MICHIGAN DEPARTMENT OF TRANSPORTATION
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SECOND YEAR PERFORMANCE OF THE EUROPEAN CONCRETE PAVEMENT ON NORTHBOUND I-75 - DETROIT, MICHIGAN

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INTRODUCTION

This report describes the performance of the I-75 European concrete pavement reconstruction project approximately two years after construction. The design and construction attributes of the project are documented in Research Report No. 1335, which was published in September 1994 as part of Research Project No. 92 B-0105. The results of the first year of performance after construction were published in Research Report No. 1338 in January 1995. The experimental features of the pavement design were assimilated from designs used in Germany and Austria. The construction project is identified as federal project IM 75-1(420) and Michigan project IM 82251-30613A.

The objective of this project is to determine whether innovative features of typical rigid pavement designs used in European countries can be applied cost effectively to conventional design and construction methods used for rigid pavements in the United States. Two concerns that currently prohibit their use in American designs are: (1) their relative high initial costs and (2) their unknown effect on life cycle costs over the pavement's service life. Their adoption with Michigan rigid pavement designs depends upon an analysis of point (2) as applied to Michigan's pavement selection process. This postulate will be examined in the final report after the completion of the five year evaluation period.

The approximately one mile long European pavement is located on northbound I-75 between the Warren Avenue exit ramp northerly to Picquette Avenue, which is just north of I-94. Construction began in July 1993 and the pavement was opened to traffic on November 23, 1993. During the 1994 construction season, southbound I-75 traffic was detoured onto northbound I-75, while it was reconstructed. Southbound traffic was restricted to the two inner lanes (median side) on northbound I-75. The entire I-75 reconstruction project was completed and both directions resumed normal traffic operation on October 5, 1994.

The European pavement was part of a major Michigan project to reconstruct 3.7 km (2.3 miles) of the I-75 (Chrysler) freeway in downtown Detroit between I-375 and the I-94 (Edsel Ford) freeway. I-75 is six to eight lanes wide and carries approximately 111,000 vehicles a day, including about 11 percent trucks. The remaining portions of northbound I-75 and southbound I-75 are a conventional Michigan concrete pavement design that serves as a control section to the European design. Typical cross-sections of the European and Michigan pavements are shown in Figures 1 and 2, respectively.

PROJECT EVALUATION

The parameters used to determine long term performance of the European pavement were defined in Michigan Work Plan No. 130, dated February 1993. The project agreement with the FHWA specifies a five year monitoring period with the final report due by December 31, 1998. This report is the second performance evaluation study of the project.

Performance criteria to be evaluated for both the European and Michigan sections are ride quality, surface distress characteristics, surface friction levels, and traffic/tire noise levels. During the five year monitoring period, seasonal pavement deflection measurements will be taken to identify any structural inadequacies that may have developed with either pavement section.

Traffic/Tire Noise

An initial traffic/tire noise study was conducted in June 1994 by the Materials and Technology Division's Instrumentation and Data Systems Unit, while southbound I-75 traffic was detoured to the northbound side of I-75. The study results are documented in the first year performance report. The study concluded that the exposed aggregate surface provides only a slight reduction (0.4 dBA) in exterior Leq noise levels, as compared to the traditional transverse tining of concrete surfaces. In contrast, company literature by Robuco, Ltd. claims a 4 to 5 dBA reduction with similar European projects. Interior car Leq noise levels are only reduced by similar levels, while reported reductions in Europe range from 3.5 to 4.5 dBA. No additional noise evaluations were performed in 1995.

Surface Distress

In October 1995, a visual inspection of the entire European section was made when the surface was wet by slowly driving the outside shoulder. Surface distress features remain minimal as the pavement condition is very similar to the condition found one year earlier. The only transverse crack reported in 1994 in one 4.3 m (15 ft) long pavement panel in the driving lane has reopened to about 6 mm (1/4 in) in width as the epoxy injection treatment failed. The occasional surface popouts that are normally 25-50 mm (1 in - 2 in) in diameter appear not to have increased in number. Newly noticed in 1995 were six panels with very tight longitudinal cracks extending from a drainage structure to the next contraction joint. It is assumed they are caused by the fixed position of the structure as the pavement structure moves from expansion/contraction forces.

