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Summary Report—

U.S. Tour of European Concrete Highways (U.S. Tech)

Follow-up Tour of Germany and Austria

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15. Supplementary Notes
Team members included Roger Till and Randy Van Portfliet, Michigan Department of Transportation; Ray Gemme, New York State Department of Transportation; and Patrick Nolan, Interstate Highway Construction, Inc., representing the American Concrete Pavement Association. The tour was arranged by BASt, the German Federal Highway Research Institute in Cologne.

16. Abstract
The purpose of this report is to describe the findings and recommendations of the follow-up U.S. Tour of European Concrete Highways conducted October 10 to 22, 1992. The goal was to obtain sufficient information to construct experimental highway sections in Michigan and other States using the German design and to review an active construction project in Austria to obtain information on the exposed aggregate surface treatment technique to reduce tire/pavement noise.

The report addresses some of the differences in the German and U.S. approaches to the design of concrete highways. Major technical issues relating to the design of portland cement concrete pavements are discussed. A major feature of the German cross section for new or complete reconstruction is the use of a 15cm (6 in) lean concrete or cement bound pre-notched base, to which the PCC slab is bonded. Other major features are the provision of a thick granular blanket layer under the stabilized base and the provision of longitudinal edge drains, usually outletted to the storm drain system. Plate bearing quality assurance tests are run on the subgrade and the granular blanket surfaces to assure strong support for the stabilized pavement structure. The construction of a recently completed exposed aggregate surface treatment project in Austria is discussed. This technique has been routinely used in Austria since 1989 to provide a durable high quality surface with high friction and low tire/pavement noise characteristics.

Unique equipment observed included the cart used to place the plastic sheeting for curing and motorized brush for constructing the exposed aggregate surface treatment. Also unique was a concrete paver designed to place both the upper and lower layers of concrete for the PCC slab in one pass. This allows higher quality aggregates to be used in the top layer to improve friction characteristics and long-term surface durability

Recommendations are made regarding various technical issues to be evaluated further and ways to improve the international exchange of technical information. Also, copies of the tour report by the Michigan Department of Transportation representatives and of the special provisions included in the bid documents to construct a one-mile hybrid German/Austrian experimental section on I-75 in Detroit, Michigan, are included in the appendices.

17. Key Words	18. Distribution Statement
Jointed plain concrete pavement, PCC surface texturing, Austria, Germany, Michigan, concrete mix dowels, subgrade, granular blanket layer, transverse and longitudinal joints, lean concrete base.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

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Based on the May 22 to June 6, 1992, initial findings of the U.S. Tour of European Concrete Highways (U.S. TECH), follow-up visits to Germany and Austria were made October 10 to 22, 1992. The purpose of the tour was to accomplish the following:

1. Obtain sufficient information to construct experimental sections in Michigan and other States using the German design.

2. Review an active construction project in Austria to obtain information on the exposed aggregate surface treatment technique to reduce tire/pavement noise.

The team was comprised of the following individuals:

Federal Highway Administration	Roger M. Larson, Suneel Vanikar, Dr. Stephen Forster
Michigan Department of Transportation	Roger Till, Randy VanPortfliet
New York Department of Transportation	Ray Gemme
American Concrete Pavement Association	Patrick Nolan from Interstate Construction Company, Denver, Colorado

Considerable technical information was accumulated during the tour and in follow-up contacts with various German and Austrian engineers. These documents include original versions in German, copies of English translations of various reports, and related reports available in English. A number of the German reports will be translated into English in the future. This report summarizes the major findings and recommendations made as a result of the tour.

II. TOUR OF GERMANY

A. General

The tour included a visit to BASt, the Federal Highway Research Institute in Cologne, Germany, and visits to construction projects in the following areas:

- Highway A27 near Langwedel (Bremen), hosted by the Road Administration of Lower Saxony in Hanover.

- Highway A10, southern Berliner Ring Route, near A13, hosted by the Brandenburg Autobahn Authority in Stolpe (north of Berlin).

- Highway A9 from A14 near Halle/Leipzig south 43 km (25 miles), hosted by the Halle Autobahn Authority in Halle.

- Highway A8 relocation around Stuttgart airport runway extension, hosted by the Baden-Wüttemberg Autobahn Authority in Stuttgart.

We reviewed typical projects in the former East Germany as well as in the former West Germany. Mr. G. Zimmerman and his staff of the International Co-operation Section of BASt were instrumental in making the trip arrangements on relatively short notice. Their assistance was greatly appreciated.

B. Philosophical Approach to Highways

Before the major technical issues are addressed in the next section, it is useful to review some philosophical differences between the United States and Germany regarding highways. This section is based on observations during the tour and particularly on discussions with Dr. Canisius, head of the Highway and Bridge Construction Technology Department of BASt. Dr. Canisius' comments were particularly informative and helpful.

1. General Technical Approach

The Germans use a design catalog for selecting pavement designs. The catalog was developed by a panel of experts in 1965 based on the results of the AASHO Road Test and has received only minor refinements since that time. A total pavement structure of 50 to 90 cm (20 to 36 in) is specified for both asphalt and portland cement concrete pavement types and includes a variable thickness "blanket" layer to provide frost protection to the subgrade and some vertical drainage. No significant structural design variations are allowed unless tested in the laboratory at BASt before construction. An English translation of the current German design catalog was subsequently obtained from the British Transportation Research Laboratory library.[(1)] Individual project designs are not used.

