0	3.3
15' (4.6 m) Doweled	3.3	3.3	3.3	3.3
20' (6.1 m) No Dowels	3.2	3.3	3.1	3.2
20' (6.1 m) Doweled	3.5	3.2	3.4	3.4
33' (10 m) (0.10% Steel)	2.8	3.2	3.2	3.1
33' (10 m) (0.15% Steel)	3.3	3.1	3.2	3.2
65' (20 m) (0.15% Steel)	2.9	3.1	3.2	3.1
65' (20 m) (0.18% Steel)	2.9	3.0	3.0	3.0
Average	**3.2**	**3.2**	**3.2**	**3.2**

3.24 COPES Rating

Appendix F is a summary of the COPES distresses for the sections. There were twelve different distresses in the sections. The most common defects were transverse cracking, partial depth repairs, and partial depth repairs that were spalled. There was good similarity between the COPES data and the PQI ratings, except for the 15 foot (4.6 m) doweled section which had a poor COPES rating and a high PQI rating, and the 65 foot (20 m) (0.15% steel) which had a good COPES rating and a poor PQI Rating. Table 9 summarizes the COPES and the PQI data.

Table 9 - 1990 Summary of COPES & PQI Ratings T.H. 36

Section	COPES - Total Distresses/Mile (km)	Structural Rating	PSR	PQI
15' (4.6 m) No Dowels	188 (117)	4.0	2.8	3.3
15' (4.6 m) Doweled	235 (146)	3.6	3.0	3.3
20' (6.1 m) No Dowels	106 (66)	3.6	2.9	3.2
20' (6.1 m) Doweled	205 (127)	3.6	3.1	3.4
33' (10 m) (0.10% Steel)	243 (151)	3.3	2.9	3.1
33' (10 m) (0.15% Steel)	211 (131)	3.4	3.1	3.2
65' (20 m) (0.15% Steel)	135 (84)	3.5	2.9	3.1
65' (20 m) (0.18% Steel)	216 (134)	3.4	2.8	3.0

3.25 Dowel Ratings

The final pavement evaluation was of each individual panel joint. The purpose was to examine each joint with regard to dowel type and panel length. Table 10 shows the distresses of the joints for panel lengths and types of dowels. The 15 foot (4.6 m) and 20 foot (6.1 m) panel lengths had all four dowel sections: bituminous coated, rust inhibitor painted, sleeved, and non-doweled. The best joints were those with bituminous or rust painted dowels. Summing the 15 foot (4.6 m) and 20 foot (6.1 m) sections, the percentage of joints with distresses were 18%, 11%, 59%, and 44% for the bituminous, painted, sleeved, and non-doweled sections respectively.

The 33 foot (10 m) and 65 foot (20 m) sections also indicated that the sleeved dowels performed the poorest. The 33' (10 m) and 65' (20 m) sections had 71%, 86%, and 100% distresses per joint for the bituminous, painted, and sleeved dowels respectively.

These tests are the best indication of pavement performance. This is the only test that separated out the particular doweled sections. It clearly shows that the 15 foot (4.6 m) and 20 foot (6.1 m) doweled sections performed the best. The COPES and PQI ratings of these sections would have been significantly higher, if one was able to separate out the sleeved dowel joints. The performance of the 33 foot (10 m) and 65 foot (20 m) sections was less dependent on dowel type.