The Michigan control section on northbound was also visually inspected at the same time as the European pavement. The only noticeable distress type was transverse cracks. Approximately 20%* of the 10.3 m (41 ft) long panels had either one mid-panel or occasionally two transverse cracks at the panel's one-third points. The cracks were tight and typically irregular in direction. They were usually only in one lane and had not propagated across an adjacent lane. The cracks were equally scattered across all lanes. This initial crack pattern is typical of Michigan's 10.3 m (41 ft) long reinforced pavement panels.

*NOTE: In the first year report, the number of panels with transverse cracking was incorrectly reported as 50% (should have been 20%). There was no noticeable increase in cracking from the first year.

Ride Quality

Ride quality performance is measured by two parameters for this study: (1) the Michigan Ride Quality Index (RQI) and (2) the International Roughness Index (IRI) which is the more universally accepted method for measuring road surface roughness.

Michigan's RQI was developed about 25 years ago from a department research study that correlated the pavement's longitudinal profile with a driver's subjective rating of the pavement's ride quality. First, the pavement's longitudinal profile is measured in the lane's right wheel path by the department's Rapid Travel Inertial Profilometer, which was constructed by the department from methodology developed by General Motors in the 1960's. The profile is digitized and divided into three spatial wavelength bands by using third order Butterworth high and low pass filters. Variance of the profile in each band is then calculated from:

$$Var_i = \frac{\Sigma x^2}{N} - \Sigma\left(\frac{x}{N}\right)^2$$

Where x is a profile elevation value in inches and N is the number of x values.

i = 1 for 50-25 feet, i = 2 for 25-5 feet, and i = 3 for 5-2 feet

RQI is then given by the formula:

$$RQI = 3.077 \ln (Var_1 \times 10^8) + 6.154 \ln (Var_2 \times 10^8) + 9.231 \ln (Var_3 \times 10^8) - 141.85$$

The resulting value is a unitless number that provides a rating scale from O (a perfect pavement surface) to 100 (the roughest surface). This RQI measure was found to have a 90 percent correlation with the subjective opinion of the thirty-two pavement sections used in the study.

A scale for rating RQI values in subjective terms is:

RQI Value	Rating
0 - 30	Excellent
31 - 50	Good
51 - 70	Fair
> 70	Poor

Michigan's 1995 ride quality specification for new concrete pavements requires an RQI value of less than 49.8 to be acceptable. Pavements with an RQI value between zero and 40.5 receive a prorated bonus payment.

The respective RQI and IRI values for the European pavement and the Michigan control section are shown in Tables I and II, respectively. The values were derived from the longitudinal profile in the right wheel path of the outside driving lane. Both measurement methods indicate only minor fluctuations in the 1/10 mile increments in the two years since construction took place. These fluctuations are likely caused by the mismatching of individual segments from year-to-year because it is difficult to maintain the same exact starting and ending points of each roadway segment from one year to another in the state network computer file. Average RQI values indicate the Michigan section has slightly better ride quality than the European section and that no significant change has occurred with either section. The February 1995 measurement was taken to determine if frost expansion in the European dense-graded base or the Michigan sand subbase was great enough to adversely affect ride quality (see Aggregate Subbase, p. 11).

TABLE I - EUROPEAN PAVEMENT RIDE QUALITY

EUROPEAN - (RQI) (1/10 mile segments)*				EUROPEAN - (IRI) (1/10 mile segments)*		
Dec. 93	Feb. 95	Jul. 95		Dec. 93	Feb. 95	Jul. 95
48	54	48		106	139	84
40	43	44		95	74	83
47	52	57		97	111	98
45	50	51		105	111	102
42	45	46		81	101	82
36	46	43		97	98	68
35	44	42		88	99	74
30	43	40		73	85	77
38	45	42		106	99	71
52	48	63		93	104	107
Avg. 41	Avg. 47	Avg. 46		Avg. 94	Avg. 102	Avg. 85