In Germany there is a much higher commitment to research at the national level than there is in the United States. For example, BASt has an annual budget of 50 million German marks (about $33 million) and a permanent staff of 440 at Cologne. In addition, a Berlin branch was established in 1990, and a winter maintenance branch is at Inzell, Bavaria. In addition to advising the Federal Department of Transport, BASt has a leading role in the formulation of specifications and standards. It also collaborates with other agencies, particularly the Universities. BASt's laboratory facilities and capabilities are extremely impressive. BASt has funds to supplement living costs for visiting researchers for three months but not to pay travel costs. So far no one from the U.S. has taken advantage of this offer. A more detailed discussion of German research is included in appendix B.

Germany has a high level of commitment to technical expertise regarding pavements. This is apparent at the Federal research level and on the part of contractors and industry. Careers in the pavement area are rewarded with little emphasis on rotation to develop generalist managers, as is common in the United States. Cooperation between government engineers, contractors, and universities is apparent. Engineers are encouraged to attend technical conferences in Europe and also abroad. It is apparent that they keep abreast of and refine technological developments obtained from the United States. Some of the designs in East Germany in the 1930s were based on the results of Bureau of Public Roads' research. As noted earlier, their design catalog was based on the AASHO Road Test.

Dr. Canisius also emphasized that *the largest technology transfer effort underway is the harmonization of European standards by 18 countries.* He was surprised that the United States was not involved with this effort. Copies of proposed and final standards are available in both French and English. *It is recommended that we follow up and get involved in monitoring this significant effort.*

Germany is not participating in the European COncrete Pavement Evaluation System (COPES), sponsored by the PIARC Rigid Pavement Design Committee, or the European SHRP Long Term Pavement Performance test sections for the following reasons:

- There is little design variation. The same design catalog has been used since 1965.
- Most sections last at least 25 years, making short term evaluations unproductive. Early failures or problems are usually isolated construction or materials quality control problems.
- The quality of maintenance is so high that any problems that develop are fixed before research can complete any detailed evaluations.
- The entire autobahn system was surveyed in 1992 and a pavement management type system is being developed that will meet their needs.

2. Funding Differences

Another major difference between the United States and Germany is the funding available for highway improvements. Taxes are much higher in Germany. The average price of gasoline is 1.5 German marks per liter with a tax of 0.6 German marks per liter (equivalent to about $4.00 per gallon, about $1.60 of which is taxes). Approximately half of the taxes are used for highway or railroad construction and maintenance. Therefore, they have a much larger amount available for both construction and maintenance, and they can afford to fund improvements with long lives. In the U.S., much more emphasis is placed on finding the most economical approach to obtain a fairly short extension in service life because the needs are so great. Other fees, like the value added tax and registration fees, also are much higher in Germany than in the U.S. Large automobile engines are heavily taxed each year. Oil at one service station (and there were very few in former East Germany) was equivalent to about $13.00 a quart.

3. Roadway Cross Section Considerations

In Germany, the paved roadway width is planned with future reconstruction in mind. The outer mainline lanes of each roadway are widened 0.5 m (1.6 ft) to 4.25 m (13.9 ft) to provide additional support, but the traffic stripe is placed at 3.75 m (12.3 ft). The shoulders are considered emergency lanes. They are tied and doweled to handle two-way traffic on each roadway during future stages of rehabilitation or reconstruction activities. As the older existing pavements are reconstructed, they are often widened and upgraded at the same time to minimize disruption to traffic. Many of the four-lane divided autobahns are currently being upgraded to six-lane facilities. See figure 1 for an example of the typical staging of traffic during reconstruction of a four-lane highway into a six-lane facility.(2) Some of their procedures for handling traffic through construction would not meet U.S. safety standards.

The traffic volumes, both automobile and truck, are substantial. Truck traffic on the autobahns is often in the 25 to 40 percent range. About 70 percent of freight is now moved on the highway system. The average accident rate in Germany is about one and a half times what is typical in the United States. Their motoring public apparently tolerates higher accident rates and delays during reconstruction than are common in the U.S. The typical project length is 5 to 6 km (3 to 3.6 miles) unless there is a longer existing section that is dangerous and needs replacement. In projects not maintained through the winter, opposing traffic is separated by a low, movable, segmented curb-type barrier with periodic vertical warning panels. In projects that will be maintained through the winter, opposing traffic is separated by a New Jersey-type barrier. A French-style movable barrier was being used at Stuttgart. Truck legal axle weights are now 11.5 t (25,300 lbs) and are expected to be raised to 13 t (28,600 lbs). There was no evidence of truck weight enforcement. Most trailers had triple rear axles with super single tires.

The mainline roadway pavement has a uniform cross slope from the median of 2½ percent. There typically is a metal beam-type median barrier and a beam-type barrier on each shoulder. To minimize right of way, the side slopes are typically 3 to 1 or steeper with 1 m (3 ft) or deeper ditches. Figure 2 shows the general cross section geometric elements.(3)