Table 10 - 1990 T.H. 36 Summary of Dowel/Joint Distresses

Dowels	Panel Length	Station	Quantity	Full Depth Repairs	Partial Depth Repairs	Joint Spalling	Percent With Distresses
Bituminous	All	182-202	24	3	5	0	33
Painted	All	182-202	26	3	5	0	33
Sleeved	All	182-202	23	9	5	2	70
No Dowels	15' & 20'	All	90	1	26	13	44
Bituminous	15' (4.6 m)	182-202	8	0	1	0	13
Painted	15' (4.6 m)	182-202	9	0	0	0	0
Sleeved	15' (4.6 m)	182-202	8	0	3	1	50
No Dowels	15' (4.6 m)	All	45	0	17	5	49
Bituminous	20' (6.1 m)	182-202	9	0	2	0	22
Painted	20' (6.1 m)	182-202	10	0	2	0	20
Sleeved	20' (6.1 m)	182-202	9	3	2	1	67
No Dowels	20' (6.1 m)	All	45	1	9	8	40
Bituminous	33' (10 m)	182-202	4	0	2	0	50
Painted	33' (10 m)	182-202	3	0	2	0	67
Sleeved	33' (10 m)	182-202	3	3	0	0	100
Bituminous	65' (20 m)	182-202	3	3	0	0	100
Painted	65' (20 m)	182-202	4	3	1	0	100
Sleeved	65' (20 m)	182-202	3	3	0	0	100
Bituminous	33' & 65'	182-202	7	3	2	0	71
Painted	33' & 65'	182-202	7	3	3	0	86
Sleeved	33' & 65'	182-202	6	6	0	0	100
Bituminous	15' & 20'	182-202	17	0	3	0	18
Painted	15' & 20'	182-202	19	0	2	0	11
Sleeved	15' & 20'	182-202	17	3	5	2	59
No Dowels	15' & 20'	All	90	1	26	13	44

4.0 Summary and Results

4.1 Joint Openings

Average joint openings increased with panel length, and the joints with sleeved dowels had wider openings than the joints with bituminous, painted, or with no dowels.

4.2 Joint Filler

Within three years all transverse joint sealers had failed. These sealers included rubber asphalt M.H.D. spec. 3723, and "Presstite 77". Neither of these sealers is currently being used by Mn/DOT.

4.3 Dowel Assemblies

The dowel assemblies which performed the best were the bituminous coated and painted dowels. These dowels showed the least distresses per joint. The poor performance of the sleeved dowels may be explained by the failure of the joint fillers. Over time, water was able to penetrate into the sleeved dowels and rusted them out.

4.4 Panel Deterioration

The panels which performed the best were the 15 foot (4.6 m) and 20 foot (6.1 m) sections, and there was good correlation between the COPES ratings and the PQI ratings. The 15 foot (4.6 m) non-doweled section had the second highest PQI rating (3.3) and the third best COPES rating, 188 (117) distresses/mile (km). The 20 foot (6.1 m) non-doweled section had the best COPES rating, 106 (66) distresses/mile (km) and the fourth highest PQI rating (3.2). The 20 foot (6.1 m) doweled section had the highest PQI rating (3.4) and the fourth best COPES rating, 205 (127) distresses/mile (km). The reason the non-doweled sections appeared to have a better rating than the doweled section is because the poor performance of the sleeved dowels lowered the overall performance of the doweled sections; the PSR and SR data could not separate out the different dowel sections, and the Structural Ratings did not count previously repaired joints. If the sleeved dowels were not installed, the doweled sections would have performed significantly better. The good performance of the non-doweled section seems to be the result of a well-drained foundation.

5.0 Conclusions

The sections which performed the best were the 15 foot (4.6 m) and 20 foot (6.1 m) sections. They had the highest PQI ratings and the best COPES ratings. Among these shorter sections, it appears that the non-doweled panels performed better. But, if one examines Table 10 a different result is evident. It shows, that among the 15 foot (4.6 m) and 20 foot (6.1 m) panels, the best joints were those that had bituminous or painted dowels, with the sleeved dowels performing the worst. The non-doweled section performed the third best, better than the sleeved section.

Because the joints within the doweled section alternated between bituminous, painted, and sleeved, the COPES and PQI rating tests were not able to differentiate between them, this made these doweled sections appear to have a lower rating than the non-doweled sections. Since most deterioration on a well-paved concrete roadway occurs at the joints, the 15 foot (4.6 m) and 20 foot (6.1 m) sections with bituminous or painted dowels performed the best. There was little faulting in the undoweled areas, because of the well-drained foundation.

The 33 foot (10 m) and 65 foot (20 m) sections had lower PQI ratings and higher COPES distresses. Major joint repair was performed at almost every joint of the 33 foot (10 m) and 65 foot (20 m) sections; almost every joint had a full or partial depth repair. The different dowel sections had little effect on these joints; the controlling factor in these panels was their length. The best joint, the bituminous doweled joint, performed well only 29% of the time. The 33 foot (10 m) and 65 foot (20 m) sections had major repair to install intermediate joints in each panel. The 33-foot section now consists of three 11 foot (3.4 m) panels, while the 65 foot (20 m) section consists of five 13 foot (4.0 m) panels. The panels with 0.15% steel per area of concrete performed slightly better than the panels with 0.10% and 0.18% steel.

