# MICHIGAN DEPARTMENT OF TRANSPORTATION
## M•DOT

# EUROPEAN CONCRETE PAVEMENT TOUR



MICHIGAN DEPARTMENT OF TRANSPORTATION

**MATERIALS and TECHNOLOGY DIVISION**

TESTING AND RESEARCH SECTION
CONSTRUCTION AND TECHNOLOGY DIVISION
RESEARCH REPORT NO. R-1462

# MICHIGAN DEPARTMENT OF TRANSPORTATION
# M•DOT

## EUROPEAN CONCRETE PAVEMENT TOUR

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Construction Division


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# INDEX

# EXECUTIVE SUMMARY

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Legal single axle loads consisting of 11.5 metric tons (25.3 kips) currently exist in Germany and Austria. The axle load limits will be increased to 13 metric tons (28.6 kips) in 1993. These high axle loads require a thicker pavement structure than typically constructed in the U.S. The surface texture in Germany consists of a burlap drag, where as in Austria it consisted of an exposed aggregate surface treatment. A transverse tined surface is seldom, if ever, used because of the higher noise level. It was contended that the burlap drag surface finish has an adequate friction; however, it would seem that over time the friction provided by the burlap drag surface would degrade.

The transverse joint spacing is typically at 5 m (16.4 ft) and dowel bars are variably spaced in these joints. More dowel bars are placed in the wheel paths to provide increased load transfer. Lane ties are typically used and consist of three to four lane ties for each 5-m (16.4-ft) slabs.

Materials used for their concrete pavement construction are available to Michigan for use in trial sections.

Automated equipment used both in Austria and Germany allow for smaller crew sizes and a production rate similar to that in the United States.

A trial section using a combination of German and Austrian designs has been selected. The trial section, on northbound I-75, will be approximately one mile long and will be between I-94 and I-375 in downtown Detroit. The entire project is 2.1 miles long and includes replacing both the northbound and southbound concrete pavement. Our concrete pavement design will be used on the remaining portion of the project to serve as a control section.

The trial section pavement structure will have transverse joints spaced a 5 m (15 ft) and will consist of 26 cm (10 in.) of concrete pavement, over 15 cm (6 in.) lean concrete base, over a 39 cm (16 in.) frost layer. (Hard metric conversion was used in determining the English equivalents for the trial section.) Expansion joints will not be used in the concrete pavement. The concrete pavement will be constructed using a two-layer type construction with an exposed aggregate surface treatment. The concrete pavement will not contain steel reinforcement. Durability requirements for the aggregates will be similar to those used by Germany and Austria. An enclosed drainage system will be incorporated into the trial section and our standard section. Slight modification of the German and Austrian designs were necessary because of project constraints (ramps and structures present). See Figure 1 for details of the trial section. This project will be let in early 1993 for construction during that season.

## INTRODUCTION

Seven engineers from the United States returned from a twelve day tour of Europe on October 22, 1992. Three engineers from the Federal Highway Administration (Roger Larson, Suneel Vanikar, and Steve Forster), two engineers from the Michigan Department of Transportation (Randy VanPortfliet and Roger Till), one engineer from the New York Department of Transportation (Ray Gemme), and one engineer from the American Concrete Pavers Association (Pat Nolan) were involved in the trip. The tour included reviewing the design and construction practices of freeways (autobahns) in Germany and Austria. Five cities and eight construction sites were visited in Germany, and two cities and four construction sites in Austria. The purpose of the trip was to gain insight into European design and construction practices for possible application in the United States and Michigan.

Upon arrival in Germany, it became evident that they are building new highways in preparation for the unification of the European Community. Germany is also rebuilding the neglected highways in the east in response to its reunification in 1990.

Funding levels for transportation in Germany are apparently higher than in the United States. Gas prices are about 1.5 marks per liter, which includes a tax of about 0.6 marks per liter. This is about 40 percent of the fuel price. Equivalent cost in the United States would be $4.00 per gallon, with a $1.60 per gallon gas tax. It was noticed at a gas station that a liter of oil was priced at 20 marks ($13.00 per quart). A vehicle tax based on engine size is also paid on a yearly basis. These funds from the gas and vehicle taxes are spent for both highway and railroad construction.

Truck axle load characteristics in Germany are much different than in the United States. Single axle loads are allowed to be 11.5 metric tons (25.3 kips) and will be increased to 13 metric tons (28.6 kips) in 1993. Single, super tires (inflated to 125 psi) are permitted on the single axle. These axle weights are in response to the European Community, and will be legal throughout Europe.

Vehicular volume on freeways is normally 40,000 to 60,000 vehicles per day with 25 to 40 percent being trucks. This volume of truck traffic, use of super tires, and permitted single axle loads requires the pavement design thickness to be greater than that in the United States.