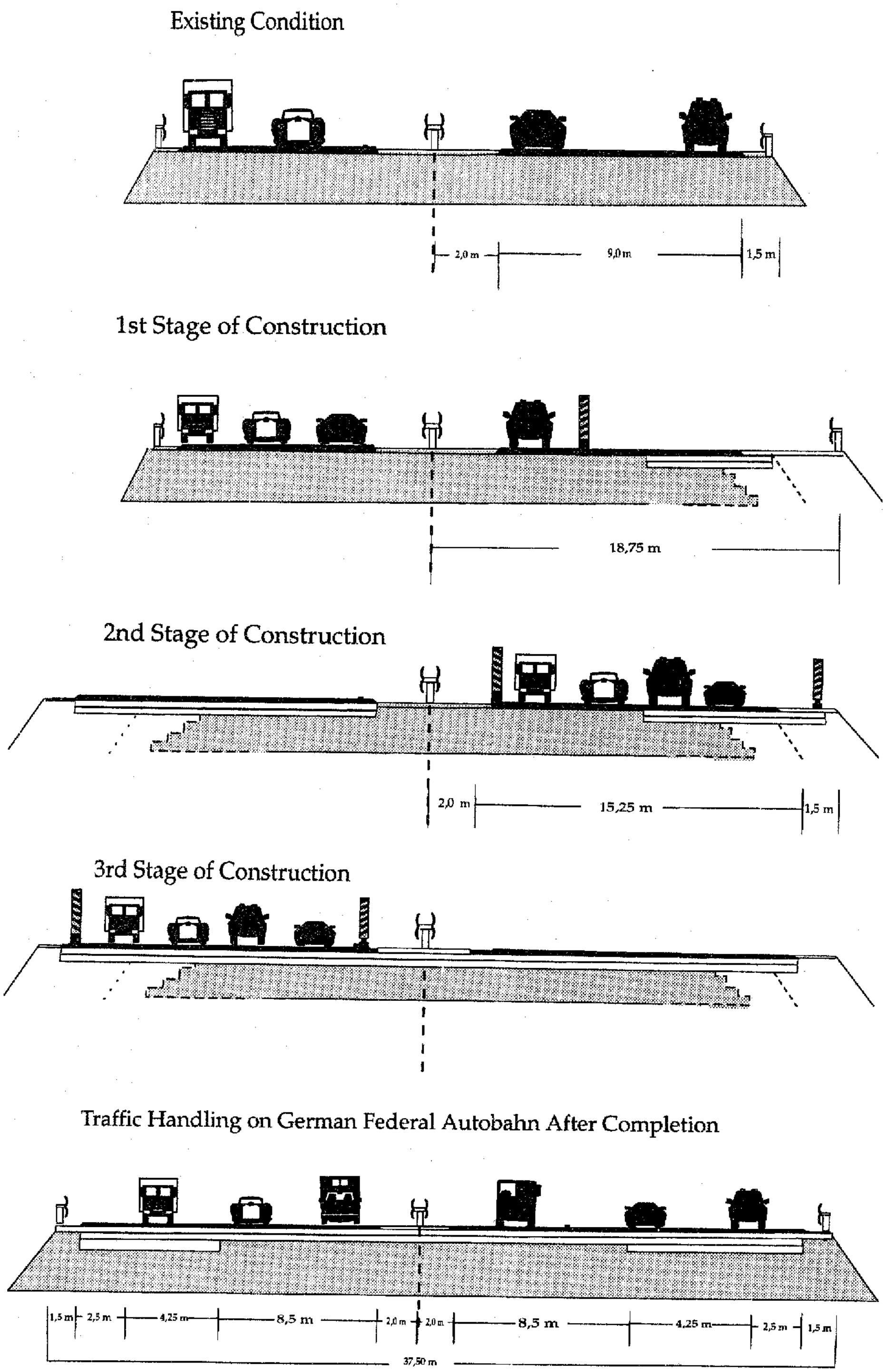

Existing Condition
2,0 m
9,0 m
1,5 m
1st Stage of Construction
18,75 m
2nd Stage of Construction
2,0 m
15,25 m
1,5 m
3rd Stage of Construction
Traffic Handling on German Federal Autobahn After Completion
1,5 m
2,5 m
4,25 m
8,5 m
2,0 m
2,0 m
8,5 m
4,25 m
2,5 m
1,5 m
37,50 m

Figure 1.

4. Contractor Relationships

A major difference from the U.S. practice is that contractors in Germany are required to provide two- to four-year warranties during which time a small portion of the contract amount is withheld. Any problems that develop are expected to be corrected by the contractor at no cost to the government. On the Highway A27 project north of Hanover, for example, 14 slabs that cracked due to late sawing were removed and replaced by the contractor at no extra cost. The contractor also is given much more flexibility to innovate and to propose materials type changes. In many cases, he is allowed to choose whether to construct an asphalt concrete (AC) or a portland cement concrete (PCC) pavement from the design catalog for a particular project. Any defective work affects the contractor's reputation and is considered when awards are made on future projects. The contractor is responsible for process control testing, and the government does a limited amount of quality assurance testing during and after construction. Dr. Canisius stated that this is a very different philosophy from the more detailed specifications provided in France, for example. This is another major issue that will have to be resolved during efforts to harmonize European standards.

There reportedly are 12 concrete paving contractors in Germany. All of the projects visited were being constructed by large firms where highway work comprised only about 10 percent of their total business. This was reported to be quite common.

C. Major Technical Issues

1. General Design

Jointed plain concrete pavement (JPCP) is used with 5 m (16.4 ft) square joints. In most cases, the maximum slab thickness was 26 cm (10 in). This is in spite of the heavier legal axle load in Germany and is related to their much greater emphasis on support under the pavement slab, their high quality concrete (compressive strengths of 20 cm (8 in) cubes at 28 days are 35 to 65 N/mm^2 (5075 to 9425 psi)), and their 0.5 m (1.6 ft) widened lane design. In the U.S., most of the emphasis is on slab thickness. In Germany, they also pay for increased concrete materials up to one additional centimeter in thickness to help assure that the minimum design slab thickness is constructed. The slabs were individually numbered in the truck lane for future reference. Figure 3 is a typical section of the German jointed plain concrete pavement showing structural features.[3]

Based on information obtained during the May 1992 U.S. TECH visit, there also is a major difference in thickness design of unbonded overlays in Germany and the U.S. The old slab (usually a lightly reinforced jointed concrete pavement) is cracked at a maximum spacing of 50 cm (20 in), and a 10 cm (4 in) layer of either PCC (which is notched like a concrete base) or AC is used as a bonded separator layer. The new