Three other findings to note in this study were: joint width increased with panel length, joint width was greatest with sleeved dowels, and the transverse joint fillers had failed within three years. This may account for some of the problems in the 33 foot (10 m) and 65 foot (20 m) sections and those sections with sleeved dowels.

Since joint spacing and dowel type can easily be controlled, joint spacing should be less than 33 feet (10 m), and sleeved dowels should not be used.

APPENDICES

Appendix A - Experimental Sections

Location	# of Panels	Reinforced	Fabric	Dowels	Panel Length	Abbreviation
W.B. STA. 71+00 To 91+37	15	No	No	No	20'-0" (6.1 m)	20ND
	15	No	No	No	15'-0" (4.6 m)	15ND
M.P. 0.51 to 0.90	5	Yes	612-24	Yes	33'-4" (10 m)	33HS
	5	Yes	612-55	Yes	33'-4" (10 m)	33LS
	15	No	No	Yes	15'-0" (4.6 m)	15D
	15	No	No	Yes	20'-0" (6.1 m)	20D
	2	Yes	612-24	Yes	65'-4" (20 m)	65LS
	2	Yes	612-06	Yes	65'-4" (20 m)	65HS
W.B. & E.B. STA. 182+50 To 202+80	15	No	No	No	20'-0" (6.1 m)	20ND
	15	No	No	No	15'-0" (4.6 m)	15ND
M.P. 2.57 To 2.96	5	Yes	612-24	Yes	65'-4" (20 m)	65LS
	5	Yes	612-06	Yes	65'-4" (20 m)	65HS
	5	Yes	612-24	Yes	33'-4" (10 m)	33HS
	5	Yes	612-55	Yes	33'-4" (10 m)	33LS
	15	No	No	Yes	15'-0" (4.6 m)	15D
	15	No	No	Yes	20'-0" (6.1 m)	20D

Percent Steel Area/Area of Concrete	Fabric
0.10%	612-55 Steel Fabric (37 lbs./100 ft^2, 1.8 kg/m^2)
0.15%	612-24 Steel Fabric (54 lbs./100 ft^2, 2.6 kg/m^2)
0.18%	612-06 Steel Fabric (65 lbs./100 ft^2, 3.2 kg/m^2)

The mesh specifications were AASHO M55-57 and M32-42. The minimum tensile strength was 70,000 psi (480 Mpa) with a yield point of 56,000 psi (390 Mpa).

W.B. STA. 71 + 00 to 91 + 37 is located near Fairview Avenue.
W.B. & E.B. STA. 182 + 50 to 202 + 80 are located near Victoria Avenue.

Appendix B - Gradations for In Place Class 4 and Class 5 Aggregates

Percent Passing	Class 4 - Gravel/Sand Subbase	Class 5 - Gravel or Stabilized Gravel Base
3", 76 mm	100	---
1", 25 mm	---	100
3/4", 19 mm	---	90-100
3/8", 9.5 mm	---	65-95
#4, 6.4 mm	55-100	50-80
#10, 2.5 mm	35-100	35-70
#40, 0.64 mm	5-50	10-35
#200, 0.13 mm	0-10*	3-10*
Plasticity Index	0-6	0-6
Liquid Limit	Maximum 25	Maximum 25

* The fraction passing the #200 (0.13 mm) sieve shall not be more than 40% of the fraction passing the #40 (0.64 mm) sieve.

Appendix C - Pavement Rating Criteria

A) Structural Rating (SR) from Mn/DOT Structural Rating Manual

This survey was performed by evaluators from a vehicle moving slowing along the shoulder of the roadway. Each rater was responsible for observing several types of pavement deficiencies. No physical measurements were performed on the roadway. All evaluations were performed from the inside of a van.

Usually only a representative segment of a longer area is rated, but for the purpose of this study the entire test section was rated.

Below is a list of the concrete defects that were measured.