# FINDINGS

## Austrian Experience

### Design

An unusual feature of the Austrian design is that three layers of asphalt and subbase are placed for a new roadway. After completion, these three layers of asphalt carry traffic for five to seven years in order for any settlement to occur. The ruts and bumps created in the asphalt are then ground, weak spots in the subbase revealed by traffic are replaced, and a concrete pavement is placed on top of these layers. There are no problems with the concrete bonding to the asphalt subbase layer because the five to seven years of traffic wears the surface to an irregular, open pattern. This procedure is used to accommodate the mountainous terrain, which requires widespread use of embankments on the side of these mountains.

The concrete pavement consists of a two-layer construction, wet on wet. That is, fresh concrete of the top layer is placed on the fresh concrete of the bottom layer in one continuous operation. This pavement is typically 22 cm (8.7 in.) in total thickness, 18 cm (7.1 in.) of the bottom layer is made from their standard concrete and the top 4 cm (1.6 in.) consists of a premium concrete with an exposed aggregate surface treatment. Five-meter (16.4-ft) transverse joint spacing is used in the concrete slab. The concrete pavement is non-reinforced. Dowel bars in the transverse joint are variably spaced, with a smaller dowel bar spacing used in the wheel paths. The dowel bars are 20 mm (0.8 in.) in diameter by 60 cm (23.6 in.) in length and are plastic coated. Lane ties are epoxy coated with three placed in each 5-m (16.4-ft) slab. A 2.5 percent straight crown slope from the inside edge of pavement to the outside edge of pavement is used.

The exposed aggregate treatment began in Belgium in 1980 and was tried in Austria in 1989. This surface treatment on the concrete pavement is a patented process by Robuco. The royalty fees are about $0.12 per square meter. The exposed aggregate surface treatment is performed only on the traveled roadway. A burlap drag surface treatment is used on the shoulder. Because of the random pattern of the coarse aggregate, this exposed aggregate treatment results in a decrease in noise level from traveling vehicles of greater than 4 dbA when compared to transverse tined surface treatment. The noise level of the exposed aggregate surface treatment is comparable to that of an asphalt surface. The friction characteristics are comparable to a transverse tined surface due to the aggregate surface roughness and a high resistance to polishing.

The Robuco process of exposing the aggregate consists of spraying a retarder on the top surface immediately after finishing, then covering immediately with a 50 micron (2 mil) thickness plastic sheeting. The joints are saw cut through the plastic sheeting within 24 hours. The plastic sheeting is then removed within 24 to 72 hours and the retarded concrete surface is dry wire brushed to the remove the mortar from the coarse aggregate particles. Wet brushing had been used in the past, but slurry disposal became a problem. Hydroblasting had been used to expose the aggregate, but it displaced many of the coarse aggregates and left the aggregate interface with the cement matrix in a less than desired condition.

Pavement costs for a 22 cm (8.7 in.) thick, two-layer construction, with exposed aggregate surface treatment is about $32 per square meter. This includes the pavement with a premium aggregate top course, the joints, and the exposed aggregate surface treatment.

## Materials

### Concrete Mix Design

The top layer of premium concrete normally contains 450 kilograms of cement per cubic meter (759 lb per cyd) with a water-cement ratio of less than 0.40. It is superplasticized and contains about 4 percent entrained air. Compressive strength from the top cores tested at 28 days is 60 Newtons per square millimeter (8700 psi). The bottom layer, consisting of their standard concrete, contains 350 kilograms of cement per cubic meter (590 lb per cyd). The water-cement ratio is 0.42, and a retarder is normally used. Entrained air of 5 percent is used for this bottom layer. The 28-day compressive strength from testing the second layer cores is 35 Newtons per square millimeter (5075 psi).

### Coarse Aggregate

Coarse aggregate in the top layer is a basalt (diabase) consisting of sizes from 4 to 8 mm (0.16 to 0.32 in). The bottom layer coarse aggregate is typically a gravel. Both top and bottom layer coarse aggregates have high resistance to freeze-thaw damage.

### Exposed Aggregate Surface Treatment

The retarder that is used in the exposed aggregate process can be either a sugar-based admixture (red color tint), which provides about 1 mm (0.04 in.) of exposed aggregate when completed, or a citric acid chemical-based admixture (green color tint), which provides about 2 mm (0.08 in.) of exposed aggregate. Application rate for the sugar-based retarder is about 500 grams per square meter (0.9 lb per syd) and is about 100 grams per square meter (0.2 lb per syd) for the chemical-based retarder. These retarders are color tinted in order to visually check for uniform application rates. The citric acid chemical-based retarder also acts as a curing compound; however, the sugar-based does not act as a curing compound. When using the sugar-based retarder, a geotextile must be placed over the cut plastic after the joints are saw cut through the plastic in order for the concrete curing to continue.