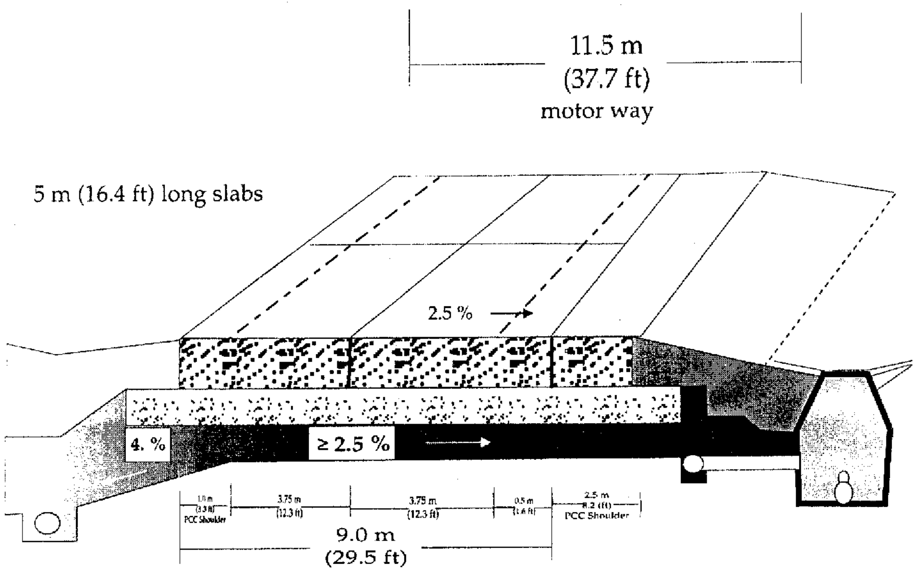


Figure 2. German concrete pavement geometric elements.

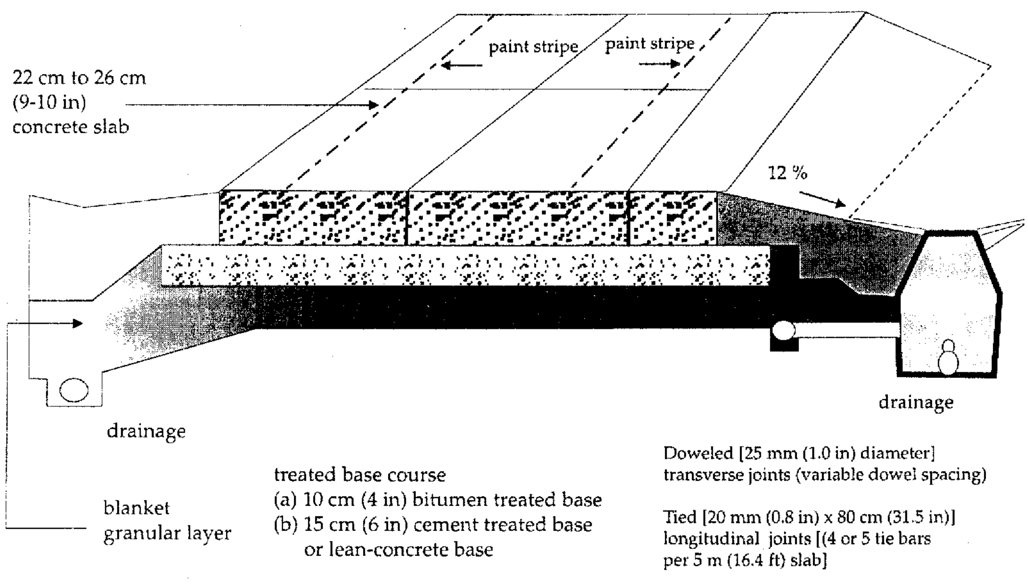


Figure 3. German jointed plain concrete pavement structural features.

slab is the same thickness as is used for new construction. Many U.S. design procedures reduce the slab thickness if it is placed over an old PCC pavement. If a geotextile combined drainage/separator layer is used, the PCC slab thickness is increased one centimeter. If a full-depth reconstruction with an untreated, open-graded permeable base (similar in gradation to many of our dense graded bases) is used, the slab thickness is increased to 30 cm (12 in). This is done because the untreated, slightly permeable base is considered to provide less support than does the dense graded stabilized base it replaced. For full-depth reconstruction of traffic lanes, as well as for pavement widenings, the use of a porous concrete as a base course is recommended. In these cases drainage is given special consideration and 5 corrosion protected tie bars 20 mm (0.8 in) in diameter per 5 m (16.4 ft) slab are used. *These designs are provided for in the standard catalogue (RStO-E 91—Design of Reconstruction of Old Pavements) which has now been obtained. It is recommended that this document be translated so the assumptions made can be studied.* Figure 4 shows the typical sections for pavement reconstruction.[3] This information is included because it illustrates their design philosophy, which is different than that commonly used in the U.S.