*Segments listed as they are driven

TABLE II - MICHIGAN PAVEMENT RIDE QUALITY

MICHIGAN - (RQI) (1/10 mile segments)*				MICHIGAN - (IRI) (1/10 mile segments)*		
Dec. 93	Feb. 95	Jul. 95		Dec. 93	Feb. 95	Jul. 95
69	44	37		146	84	61
53	52	44		98	99	78
43	34	41		66	64	81
42	48	38		72	73	66
46	49	44		71	75	72
38	43	43		56	67	70
40	41	48		67	72	82
43	45	47		65	70	81
39	44	40		55	62	65
30	34	37		44	53	62
38	42	36		57	68	58
Avg. 44	Avg. 43	Avg. 42		Avg. 73	Avg. 72	Avg. 67

*Segments listed as they are driven

Deflection Analysis

Deflection testing for each pavement has occurred twice (initially in November 1993 and in April 1995) since construction was completed. The November 1993 measurements were taken during daylight hours prior to the pavement being opened to traffic. In contrast, the April 1995 measurements were taken at night from 1:00 AM - 5:00 AM. The pavement was also closed to traffic. The measurements were taken with the department's falling weight deflectometer (FWD) using a 4000 kg (9000 lb) impact load. Each value is an average of three drops.

Table III shows a comparison of mid-slab deflection measurements for each pavement section. These data indicate both sections are relatively stiff with minimal change among lanes. As expected, the European section is slightly stiffer (higher layer modulii values) than the Michigan section because of its lean concrete base and stiff dense-graded subbase.

Table III - MAXIMUM MIDSLAB DEFLECTION MEASUREMENTS

MICHIGAN PAVEMENT

LANE	NBIL		NB2		NBOL	
YEAR	**Nov. 93**	**Apr. 95**	**Nov. 93**	**Apr. 95**	**Nov. 93**	**Apr. 95**
UNIT	**mils**	**mils**	**mils**	**mils**	**mils**	**mils**
Average	2.28	2.07	2.13	2.07	1.99	2.05
Std. Dev.	0.18	0.16	0.16	0.22	0.22	0.24
Max.	2.56	2.33	2.55	2.50	2.51	2.57
Min.	1.98	1.82	1.91	1.66	1.36	1.66
Count	11	10	24	22	46	13
Temp. F.	43	44	43	43	46	43

EUROPEAN PAVEMENT

LANE	NBIL		NB2		NBOL	
YEAR	**Nov. 93**	**Apr. 95**	**Nov. 93**	**Apr. 95**	**Nov. 93**	**Apr. 95**
UNIT	**mils**	**mils**	**mils**	**mils**	**mils**	**mils**
Average	1.27	1.33	1.37	1.32	1.3	1.41
Std. Dev.	0.1	0.23	0.08	0.23	0.08	0.15
Max.	1.42	1.97	1.5	1.81	1.44	1.85
Min.	1.15	1.1	1.25	1.18	1.15	1.17
Count	18	24	28	20	50	27
Temp. F.	45	44	45	42	43	44

NOTE: All tests taken on outside wheelpaths (owp).
Temp. F - Is pavement surface temperature taken at time of test.
NB2 - First lane left of outside lane.

WEATHER INFORMATION		
	Nov. 93	Apr. 95
Average Air Temp. 5 Days Prior to Tests (F.)	44	54
Total Precipitation 5 Days Prior to Tests (in.)	0.37	0.07
Total Precipitation 30 Days Prior to Tests (in.)	1.2	2.6

Table IV shows a comparison of deflection values taken in the right wheel path at transverse contraction joints and the calculated load transfer efficiencies (LTE) between 1993 and 1995. LTEs were calculated by dividing the deflection on the unloaded side of the joint by the deflection (load plate) on the loaded side of the joint and then converting to a percentage. The average LTEs appear to be relatively low for both pavements, especially the low average LTE in 1995 for the European section. The European section is expected to have higher LTEs because of its stiffer lean concrete base (minor help) and closer spacing between dowel bars (240 mm vs. 300 mm in the outside lane). The weather data shown for the site indicate the lower LTEs for the European pavement may be caused from moisture warping in the top slab during testing. During the thirty days preceding the testing there were many days recording some rainfall, although little rain occurred during the week before testing. It should be noted that the actual location relationship between the FWD load plate and the joint's dowel bars was not determined for this testing.