### Sample Analysis

A concrete sample (thin wafer of pavement section) and a sample of the coarse aggregate contained in the top layer of the concrete pavement were brought back from Austria for a petrographic examination. The results of this examination are contained in Appendix A. It appears that sources for both the coarse aggregate in the top layer and the coarse aggregate in the bottom layer are available to the State of Michigan for use in trial sections.

## Construction

The Austrian roadway construction methods are similar to the methods employed in Michigan. The major difference was the paving operation. A short paver was used for both the bottom and top layer of concrete pavement. These pavers ran in tandem with concrete being delivered to the second paver by a conveyor. Line and grade control were established for each paver. The first paver had a dowel bar inserter. The dowel bar inserters were mounted on a beam, which allowed for variable spacing of the dowel bars. Both pavers contained an auger and a screed.

The exposed aggregate process was constructed pursuant to the material section herein. The equipment and materials used are not uncommon to highway construction. The process is not labor or equipment intensive.

The equipment used by Austria is available to the United States.

# German Experience

## Design

About equal proportions of concrete and asphalt freeways currently exist since the German reunification in 1990. These proportions are about equal now because East Germany had many more miles of concrete pavement than asphalt pavement.

Germany has developed a design catalog for both new construction and rehabilitation of their freeways and other types of roads. The design life of their freeways is between 20 to 30 years. Both concrete and asphalt alternates are usually stated in their proposal. It is interesting to note that their design for concrete pavements has changed somewhat though the years, but basically has remained the same.

As an example of how their concrete pavements perform, a section of Autobahn A-10 around Berlin, built in 1935, was visited by the tour group. This pavement is 57 years old and is in good condition. The pavement structure consists of 23 cm (9.1 in.) of unreinforced concrete over the existing sand subgrade. Transverse joints were spaced at 10 m (32.8 ft) and are doweled with 25 mm (1 in.) in diameter by 50 cm (19.7 in.) long dowels. Lane ties were used, which were 20 mm (0.8 in.) in diameter by 80 cm (31.5 in.) in length. The longevity of this pavement is attributed to very good drainage of the subbase and a concrete strength of 65 Newtons per square millimeter (9425 psi). Annual traffic volumes for this roadway were not available.

The current concrete pavement design consists of 26 cm (10.2 in.) of concrete pavement without steel reinforcement. The pavement is constructed in two layers, wet on wet, using burlap drag surface finish. This is placed over a 15 cm (5.9 in.) lean concrete base. These two sections of concrete are placed over a frost layer that is 29 to 49 cm (11.4 to 19.3 in.) thick. Climate and soil conditions dictate the thickness that will be used. This frost layer serves as structural support for the pavement and is drainable. A straight crown slope of 2.5 percent from the inside edge of pavement to the outside edge of pavement is used for both the concrete pavement and the subgrade.

A 5-m (16.4-ft) transverse joint spacing is used with variably spaced, plastic coated dowel bars. The dowel bars are spaced closer together in the wheel paths. Lane ties are used and consists of three to four lane ties per 5-m (16.4-ft) slab. The lane ties are epoxy coated in middle one-third of the bar only. Transverse and longitudinal joints are saw cut in the concrete pavement. The joints are either saw cut or vibrated into the lean concrete base. Joints that occur in the lean concrete base will have a joint above them in the concrete pavement. Neoprene seals are used for both the longitudinal and transverse joints in the concrete pavement.

It is anticipated that the bond between the concrete pavement and the lean concrete base will last about five years. Initially the debonding starts at the joint and works its way toward the center part of the slab. Subsurface drainage is required because the bond of the concrete pavement to the lean concrete base is not permanent. This entails an enclosed drainage system (using edge drains and sewers) in order to evacuate the water from the subbase.

Traffic lanes in Germany are 3.75 m (12.3 ft) wide. The edges of the concrete pavement extends 0.5 m (1.6 ft) beyond the traffic lane in order to provide good edge support of the wheel loads. Shoulders are paved with the full-depth concrete sections (pavement and lean concrete base) and are 2.5 m (8.2 ft) wide. The lean concrete base extends beyond the shoulder by about 0.5 m (1.6 ft). Aside from providing good edge support, this extra width of lean concrete base provides a good surface for the paving equipment to ride.

Modifications to the German design occur only after full scale lab tests occur in the BASt test pit (BASt is equivalent to a Federal Research Institute). This is done to ensure that premature failure of the concrete pavement will not occur.

It was interesting to note that expansion joints are used only at bridges. It is the German's belief that there is enough concrete shrinkage in their 5-m (16.4-ft) slabs to accommodate the expansion that occurs in the summer months. In order to ensure that adequate expansion of the transverse joints is present, the joints are made using a double saw cut procedure. The initial saw cut is about one-third the depth of the concrete pavement. A plastic band with a diameter equal to the initial saw cut width is then placed in the saw cut at about one-half its depth. This plastic band prevents the slurry from the subsequent saw cut for the placement of the neoprene joint seal from entering the cut joint, thereby preventing incompressibles from entering the joint.