1) a) Slightly Spalled Joints: The total number of joints which are spalled a minimum of two inches (51 mm) from the edge of the panel for a minimum continuous length of one foot (0.3 m) along the joint are counted. Joints that have a bituminous patch for a minimum of one foot (0.3 m) are also counted.

b) Severely Spalled Joints: The total number of joints which are spalled a minimum of three inches (76 mm) back from the edge of the panel for a minimum continuous length of three feet (0.9 m) and in the wheel-track are counted. Joints that have bituminous patches at least three continuous feet (0.9 m) in length and in the wheel track are also counted.

2) Faulted Joints: The total number of joints faulted 1/4 inch (6.4 mm) or more at any point along the joint are counted.

3) Cracked Panels: The total number of panels having one or more cracks larger than 1/16 inch (1.6 mm) in width and two or more feet (0.6 m) in length are counted as cracked panels.

4) Broken Panels: The total number of panels having three or more cracks larger than 1/16 inch (1.6 mm) in width and two or more feet (0.6 m) in length, is counted as broken panels.

5) Faulted Panels: The total number of cracked or broken panels which have one or more cracks that are faulted a minimum of 1/4 inch (6.4 mm) at any point along a crack.

6) Overlaid Panels: The total number of panels that are completely overlaid is counted.

7) Patched Panels: The total number of panels having an accumulated area of at least five square feet (0.5 m^2) of patching which is in a deteriorated condition (excluding patching within one foot (0.3 m) of a joint) are counted. A deteriorated condition is a bituminous patch or is a concrete patch which shows such things as spalling or raveling at the edge of the patch.

8) D-Cracking: The total number of panels that exhibit D-cracking is counted.

Computation of Structural Rating (SR)

To determine the SR, one first determines the percentage of occurrence of each defect. These percentages are then multiplied by factors which are weighted for the severity of the defect. These numbers are then added up and subtracted from four.

B) South Dakota Profiler from FHWA-DP-89-072-002

The South Dakota Profiler measures road profiles. The Profiler consists of a passenger van equipped with electronic instrumentation, data processing equipment, and software to analyze measurements. It uses ultrasonic sensors.

Profiles are measured in the left wheel-path and are stored on floppy disks for later analysis. These profiles are used to complete the IRA's (International Roughness Indices).

These IRA's are then converted to a PSR rating by the equation:

$$PSR = 6.47469 + [-0.26974 * IRA\ (inches/mile)^{0.5}]$$

C) COPES Evaluation - from MN/DOT COPES Manual

A COPES evaluation was performed on each test section. COPES is a computerized data storage system used for collecting, storing, retrieving, and evaluating portland cement concrete pavements. It was developed by a team of researchers at the University of Illinois at Urbana - Champaign in the late 1970's as a project for the National Cooperative Highway Research Program.

The principal idea of COPES is to record distresses in the concrete highways. This is done by using a hand-held computer unit. For this study the entire test section was surveyed. For each section the evaluator walked the section and noted the distresses. No physical measurements were made on faulting or spalling.

Below is a list of COPES distresses and their severities which were found on this study.

1) Transverse Joint Spalling: The cracking, breaking, or chipping of the slab within two feet (0.6 m) of the joint.

Low Severity: The spall does not extend more than three inches (76 mm) on either side of the joint. The spall has not been patched.

2) Longitudinal Joint Spalling: The cracking, breaking, or chipping of the slab within two feet (0.6 m) of the joint.

Low Severity: The spall does not extend more than three inches (76 mm) on either side of the joint. The spall has not been patched.

3) Localized Distress: A localized area of slab where the concrete has broken up into pieces or spalled.

Low Severity: A localized distress where low severity spalling has occurred.

4) Corner Crack: A corner crack occurs when a crack intersects the joint at a distance less than six feet (1.8 m) on each side measured from the corner of the slab.

Medium Severity: Spalling is present and the joint is slightly faulted.

5) Longitudinal Cracking: Measured in feet of length of crack.

Low Severity: Hairline crack with no spalling or faulting.

6) Transverse Cracking: Measured by occurrence.

Low Severity: Hairline crack with no spalling or cracking.

Medium Severity: Working crack with some spalling or minor faulting.

High Severity: Width is greater than one inch (25 mm), high severity spalling, or major faulting.

7) Spalling Adjacent to Reinforced Patch: Deterioration of the original concrete adjacent to a permanent patch.