A major feature of the German cross section for new construction or complete reconstruction is the use of a 15 cm (6 in) lean concrete or cement bound base, pre-notched, to which the PCC slab is bonded. The base is notched either by vibrating a bar to form the transverse joint and using a knife to form the longitudinal joint in the plastic concrete or by sawing the hardened base to form the joints. The transverse joint is constructed 0.30 to 0.33, and the longitudinal joint is constructed 0.40 to 0.45 of the base thickness. These notches are placed under the planned location of the joints in the PCC slab within 5 cm (2 in) for the transverse and longitudinal joints. The base is moist cured for a minimum of three days (two to three weeks on the project near Bremen). No construction traffic is allowed onto the base until 70 percent of the base design compressive strength of 12 to 15 N/mm^2 (1740 to 2175 psi) is achieved. When first used, the cement treated base design compressive strength was only 6 N/mm^2 (870 psi). A standard burlap drag is used for the base surface texture to promote bonding to the PCC slab. Other than to keep the base surface clean prior to paving the PCC slab, no other special efforts are taken. It was generally believed by those questioned that the concrete slab and the lean concrete or cement bound base bonded together for about four (range of two to ten) years before debonding begins to occur at the joints and slab edges. The concrete slab is usually constructed in two layers, so a very durable surface layer can economically be provided.

It also should be noted that bonding of the slab to the notched base is not universally accepted in Europe. In former East Germany, Austria, and Belgium, a 5 cm (2 in) AC separator layer was preferred for newly constructed PCC slabs over a cement bound base.

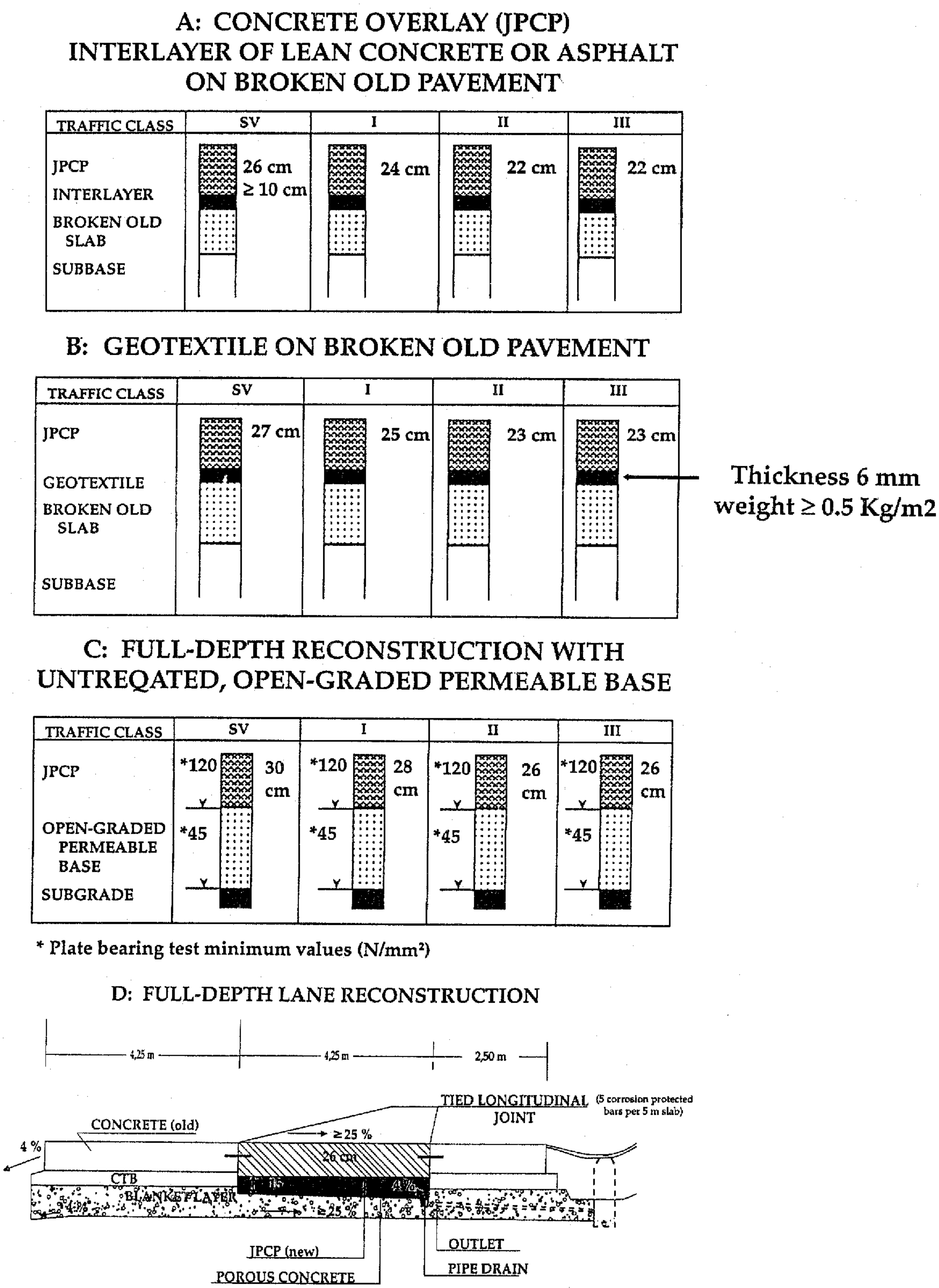


Figure 4. Designs for renewal of old concrete pavements in Germany.

We could not obtain detailed performance data because information on the traffic loading and amount of maintenance was not readily available. However, it was apparent that they maintain their pavements to a much higher level and rehabilitate (reconstruct) them before they deteriorate to the poor condition that is common in the U.S. This reflects their higher tax structure and greater infrastructure investment. The effect of the failure to maintain the autobahns in former East Germany is a striking example of the investment level needed to repair the highways and the tremendous traffic congestion that has resulted. Whether the German concrete pavement design with the bonded lean concrete base is more cost effective than the permeable base design being promoted by the U.S. Federal Highway Administration (FHWA) has yet to be determined. The one-mile experimental section of roadway being constructed in 1993 on I-75 (which carries over 5,000 heavy trucks per day) in Detroit, Michigan, will provide a direct comparison of the performance of the hybrid German/Austrian design with the standard jointed reinforced pavement with a permeable base, which is the standard design currently used in Michigan. For a more detailed description of the experimental section refer to appendices C, Michigan Department of Transportation's (DOT's) trip report, and D, Michigan's specifications for the German design and the Austrian exposed aggregate surface treatment. *The German pavement structural design might be a particularly cost effective option that requires less maintenance in the States with areas having low rainfall or on routes with medium levels of heavy truck traffic.* Colorado is proposing to construct the German design as a supplemental section to their SHRP SPS-2 experimental project.