## Materials

### Concrete Mix Design

The top layer of the concrete pavement contains 340 to 350 kilograms of cement per cubic meter (574 to 590 lb per cyd) with a water-cement ratio of 0.4 to 0.45 and an air content of about 5 percent. The compressive strength at 28 days, measured by a 20-cm (7.8 in.) cube, is 35 Newtons per square millimeter (5075 psi). A third-point flexural test is available, but seldom used because of the variability in the flexural strength test results. The bottom layer of the concrete pavement has a mix design similar to the top.

The lean concrete base mix design has a water-cement ratio of about 0.8 and an air content of 5 percent. The compressive strength of this lean concrete base, based on 20-cm (7.8 in.) cubes, is 15 Newtons per square millimeter (2175 psi).

### Coarse Aggregate

In the concrete pavement, the top layer coarse aggregate consists of crushed basalt (diabase) and high quality gravel. The bottom layer coarse aggregate consists of high quality gravel or recycled concrete. In the lean concrete base, gravel or recycled concrete is used.

### Frost Layer

The granular material that is used for the frost layer is different than that used in Michigan because not more than about 15 percent is permitted to pass the No. 100 sieve. The intent of this frost layer is to provide structural support and allow water in the subbase to escape. This is accomplished by allowing very few fines in the granular material.

### Edge Drains

The edge drains that were being placed were smoothed lined corrugated plastic pipe with a inner-diameter of 12 cm (4.7 in.). These drains are slotted and the slots are placed facing up in the trench. The drains were not wrapped with a geotextile fabric even though crushed rock was being placed in the trench for backfill.

### Sample Analysis

Samples of aggregate used for the top layer of the concrete pavement and samples of crushed concrete used for the bottom layer of the concrete pavement were brought back from Germany for a petrographic analysis. The results of this analysis indicate that similar sources of the coarse aggregate are available to the State of Michigan for use in trial sections. The petrographic analysis report appears in Appendix A.

## Construction

The typical German cross-section consists of a subbase with an enclosed edge drain system, a lean concrete base, and a two-layer, wet on wet, concrete pavement.

The lean concrete base is placed with a typical concrete paver. Longitudinal and transverse joints are cut or vibrated into the lean concrete base. The joint location matches the joints that will be constructed in the concrete pavement. The lean concrete base is paved outside the concrete pavement width. This provides a level, solid base for the paver, which results in a smoother concrete pavement surface and a better ride. The lean concrete base is mixed in a typical concrete plant. No special equipment is required for construction of the lean concrete base.

The two-layer, wet on wet, concrete pavement is slightly different from typical Michigan concrete paving. The German paver has two augers and two screeds. The paver resembles two pavers in one. Concrete is dumped in front of the paver for the first auger and screed. Approximately two-thirds of the bottom layer of pavement is placed in this operation. A dowel bar and lane tie inserter then places the bars before the second auger and screed places the top layer of pavement. Concrete for the second auger and screed is delivered by a conveyor after dowel bar and lane tie insertion.

An autofloat, burlap drag, and curing bridge follow the paver. The Germans do not tine the pavement due to the high concern for road noise. Two finishers were working between the float and burlap drag. A minimal amount of finishing was required.

The transverse and longitudinal joint operations are similar to Michigan. The main difference is that the transverse joints are cut approximately one-third of the pavement depth. A plastic band is inserted into the saw cut to keep the cut clean. The notch for the neoprene seal is then made. Neoprene joints are used for the longitudinal joint also.

In Germany, the contractor is responsible for line and grade of the pavement, and the concrete mix design. A four-year warranty from the contractor is required. No cracks in the pavement is the condition required by this warranty and a portion of the contract price to cover repair cost is withheld by the owner until the end of the warranty period. The contractors accept this warranty clause and do not discredit the pavement design for being at fault because of the many years of good performance history.

Quality control testing is performed by the contractor and quality acceptance testing is performed by the owner. These tests include the plate bearing test and density tests for the frost layer, and the plate bearing test and concrete strength test for the lean concrete base. Concrete strength tests are performed on the concrete pavement. Air content tests on the fresh concrete are also performed.

Automated methods used by Germany were evident at the construction sites visited. This allows for a smaller crew size and a production rate that is similar to that in the United States. At one construction site, near Berlin, the rate of the concrete paver was approximately 2 m (6.6 ft) per minute.

The equipment used by Germany is available to the United States.

## Maintenance

It was reported that joint sealing is done every seven to ten years and crack sealing is done as needed. However, there were few cracks visible in the concrete pavements. Sometimes an asphalt overlay is placed on a concrete pavement for rehabilitation purposes, though in most cases total reconstruction is the preferred treatment.