No Severities:

8) Partial Depth Repair Patches: The milling of concrete around a joint and replacing it with fresh concrete.

Low Severity: Only one or two hairline cracks or minor spalling.

High Severity: Several hairline cracks, one or two working cracks, or major spalling.

9) Partial Depth Repair: A partial depth repair in good condition.

10) Full Depth Repair: The removal of a full section of the old slab and replacing it with fresh concrete.

No Severities:

11) Full Depth Repair with Spalling:

Low Severity: Only one or two hairline cracks or minor spalling.

Appendix D-1 - 1990 Structural Rating - Alternative Joint Spacing T.H. 36 W.B. 71+00 - 91+37, Plastic Subgrade

		Joints			Panels						
Section	# of Joints	Slightly Spalled	Severely Spalled	Faulted	Cracked	Broken	Faulted	100% Overlay	5 ft^2 (0.5 m^2) Patched	'D' Cracked	Structural Rating
15', 4.6 m No Dowels	17	0	0	0	0	0	0	0	0	0	4.0
15', 4.6 m Doweled	15	1	0	0	0	0	0	0	0	0	3.7
20', 6.1 m No Dowels	18	3	0	0	1	0	0	0	0	0	3.3
20', 6.1 m Doweled	16	1	0	0	0	0	0	0	0	0	3.7
33', 10 m .10% Steel	7	1	0	0	3	0	1	0	0	0	3.0
33', 10 m .15% Steel	5	1	0	0	0	0	0	0	0	0	3.4
65', 20 m .15% Steel	5	1	0	0	3	0	1	0	0	0	2.8
65', 20 m .18% Steel	4	0	1	0	3	0	1	0	0	0	2.6

Appendix D-2 - 1990 Structural Rating - Alternative Jt. Spacing T.H. 36 W.B. 182+50 - 202+80, Granular Subgrade

		Joints			Panels						
Section	# of Joints	Slightly Spalled	Severely Spalled	Faulted	Cracked	Broken	Faulted	100% Overlay	5 ft^2 (0.5 m^2) Patched	'D' Cracked	Structural Rating
15', 4.6 m No Dowels	15	0	0	0	0	0	0	0	0	0	4.0
15', 4.6 m Doweled	16	0	1	0	1	1	0	0	0	0	3.5
20', 6.1 m No Dowels	17	0	1	0	0	0	0	0	0	0	3.7
20', 6.1 m Doweled	15	0	2	0	1	0	0	0	0	0	3.4
33', 10 m .10% Steel	11	0	1	0	3	0	1	0	0	0	3.2
33', 10 m .15% Steel	13	0	2	0	1	0	0	0	0	0	3.3
65', 20 m .15% Steel	23	1	1	0	1	0	0	0	0	0	3.5
65', 20 m .18% Steel	17	1	2	0	4	0	0	0	0	0	3.2

Appendix D-3 - 1990 Structural Rating - Alternative Joint Spacing T.H. E.B. 182+50 - 202+80, Granular Subgrade

		Joints			Panels						
Section	# of Joints	Slightly Spalled	Severely Spalled	Faulted	Cracked	Broken	Faulted	100% Overlay	5 ft^2 (0.5 m^2) Patched	'D' Cracked	Structural Rating
15', 4.6 m No Dowels	15	0	0	0	0	0	0	0	0	0	4.0
15', 4.6 m Doweled	15	1	0	0	0	0	0	0	0	0	3.7
20', 6.1 m No Dowels	15	0	1	0	0	0	0	0	0	0	3.7
20', 6.1 m Doweled	17	0	0	1	1	0	0	0	0	0	3.8
33', 10 m .10% Steel	10	0	1	0	0	0	0	0	0	0	3.6
33', 10 m .15% Steel	10	1	1	0	0	0	0	0	0	0	3.4
65', 20 m .15% Steel	27	0	2	0	0	0	0	0	0	0	3.7
65', 20 m .18% Steel	26	0	2	0	0	0	0	0	0	0	3.7

Appendix D-4 - 1990 Structural Rating - Alternative Joint Spacing T.H. 36 Summary