A good comparison of the performance of European designs will be possible by analyzing the European COPES data collected for 77 sections in France, Belgium, the United Kingdom, and Italy as the result of an effort by the PIARC Technical Committee on Concrete Roads. German and Austrian sections were not included. It is proposed to use this data to supplement an ongoing FHWA research contract evaluating the performance of about 300 previously constructed jointed concrete pavement experimental sections in the U.S. Depending on the completeness of the data received, this will allow an evaluation of the effect of features such as nonerodible bases (lean concrete), trapezoidal cross-sections, widened lanes, and various types of positive drainage under very heavy axle and tire loadings. The sections were selected to provide performance data on pavement sections with design features under heavier axle loadings than are available in the U.S. An analysis of the data is expected to be completed in 1993.

2. Subgrade and Granular Blanket Layer

A blanket layer is provided under all pavements in Germany. The thickness of this layer depends primarily on the Corps of Engineers' frost susceptibility criteria of the subgrade soil type, with minor adjustments for the specific project being designed. The translated version of the German design catalog gives a more complete description of the thickness design procedure.[1] This total pavement structure depth is designed to extend downward to about 100 percent of the total expected frost depth to reduce frost heaves and to provide some subbase drainage.

Another interesting design feature is the specification of a minimum bearing value or modulus for both the subgrade and the granular blanket layer to assure strong support for the stabilized pavement structure. The minimum subgrade bearing value is 45 N/mm^2 (6525 psi), and the minimum blanket layer bearing value is 120 N/mm^2 (17,400 psi). This is in addition to normal compaction control. The plate bearing test (DIN 18134-June 1990)[4] is considered as part of the quality assurance testing. *It is recommended that we purchase this test equipment so a test can be run at the same time as the impulse (falling weight deflectometer) test protocol P59, which was developed by SHRP for SPS-2 test sections.* This will help us to correlate the quality of support specified by the German design procedure with typical U.S. practices. In the current AASHTO design procedure the quality of support does not significantly affect the slab thickness design. This type of test procedure would help assure that uniform high quality support is routinely provided. NCHRP Project 1-30, Support Under PCC Pavements, is now addressing this issue.

If it is to be expected that the degree of compaction specified and/or the required modulus of subgrade deformation cannot be attained, special measures must be provided in the performance requirements.

- Creation of an improved or reinforced subgrade or foundation in accordance with ZTVE-StB or ZTVV-StB.
- Improvement of the grain composition of the frost protection layer's mineral mix by addition of supplementary granular material.
- Reinforcement of the top stratum of the frost protection layer with a binder in accordance with ZTVV-StB.
- Increasing the thickness of the frost protection layer or the bound load-bearing layer above it.
- Substitution of the frost protection layer with a suitably thicker pea gravel or gravel load-bearing layer in accordance with ZTVV-StB.
- Creation of a bound top layer.

As noted earlier much greater attention is given to assuring strong uniform support to the pavement in Germany than is typical in the U.S. The team did not observe any plate bearing tests being conducted on the projects visited.

3. Drainage

The cross slope of the mainline pavement is a uniform 2½ percent sloped away from the median. On the median side, the subgrade was sloped 4 percent towards the median from a point 1 m (3.1 ft) inside the median edge of the inside lane. This reduces the amount of water from the median area that would get under the mainline lanes. The slope on the subgrade under the heavily travelled lanes is frequently increased to as much as 4½ percent to get the water out from under these lanes faster. *Both of these features should be given consideration in the U.S.* Refer to figure 2 for typical cross section geometric details.

Another major feature of the drainage considerations is the granular blanket layer that is always provided. This furnishes frost protection to the subgrade and allows for at least some vertical drainage. *However, recent permeability tests and gradation analysis by the Michigan DOT confirm that this material is not very permeable (it is similar to conventional dense graded base courses).* This has raised some concerns about using the current German specifications for this material. This particular feature is being evaluated further. However, even when wet, this granular material provides very good pavement support due to the low deflection of the pavement slab that is bonded to the stabilized base. This reduces loss of support due to pumping, and the thick bonded slabs reduce vertical movement at the joints due to temperature curling or moisture warping stresses.

Another major drainage feature is the use of edgedrains. Most of the edgedrains placed were connected to the catch basins for the surface drainage because of the depth of the blanket layer to be drained. In environmentally sensitive areas where surface drainage must be treated to protect the water supply, this was routinely done. However, in other areas such as on fills, the edgedrain outlet was daylighted to the slope. *BASt indicated that the current thinking is to reduce the amount of edgedrain used.* Based on the low permeability of the blanket layer, it is unlikely that they drain much water except in special areas like sags. During our review, most projects had edgedrains on both the median side (to drain the section while construction was underway) as well as on the outside edge of the roadway. On the Stuttgart project, which had a bituminous surface, a drain also was provided in the subgrade directly under the roadway centerline joint.