## SUMMARY

Legal single axle loads consisting of 11.5 metric tons (25.3 kips) currently exist in Germany and Austria. The axle load limits will be increased to 13 metric tons (28.6 kips) in 1993. These high axle loads require a thicker pavement structure than typically constructed in the U.S. The surface texture in Germany consists of a burlap drag, where as in Austria it consisted of an exposed aggregate surface treatment. A transverse tined surface is seldom, if ever, used because of the higher noise level. It was contended that the burlap drag surface finish has an adequate friction; however, it would seem that over time the friction provided by the burlap drag surface would degrade.

The transverse joint spacing is typically at 5 m (16.4 ft) and dowel bars are variably spaced in these joints. More dowel bars are placed in the wheel paths to provide increased load transfer. Lane ties are typically used and consist of three to four lane ties for each 5-m (16.4-ft) slab.

The lean concrete base has joints that are vibrated into place. These joints typically run the full depth.

Materials used for their concrete pavement construction are available to Michigan for use in trial sections.

Automated equipment used both in Austria and Germany allow for smaller crew sizes and a production rate similar to that in the United States.

## CONCLUSIONS

Based on the design and construction practices observed in Austria and Germany it is apparent that the following measures improve the quality of rigid pavements:

1. Using a short joint spacing [5 m (16.4 ft)] in the concrete pavement, along with using a higher durability requirement for the aggregate. Reinforcement is not be required with this short joint spacing. The cost of using a short joint spacing and higher durability aggregate is offset by not using steel reinforcement.

2. Using a granular subbase that requires less than 15 percent passing the No. 100 sieve. The Department's granular material class II used for subbases does not meet the requirements of the German frost layer, but could be modified to require less than 15 percent passing the No. 100 sieve.

3. Using an exposed aggregate surface treatment in lieu of transverse tining. This provides an adequate surface friction and also reduces noise pollution. A burlap drag surface finish should not be used because of the possibility of low friction at some future date from the polishing of the coarse aggregate.

4. Using paving methods that require a two-layer, wet on wet, construction using automated dowel bar and lane tie inserters. The two-layer construction allows a premium aggregate to be used in the top layer and ensures that no voids occur from the dowel bars and lane ties being inserted automatically into the fresh concrete. Using premium aggregate only in the top layer conserves resources and reduces cost.

## TRIAL PROJECT

A trial section using a combination of German and Austrian designs has been selected. The trial section, on northbound I-75, will be approximately one mile long and will be between I-94 and I-375 in downtown Detroit. The entire project is 2.1 miles long and includes replacing both the northbound and southbound concrete pavement. Our concrete pavement design will be used on the remaining portion of the project to serve as a control section.

The trial section pavement structure will have transverse joints spaced a 5 m (15 ft) and will consist of 26 cm (10 in.) of concrete pavement, over 15 cm (6 in.) lean concrete base, over a 39 cm (16 in.) frost layer. (Hard metric conversion was used in determining the English equivalents for the trial section.) Expansion joints will not be used in the concrete pavement. The concrete pavement will be constructed using a two-layer type construction with an exposed aggregate surface treatment. The concrete pavement will not contain steel reinforcement. Durability requirements for the aggregates will be similar to those used by Germany and Austria. An enclosed drainage system will be incorporated into the trial section and our standard section. Slight modification of the German and Austrian designs were necessary because of project constraints (ramps and structures present). See Figure 1 for details of the trial section. This project will be let in early 1993 for construction during that season.

The selection of the pavement structure section was, in part, based on review of the weather data of Munich, Germany as compared to that of the Detroit City Airport. The average high and average low temperatures of these two cities compare very closely.

# APPENDIX A

# OFFICE MEMORANDUM

**DATE:** November 24, 1992

**TO:** Jon W. Reincke
Engineer of Research

**FROM:** Robert W. Muethel
Geologist
Petrography & Hydrology Group

**SUBJECT:** Petrographic Analysis of European Concrete and Aggregates
Research Project 92 TI-1656

This report presents the results of petrographic analysis conducted on samples of European two-course concrete pavement and aggregates submitted to the laboratory by Roger Till, Supervising Engineer of the Materials and Technology's Structural Services Unit. The petrographic analysis includes petrographic examination of the concrete and aggregate samples, and linear traverse determination of the hardened air void parameters of the concrete specimen. Wear track determination of polishing resistance was requested for one of the aggregates, and will be completed at a later date. The report also includes a requested list of available high-durability local aggregates that would be suitable for use in the top course of a two-course concrete pavement.

## Samples

The following samples were submitted for analysis:

### AUSTRIAN SAMPLES

- A slice of a two-course concrete pavement containing fine crushed basalt coarse aggregate in the top course and gravel coarse aggregate in the bottom course.
- Fine crushed basalt coarse aggregate used in the concrete top course.