TABLE IV - TRANSVERSE JOINT DEFLECTION MEASUREMENTS

MICHIGAN PAVEMENT

Lane	**NB2**				**NBOL**			
Date	**Nov. 93**		**Apr. 95**		**Nov. 93**		**Apr. 95**	
Test	**Max. Def.**	**LTE**	**Max. Def.**	**LTE**	**Max. Def.**	**LTE**	**Max. Def.**	**LTE**
Unit	**mils**	**%**	**mils**	**%**	**mils**	**%**	**mils**	**%**
Avg.	3.78	71.6	6.01	69.5	3.83	67.5	5.19	69.7
Std. Dev.	0.28	6.1	0.72	8.4	0.5	9.5	1.5	6.6
Max.	4.07	77	6.88	80	6.06	92.3	7.2	84.3
Min.	3.27	61.1	4.2	48.2	3.17	39.9	1.99	61.7
Count	6		11		40		8	
Temp. ^{0}F	41		42		43		43	

TABLE IV - TRANSVERSE JOINT DEFLECTION MEASUREMENTS

EUROPEAN PAVEMENT

Lane	**NB2**				**NBOL**			
Date	**Nov. 93**		**Apr. 95**		**Nov. 93**		**Apr. 95**	
Test	**Max. Def.**	**LTE**	**Max. Def.**	**LTE**	**Max. Def.**	**LTE**	**Max. Def.**	**LTE**
Unit	**mils**	**%**	**mils**	**%**	**mils**	**%**	**mils**	**%**
Avg.	3.29	79.1	5.14	61.9	3.39	77	4.85	58.8
Std. Dev.	0.46	6.6	1.01	4.1	0.5	9.1	0.61	4.6
Max.	4.21	88.1	7.75	69.7	4.28	90.3	6.01	69
Min.	2.35	67.9	3.61	54.7	2.47	56.9	3.75	51.5
Count	15		15		11		15	
Temp. °F	48		43		41		43	

NOTE: All tests taken on outside wheelpaths (owp)
LTE = D5/D0*100 (D0 sensor at load plate with transverse joint between D0 and D5
Temp °F - is pavement surface temperature at time of test
1993 testing done during daytime and before roadway was open to traffic
1995 testing done between 1:00 a.m. - 5:00 a.m. at night
NB2 - first lane left of outside lane

Surface Friction

Friction Numbers (FN) are Michigan's measurement unit for available wet sliding friction on pavement surfaces. The values are acquired by field testing using a full scale locked wheel trailer under controlled test parameters according to ASTM E-274. The field values are converted to equivalent standard FN units by use of a correlation equation developed at the Field Test and Evaluation Center for Eastern States near East Liberty, Ohio.

Table V shows a comparison between the initial FN test results taken just prior to opening the new pavement to traffic in 1993, the following spring test results taken prior to detouring traffic for southbound I-75 construction, and the latest test results taken in July 1995. The initial November 1993 FN values were taken when the curing compound was still present on both the Michigan and European pavement surfaces.

TABLE V - SURFACE FRICTION VALUES

FRICTION NUMBER (FN)							
MICHIGAN SECTION				EUROPEAN SECTION			
Lane	Nov 93	Apr 94	Jul 95	Lane	Nov 93	Apr 94	Jul 95
	Avg FN	Avg FN	Avg FN		Avg FN	Avg FN	Avg FN
NB#3	44	52	49	NB#3	42	40	40
NB#2	46	53	54	NB#2	36	42	41
NBIL	49	54	59	NBIL	35	44	45
AVG	46	53	54	AVG	38	42	42

NOTE: NBIL - Lane closest to median
NB#2 - 2nd lane from median
NB#3 - 3rd lane from median

Over the five month period from initial testing, the FN values increased for both the Michigan and European pavement sections. However, the latest friction measurements from July 1995 indicate FN values for both surfaces have stabilized. The Michigan section retains higher values, although both have acceptable FN values.