4. Transverse and Longitudinal Joints

Transverse joint spacing in the slab and the lean concrete base is limited to 5 m (16.4 ft) to reduce temperature curling and moisture warping stresses. The shorter joint spacing also reduces the horizontal joint movement due to temperature changes and improves the performance of the joint sealants. The transverse joints are sawn 0.30 of the slab depth. Deeper saw cuts are not recommended as they are expected to contribute to blow-ups of the slab in the future. A second or widening sawcut is made to get the correct shape factor for the sealant used.

A unique feature observed was the use of a plastic cord in the initial sawcut to prevent incompressibles and slurry from the widening cut from getting into the crack under the joint. This also would help prevent later blow-ups or compression failures.[5]

Another advantage of bonding the PCC slab to the notched cement bound or lean concrete base is that the joints crack more uniformly. This results in less probability of random transverse cracks developing and also should result in better performance of the preformed compression joint seals. Some recent projects in the U.S. over dense graded or open graded asphalt bases have resulted in only every sixth or seventh joint cracking initially. This results in the intermediate uncracked joints having the initial saw cut width while the other cracked joints open as much as 25 mm (1 in) or more. *The design and construction of the joint seals and backer rods should recognize that all joints may not crack or open equally, and this should be carefully considered to ensure satisfactory long-term performance.*

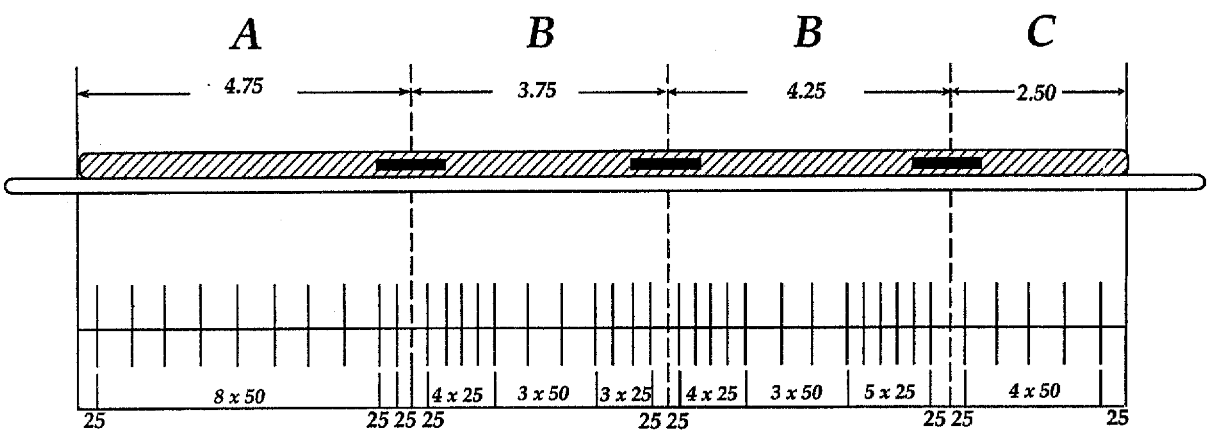
German experience has documented that dowel bars are needed to extend the pavement service life, even if high quality support and stabilized bases are provided. Dowels were not allowed to be used in former East Germany during part of the 1930's and from 1970 to 1990. *Some of the undoweled pavements constructed since 1970 have developed significant faulting within 15 years, even with the strong stabilized base and subbase [usually 5 cm (2 in) AC over a lean concrete or cement bound base and an aggregate blanket layer] support provided.*

One major difference between U.S. and German practice is that 26 mm (1 in) diameter dowels are used routinely in Germany. In former East Germany on the project near Halle/Leipzig that was an earlier design, 20 mm (0.8 in) diameter dowels were being used. They were coated with a 0.3 mm plastic that needs no bond breaker and appeared to be very durable. Possible reasons for the apparent satisfactory performance include closer spacing (25 cm/10 inches) in the wheelpaths of the truck lane, the higher quality of base and subgrade support, and the generally higher quality concrete mix. The reason larger diameter dowels were not used is believed to be the concern that the concrete under the dowels will not be adequately consolidated without sinking the dowel due to the standard use of the dowel bar inserter. *The density of the concrete under the dowels in the U.S. should be reviewed, as this is potentially an even greater problem with larger diameter dowels and one-layer construction. However, due to the increasing truck volumes and axle loads, it is not recommended that current U.S. practice of using larger dowel bar sizes be changed.* A minimum diameter of 32 mm (1¼ in) is still recommended. As most failures are joint related and are not due to typical slab fatigue, it is believed this will significantly extend the pavement service life at a minimal cost.

Germany has used dowel bar inserters routinely since 1975 with excellent success. Due to roughness of the pavement surface when the dowel bar inserter was used on one-layer construction and the desire to provide a more durable pavement surface, two-layer construction of the pavement slab has now become standard. It should be noted that Theodore Moss, a representative of HOCHTIEF, stated that even with the very stiff concrete mix used in Germany, the dowel bars placed in the lower layer could be sunk by excessive vibration of the top layer of concrete. This is perhaps one reason for the T-shaped vibrators used by German and Austrian contractors for the top concrete layer. It also was stated that dowel bars misaligned by 0.5 cm or more caused problems. There also was an occasional problem with no bars being placed in the inserter. We did see two dowel bars sticking out of the lower layer of the shoulder concrete on A10 on the south Berliner Ring Route that were obviously misplaced (one end of the bars must have fallen out of the inserter fingers). *Therefore, it seems that an improved method to quickly check the accuracy of dowel bar placement is still needed.*

Routine use of the dowel bar inserters also has allowed Germany to vary the spacing on the dowels. They concentrate most of the dowels in the wheelpath of the truck lane and increase the spacing in other lanes. They also install dowels with greater spacing in the emergency lanes (shoulders). Figure 5 shows the spacing of the dowel bars. Square joints and uniform joint spacing are used. The 5 m (16.4 ft) joint spacing used is slightly greater than currently recommended by FHWA for unbonded, unreinforced PCC slabs over cement stabilized or lean concrete bases. The variable spacing of dowels is a feature we should give more consideration to, possibly as an incentive to use dowel inserters. However, the dowel bar spacing and square or skewed joints should be standardized as the cost to change the dowel bar inserters, once purchased, is over $100,000.