### GERMAN SAMPLES

- Crushed diabase (Splitt 11/22), coarse gravel (Weser Kies 8/16), and fine gravel (Weser Kies 2/8) blend components to be used in the top course of a two-course concrete pavement.
- Coarse, medium, and fine crushed recycled concrete to be used in the bottom course of a two-course concrete pavement.
- Sand (0/2) to be used as fine aggregate in the two-course pavement.

## Analysis

Petrographic analysis was conducted according to ASTM C856, "Petrographic Examination of Hardened Concrete", and ASTM C295, "Petrographic Examination of Aggregates for Concrete". Analysis of the hardened air content of the top and bottom courses of the concrete pavement slice was conducted by the linear traverse procedure according to ASTM C457, "Microscopical Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete".

## Results

The results of petrographic examination and hardened air content analysis of the concrete slice, and the petrographic examination of the aggregates are as follows:

### AUSTRIAN SAMPLES

## Pavement Slice

The top course is composed of approximately 1½ inches of concrete containing coarse aggregate composed entirely of fine crushed basalt with quartzose sand fine aggregate. The basalt is reddish brown to dark gray, and fine-grained to microcrystalline.

The bottom course is composed of approximately 7½ inches of concrete containing gravel coarse aggregate composed of igneous, metamorphic, and sedimentary rock particles. The fine aggregate is quartzose sand. The petrographic composition of the coarse aggregate in the bottom course, determined from the examination of 70 lineal inches of traverse on ten full-depth scan lines spaced one inch apart on both sides of the concrete slice, is as follows:

| Rock Type | Amount of Sample | |
|---|---|---|
| | No. of Particles | Percent |
| Igneous | 35 | 34.7 |
| Metamorphic | 49 | 48.5 |
| Sedimentary | 17 | 16.8 |
| Totals | 101 | 100.0 |

## Remarks

The igneous rock category includes granite, rhyolite, and basalt particles. The metamorphic rock category contains predominantly quartzite particles. A few gneissic and metasedimentary particles are present. The sedimentary rock category includes dolomite and limestone particles.

Gradation of the coarse aggregate contained in the bottom course has the appearance of the MDOT 6A designation, with particles of 3/4-in. through No. 4 size represented.

The following hardened air parameters were determined from the linear traverse analysis conducted on the top and bottom course concrete.

| Parameter | Top Course | Bottom Course |
|---|---|---|
| Aggregate, % | 64.1 | 78.5 |
| Paste, % | 28.8 | 16.6 |
| Hardened Air, %<br>Voids per Inch<br>Specific Surface, $in^2/in^3$<br>Spacing Factor, in. | 7.1<br>9.3<br>525<br>0.008 | 5.0<br>8.8<br>689<br>0.006 |

The hardened air void distributions in the top and bottom courses were typical of air entrained concrete, with predominant air void chord intercepts less than 100 microns.

<u>Basalt Top Course Aggregate</u>

The fine crushed basalt aggregate is similar to that contained in the top course of the concrete specimen.

Sieving of the sample produced the following amounts retained on the indicated sieves:

| Sieve Size | Amount Retained | |
|---|---|---|
| | Weight, g | Percent |
| 3/8-in. | 2.8 | 0.8 |
| No. 4 | 252.8 | 75.8 |
| No. 8 | 76.7 | 23.0 |
| <No. 8 | 1.4 | 0.4 |
| Totals | 333.7 | 100.0 |

## GERMAN SAMPLES

Diabase for Top Course Blend

The sample of diabase (Splitt 11/22) is composed of crushed igneous trap rock. The aggregate is medium to very fine grained, dark gray in color, and contains a small amount of felsitic to basaltic particles. Some particles contain exposures of calcite. Sieving of the sample produced the following amounts of particles retained on the sieves indicated.

| Sieve Size | Amount Retained | |
|---|---|---|
| | Weight, g | Percent |
| 3/4-in. | 328.4 | 37.1 |
| 1/2-in. | 411.0 | 46.5 |
| 3/8-in. | 123.0 | 13.9 |
| No. 4 | 18.5 | 2.1 |
| <No. 4 | 3.7 | 0.4 |
| Totals | 884.6 | 100.0 |

Gravel for Top Course Blend

The coarse gravel (Weser Kies 8/11), and fine gravel (Weser Kies 2/8) top course blend components contain heterogeneous mixtures of igneous metamorphic, and sedimentary rock types, as follows:

| Rock Type | Amount Contained in Sample Fraction No. 8 and Coarser | | | |
|---|---|---|---|---|
| | Coarse Gravel | | Fine Gravel | |
| | No. | Percent | No. | Percent |
| Igneous | 63 | 15.7 | 181 | 30.0 |
| Metamorphic | 206 | 51.4 | 331 | 54.8 |
| Sedimentary: | | | | |
| Carbonates | 122 | 30.4 | 74 | 12.2 |
| Sandstone | 3 | 0.8 | 4 | 0.7 |
| Siltstone | 5 | 1.2 | 13 | 2.1 |
| Chert | 2 | 0.5 | 1 | 0.2 |
| Totals | 401 | 100.0 | 604 | 100.0 |

Remarks

The igneous rock category includes granite and felsite particles. The metamorphic rock category includes predominantly quartzite particles and a few black, hard metasedimentary particles. The sedimentary carbonate rock category includes limestone particles.