As reported in the first year report, sample FN values indicate the small differences in texture depth on the exposed aggregate surface do not appreciably affect friction numbers for the European section. This postulate was confirmed by 1995 testing that compared surface texture depths with FN values as shown on Tables VI and VII (see discussion for Exposed Aggregate Surface, below).

Exposed Aggregate Surface

Although surface texture is not a specific performance parameter for this project, it deserves special attention because of the unique exposed aggregate surface used on the European pavement. The construction procedure detailed in the construction summary report (Research Report No. 1333) is a patented process (International Patent No. 0086188) developed by Robuco, Ltd. of Belgium. Its stated advantages are, less tire noise levels and higher skid resistance (FN values), to be evaluated with this project versus the typical surface drag and transverse tining used on the Michigan pavement.

Visual observations of the exposed aggregate surface were made during the October 1995 distress inspection. As previously reported in the construction report and the first year report, the surface appears erratic in texture depth and color. This appearance results from the non-uniform distribution and spacing of the exposed dark blackish gray aggregate particles. The nominal aggregate particle diameter is 6-8 mm (0.25 in. - 0.32 in.). The aggregate particles appear to be staying in place as very few particles were noticeable in joint cavities or lying on the shoulder.

Sand patch testing, using British Standard BS598 Part 105, was performed in April 1995 to confirm whether texture depths have changed since construction. Table VI shows the change in texture depths that has occurred for areas that received shotblasting during construction to increase low texture depths to acceptable levels by specification.

TABLE VI - COMPARISON OF TEXTURE DEPTHS IN AREAS RECEIVING SHOTBLASTING

Station	Lane	Original mm	After Shotblast mm	Test on 4/17/95 mm
131+00 to 132+50	2	1.0	1.1	0.7
138+00 to 139+50	1	0.9	1.1	0.7
142+50 to 144+00	1	1.0	1.1	0.9
150+00 to 151+50	1	0.9	1.1	0.8
150+00 to 151+50	2	0.9	1.1	0.8
152+50 to 154+00	1	1.0	1.1	0.8
161+00 to 162+50	1	1.0	1.1	0.8
165+00 to 166+50	1	0.9	1.0	0.6
165+00 to 166+50	2	0.9	1.1	0.6

NOTE: Lane numbering begins with lane nearest the median

TABLE VII - FRICTION COMPARISONS WITH TEXTURE DEPTHS

Station	Lane	Friction # Apr 94	Texture Depth 4/17/95 mm
121+33	1	46.2	0.9
129+78	1	43.6	0.6
133+48	1	41.2	0.7
124+40	2	43.4	0.6
128+62	2	40.4	0.7
125+56	3	44.5	0.8
144+04	3	40.2	0.7
149+85	3	35.7	0.6

NOTE: Lane numbering begins with lane nearest the median

The results of sand patch testing, as well as testing in normal areas shown in Table VII, confirm the premise that there has been a loss of texture depth. The reason for this loss is a mystery at this time. It is not likely that the exposed coarse aggregate is abrading because of its low abrasion qualities. Department records indicate a Los Angeles Abrasion loss value of only 14 percent for the aggregate source. Perhaps the loss in texture depth is due to the sharp angular points of the crushed particles which are being chipped off by truck blades during snow removal operations.

Aggregate Subbase

During project design, the proper permeability characteristic of the aggregate subbase for the European pavement was debated. An actual German aggregate gradation was used which is a dense-graded crushed limestone with a permeability determined by laboratory testing of less than 300 mm (1 ft) per day. The permeability of the Michigan subbase was about 4.3 m (15 ft) per day. Michigan pavement engineers were concerned because Michigan rigid pavement designs use an open-graded base to alleviate water induced problems, like lower or differential base support values and durability cracking of the concrete pavement.