		Joints			Panels						
Section	# of Joints	Slightly Spalled	Severely Spalled	Faulted	Cracked	Broken	Faulted	100% Overlay	5 ft^2 (0.5 m^2) Patched	'D' Cracked	Structural Rating
15', 4.6 m No Dowels	47	0	0	0	0	0	0	0	0	0	4.0
15', 4.6 m Doweled	46	2	1	0	1	1	0	0	0	0	3.6
20', 6.1 m No Dowels	50	3	2	0	1	0	0	0	0	0	3.6
20', 6.1 m Doweled	48	1	2	1	2	0	0	0	0	0	3.6
33', 10 m .10% Steel	28	1	2	0	6	0	2	0	0	0	3.3
33', 10 m .15% Steel	28	2	3	0	1	0	0	0	0	0	3.4
65', 20 m .15% Steel	55	2	3	0	4	0	1	0	0	0	3.5
65', 20 m .18% Steel	47	1	5	0	7	0	1	0	0	0	3.4

Appendix E - 1990 IRA Versus PSR for Alternate Joint Spacing T.H. 36

Section	W.B. STA. 71-91 (Plastic Subgrade)		W.B. STA. 182-202 (Granular Subgrade)		E.B. STA. 182-202 (Granular Subgrade)		Average		Standard Deviation	
	IRA	PSR	IRA	PSR	IRA	PSR	IRA	PSR	IRA	PSR
15', 4.6 m No Dowels	2.35	3.1	2.71	2.9	3.72	2.3	2.93	2.8	0.71	0.4
15', 4.6 m Doweled	2.57	3.0	2.31	3.2	2.66	2.9	2.51	3.0	0.18	0.2
20', 6.1 m No Dowels	2.21	3.2	2.53	3.0	3.23	2.6	2.66	2.9	0.52	0.3
20', 6.1 m Doweled	2.19	3.3	2.41	3.1	2.62	3.0	2.41	3.1	0.22	0.2
33', 10 m .10% Steel	3.05	2.7	2.20	3.3	2.92	2.8	2.72	2.9	0.46	0.3
33', 10 m .15% Steel	2.27	3.2	2.62	3.0	2.60	3.0	2.50	3.1	0.20	0.1
65', 20 m .15% Steel	2.63	3.0	2.90	2.8	2.89	2.8	2.81	2.9	0.15	0.1
65', 20 m .18% Steel	2.18	3.3	2.83	2.8	3.53	2.4	2.85	2.8	0.68	0.5
Average	2.43	3.1	2.56	3.0	3.02	2.7	2.67	2.9	0.41	0.3
Standard Deviation	0.30	0.2	0.25	0.2	0.43	0.3				

Appendix F - T.H. 36 Total Distresses for Different Joint Spacings

Section & Length	1 Transv. Jt. Spall.	2 Long. Jt. Spall.	4 Local Distr.	5 Corner Crack	18 Long. Crack	19 Transv. Crack	25 Adj. Spall Next to FD	28 Part. D Spalled	30 Partial Depth	31 Full D w/ Long. Patch	33 Full D Patch w/Sp	35 Full D Patch
15', 4.6 m No Dowel 675', 210 m	2 (1)							5 (1)	17 (1)			
15', 4.6 m Doweled 675', 210 m	1 (1)				8' (1)	1 (2)		3 (1) 1 (2)	23 (1)			
20', 6.1 m No Dowel 900', 275 m			1 (1)		20' (1)			6 (1) 2 (3)	9 (1)		1 (1)	
20', 6.1 m Doweled 900', 275 m					10' (1)	1 (3)		4 (1) 1 (2) 2 (3)	26 (1)			
33', 10 m 0.10% steel 500', 150 m	2 (1)					1 (1) 3 (3)	1 (1)	3 (1) 2 (3)	8 (1)	1 (1)		2 (1)
33', 10 m 0.15% steel 500', 150 m	1 (1) 1 (2)					1 (1)		2 (1) 3 (3)	12 (1)			
65', 20 m 0.15% steel 784', 240 m	1 (1)	1 (1)				1 (1) 1 (3)		3 (1) 2 (2) 2 (3)	6 (1)			3 (1)
65', 20 m 0.18% steel 784', 240 m	1 (1)		1 (1)	1 (2)		4 (1) 4 (2) 1 (3)		6 (2) 2 (2) 1 (3)	8 (1)		1 (1)	2 (1)

Severities are in parentheses.

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