The coarse gravel contains approximately 46 percent crushed particles; the fine gravel contains approximately 17 percent crushed particles. Percentages are based upon actual counts of particles retained on the indicated sieves, with the exception of the No. 4 and No. 8 fractions from which samples of 300 particles each were analyzed.

Sieving of the gravel samples produced the following amounts retained on the sieves indicated:

| Sieve Size | Amount Retained | | | |
|---|---|---|---|---|
| | Coarse Gravel | | Fine Gravel | |
| | Weight | Percent | Weight | Percent |
| 1/2-in. | 321.8 | 44.8 | 4.5 | 0.5 |
| 3/8-in. | 260.2 | 36.2 | 4.9 | 0.6 |
| No. 4 | 127.7 | 17.8 | 468.3 | 53.8 |
| No. 8 | 3.3 | 0.5 | 344.2 | 39.6 |
| <No. 8 | 4.9 | 0.7 | 48.4 | 5.5 |
| Totals | 717.9 | 100.0 | 870.3 | 100.0 |

Recycled Concrete for Bottom Course

The coarse, medium, and fine crushed recycled concrete samples all contain gravel as the original coarse aggregate. Three distinctly different colors in the cement paste were noted, indicating possible variability in the quality of the concrete. The composition of the recycled concrete is classified according to the color of the cement paste, as follows:

| Composition by Cement Paste Color | Amount in Sample | | | | | |
|---|---|---|---|---|---|---|
| | Coarse PCC | | Medium PCC | | Fine PCC | |
| | No. | Percent | No. | Percent | No. | Percent |
| Tan | 12 | 60.0 | 34 | 59.6 | 115 | 59.3 |
| Light Gray | 5 | 25.0 | 16 | 28.1 | 63 | 32.5 |
| Dark Gray | 3 | 15.0 | 7 | 12.3 | 16 | 8.2 |
| Totals | 20 | 100.0 | 57 | 100.0 | 194 | 100.0 |

Remarks

The dark gray cement paste appears black when wet. Particle counts include all sample material.

Sieving of the recycled concrete samples produced the following amounts retained on the sieves indicated:

| Sieve Size | Amount Retained | | | | | |
|---|---|---|---|---|---|---|
| | Coarse PCC | | Medium PCC | | Fine PCC | |
| | Wt., g | Percent | Wt., g | Percent | Wt., g | Percent |
| 1-in. | 107.7 | 29.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3/4-in. | 208.4 | 56.8 | 49.0 | 17.2 | 0.0 | 0.0 |
| 1/2-in. | 46.1 | 12.6 | 190.5 | 67.0 | 92.4 | 28.9 |
| 3/8-in. | 4.8 | 1.3 | 43.7 | 15.4 | 145.7 | 45.5 |
| No. 4 | 0.0 | 0.0 | 1.0 | 0.4 | 82.1 | 25.6 |
| Totals | 367.0 | 100.0 | 284.2 | 100.0 | 320.2 | 100.0 |

Sand

The sand (0/2) sample contains considerable amounts of igneous and metamorphic rock detritus in the size fractions coarser than No. 8. A small amount of sedimentary rock material also is present. The major constituent is quartz, becoming the predominant component in the sample fractions passing No. 30 and retained on the No. 200 sieve. The sample fraction passing No. 200 is composed of argillaceous and calcareous material.

The sand particles vary from angular to rounded. Sieving the sand produced the following amounts retained on the sieves indicated:

| Sieve Size | Amount Retained | |
|---|---|---|
| | Weight, g | Percent |
| No. 4 | 4.8 | 1.3 |
| No. 8 | 2.9 | 0.8 |
| No. 16 | 29.6 | 8.0 |
| No. 30 | 97.6 | 26.6 |
| No. 50 | 151.6 | 41.2 |
| No. 100 | 67.2 | 18.3 |
| No. 200 | 12.8 | 3.5 |
| <No. 200 | 1.1 | 0.3 |
| Totals | 367.6 | 100.0 |

Comparable Local Aggregates

The following tabulation contains sources of Michigan, Wisconsin, and Ontario igneous/metamorphic aggregates that would be comparable to the European aggregates identified as blending components for the top course of a two-course concrete pavement. The aggregates listed do not contain carbonate rock, and therefore would most likely be resistant to polishing if exposed to traffic. Samples from the sources were tested for freeze-thaw durability by the MDOT Testing Laboratory. High-durability carbonates were not included in the listing due to potential traffic polishing susceptibility if used as exposed aggregate.