There was concern that the 410 mm (16 in) thick dense-graded base would be frost susceptible from poor drainability. To verify this the ride quality of both the European and Michigan sections was measured with the department's profilometer in February 1995, after a two week period of sub-freezing weather. Prior to the two week long period of sub-freezing weather, the month of January was an intermittent cycle of freezing and thawing weather with sufficient events of rain and snow to provide each base type with water. If the RQI values appreciably increased, then it would indicate that some differential frost heaving was occurring from expansion of the aggregate subbase of the European pavement or the sand subbase of the Michigan pavement.

The February 1995 ride quality data shown in Tables I and II indicate that RQI values increased for the European section on average about six points from fall values in 1993. The highest increase for an individual 1/10th mile segment was 13 points. There was no change in the average RQI value for the Michigan section, but some 1/10th mile segments did increase from one to six points.

The average ride quality for each pavement section did not change significantly from February 1995 to July 1995, although some 1/10th mile segments did show some change. This might indicate that some base expansion did take place during the winter and re-compaction of the base by traffic loading has not yet taken place.

However, considering the limitations of the data in matching individual locations among different times of measurement and its inherent statistical variability, no conclusive judgement can be made as to how frost susceptible either base type is using RQI values. More data will be collected and future attempts will be made to resolve the question.

Joint Seals

The longitudinal and transverse joints were sealed with an Ethylene Propylene Diene Terpolymer (EPDM) seal, which is another unique feature of the European pavement. Neither the transverse or longitudinal EPDM seals show any visible change since the first inspection in October 1994. There is still evidence of *camelback humping* that was reported in the first year report, but with no seal protrusion above the pavement surface. Some occasional dropping of the EPDM seal in the joint cavity is evident. The lap joint at the intersection of the transverse and longitudinal joint appears to be performing fine. The seal supplier, Phoenix North America, Inc., reports the EPDM seal has an expected 10-12 year service life.

CONCLUSIONS

There is insufficient data to conclude whether any change in condition or unexpected performance trend is occurring with the European pavement in the two years since initial construction. Therefore, the European pavement section is generally performing as expected, as is the Michigan pavement section. As previously reported, however, the expected benefits of lower tire noise and higher friction values with the European pavement's exposed aggregate surface have not occurred. Specific points of interest about the project after two years are summarized as follows:

- No significant surface distress features have developed for either the European or the Michigan pavement sections. Approximately, 20 percent of the pavement panels in the Michigan section have one or two transverse cracks, but this is expected with longer joint spacings with reinforced panels. Six pavement panels in the European section have developed very tight longitudinal cracks that protrude from a drainage structure.

- The EPDM joint seals are performing satisfactorily. There is occasional *camelback humping* and some dropping of the seal material perhaps indicating that excessive elongation of the seal took place during installation.

- Sand patch testing indicates the exposed aggregate surface has lost on average about 0.3 - 0.4 mm of texture depth from a starting base of about 1.1 mm. There is no apparent reason for the loss, but one possibility may be that the steel blades on snowplows are chipping off the sharp angular corners on the exposed coarse aggregate particles.

- Surface friction numbers are similar to the first year values with the European section averaging about 40 as compared to the Michigan section which measures about 50. A comparison of texture depths and surface friction values indicates there is no correlation between the two measurements.

- Deflection measurements indicate overall the European pavement structure is slightly stiffer (higher layer modulii) than the Michigan section, which was expected, and that there has been minimal change in deflection values since construction. However, the European section has lower load transfer efficiencies (LTE) across transverse contraction joints, which possibly concludes that the reduced spacing of the dowels has provided little benefit toward increasing LTEs. A more probable reason for low LTEs with the European section is the likelihood that there was moisture warping occurring with the top slab above the lean concrete base during testing.

- An attempt to use winter ride quality data to evaluate the frost susceptibility of the dense-graded aggregate subbase of the European pavement and the sand subbase of the Michigan pavement was inconclusive. Future attempts will be made to try and resolve the question which was a concern during the design phase of the project.