| Source Name | Pit No. | Lab. No. | F-T Durability Factor | LA Abrasion Loss, % |
|---|---|---|---|---|
| Piispanen | 27-34 | 90A-3310 | 93 | 20 |
| Dunham | 27-52 | 85A-3415 | 92 | 18 |
| Westeen | 27-85 | 90A-3987 | 100 | 11 |
| Caspian #2 | 36-40 | 89A-4138 | 96 | 15 |

| Source Name | Pit No. | Lab. No. | F-T Durability Factor | LA Abrasion Loss, % |
|---|---|---|---|---|
| Midwy Ind. Park | 52-90 | 91A-3377 | 100 | 12 |
| T-Bird (Wisconsin) | 94-24 | 91A-3471 | 99 | 19 |
| Bruce Mines (Ont.) | 95-10 | 92A-3050 | 100 | 14 |

MATERIALS & TECHNOLOGY DIVISION

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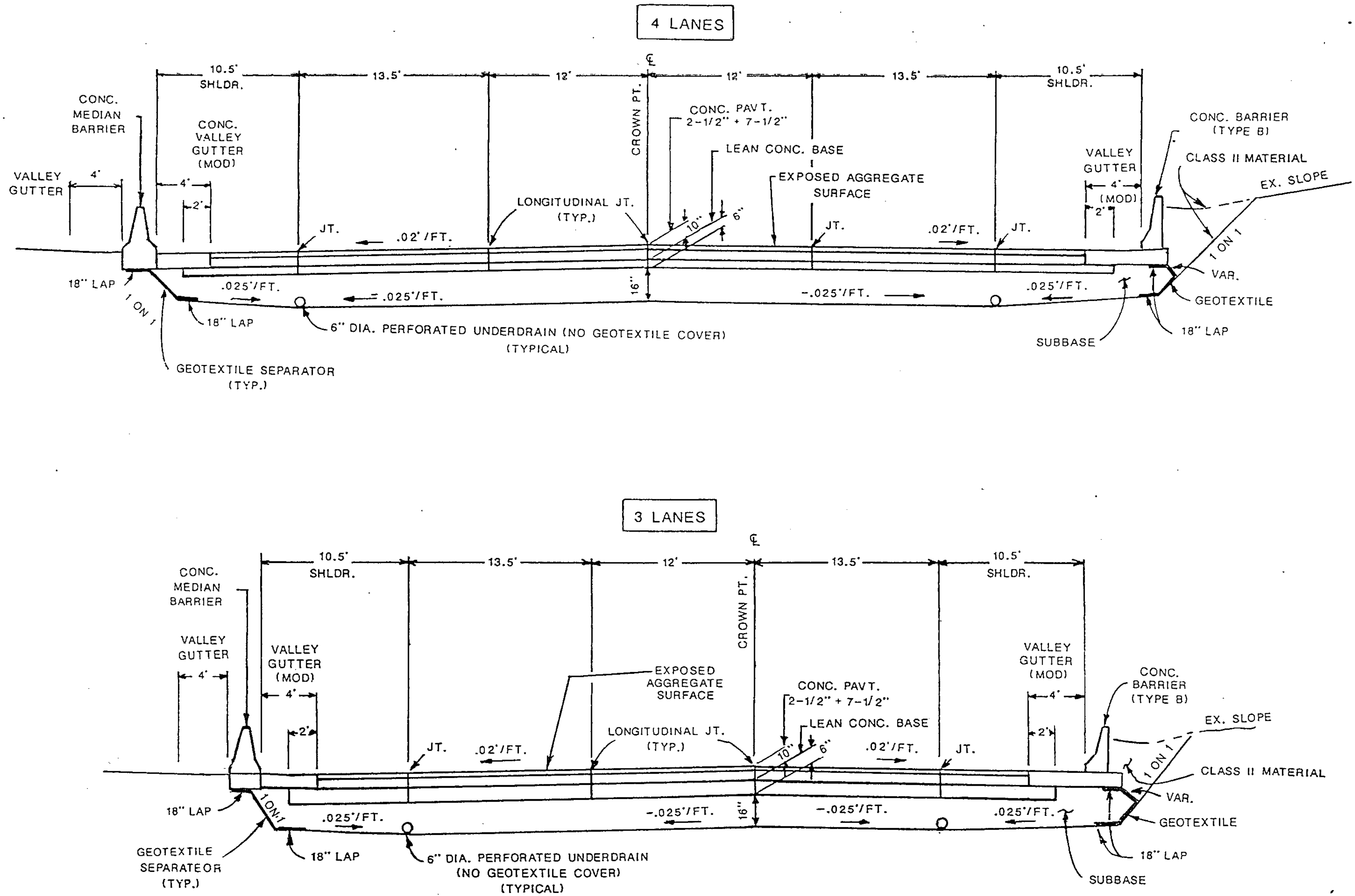


Figure 1. Typical cross-sections trial project