Germany routinely seals and maintains all joints. In the past, joints were typically resealed every five years with a low quality sealant. The use of silicone sealers was tried but was discontinued three years ago due to poor performance. They are now using an elastomeric preformed compression seal manufactured by a German firm, Phoenix, for both the longitudinal and the transverse joints. This is reported to be a harder grade material than the neoprene compression seals often used in the U.S. and has an estimated service life of eight years. No lubricant adhesive is used; the seal is just pressed into place with special equipment. This type of seal has recently been installed in 30 joints on a short experimental section in Iowa. It also will be used on the one-mile experimental section being constructed in 1993 in Detroit, Michigan.



Execution mode A:	**lanes carrying light traffic load**
Execution mode B:	**lanes carrying heavy traffic load**
Execution mode C:	**emergency parking lane (if doweled)**

Figure 5. Varying dowel bar spacing across pavement in Germany.

The Germans have used three to five tie bars at least 20 mm (0.8 inch) diameter and 80 cm (31.5 in) long per 5 m (16.4 ft) slab.[5] The depth of sawing the longitudinal joint in the mainline pavement is generally 0.40 to 0.45 of the slab depth. During the tour, it was indicated that three tie bars per slab were not performing satisfactorily and four or five tie bars would be used in the future. Five tie bars per slab are recommended where the shoulder is constructed separately after the main lanes and at ramps that are used by medium or high volumes of heavy trucks. It would seem this also should be done on truck climbing lanes. The center third of the tie bar is usually coated with 0.3 mm plastic to prevent corrosion at the joint. The tie bar is placed about one-third to one-half of the distance from the top of the slab. *A number of instances have been observed in the U.S. where the tied concrete shoulders are not providing effective long term load transfer across the longitudinal joint. This is particularly common when the shoulders are constructed separately from the main lanes and at ramps carrying higher volumes of heavy trucks. It is recommended that the diameter and spacing of tie bars be reexamined and that improved guidance be provided.*

The other major feature regarding the longitudinal joint is the routine use of 0.5 m (1.6 ft) widening of the outside and median lanes. This has reduced slab cracking, reduced reliance on the load transfer effectiveness of the tie bars at the longitudinal joint, and has reduced the amount of faulting at the joints. This feature is considered to be very effective.

5. Concrete Mix Design

In general, it appeared much greater attention is given to mix design in Germany than in the U.S. At least three sizes of aggregate are blended together to provide better control of the gradation of the coarse aggregate fraction. Two-layer construction is specified as a matter of economics. The maximum size of the coarse aggregate is normally 22 mm (0.9 in) in the top layer and 32 mm (1.3 in) in the bottom layer. A natural sand is used for the lower layer while a manufactured sand, usually with a minimum of 30 percent quartzite, is used in the top layer to provide greater friction. The minimum concrete compression strength (15 cm or 20 cm [6 in or 8 in] cubes) is usually 40 N/mm^2 (5800 psi) or 5.5 MPa (800 psi) for center point loading flexural strength at 28 days. The concrete provided is usually a higher strength than the minimum required by the specifications. Normally during construction this results in 50 N/mm^2 (7200 psi) compressive strength concrete for the lower layer and 65 N/mm^2 (9425 psi) compressive strength for the higher quality top layer. This separation of aggregate sizes allows the contractor to fine tune the mix to assure high quality concrete. As the contractor typically warranties the pavement for four years, he does not economize by reducing the concrete strength to the minimum allowed. Fly ash usually is not used in the mix because of its variability. However, in the U.S. many sources of fly ash are consistent and may be necessary to mitigate ASR. Additional details are provided in appendices B, C, and D and in references 3 and 5.

Chemical admixtures, except for air entraining agents and water reducers, typically are not used. Air entraining agents are always used, and specifications are more rigid in Germany than in the U.S. On the A27 project near Bremen the contractor was using the Danish air meter for measuring fresh concrete air entrainment. FHWA has also procured this device and is evaluating it.

Except for some alkali-aggregate reaction in former East Germany, there was no evidence of concrete durability problems, even on 50-year-old concrete. It was reported that due to recyling of the cement fines to reduce air pollution during manufacturing in the 1970s, the cement contained high amounts of alkali which, combined with the type of aggregate used, caused the problem. Cement from some plants is still not allowed in highway construction because of this problem. A thick asphalt overlay was placed on some of the worst pavement to extend the service life an expected five to eight years until the pavement can be replaced. The total amount of alkali material in the mix is limited to a total of 3.6 kg/m^3 (6 lbs/cy) to prevent this problem from happening. It is apparent that the aggregate quality test procedures used eliminates durability problems such as spalling and scaling and materials-related problems like D-cracking or alkali-silicate reaction (ASR).

In former East Germany, the preferred freeze-thaw durability test was 14 cycles in a one percent nitrium chloride solution rather than 100 cycles when plain water is used. *This should be investigated to see if it would significantly reduce the time needed for freeze-thaw durability testing.*

All concrete pavement slabs being placed in Germany were constructed in two layers with the upper layer about 7 cm (2.7 in) thick. In most cases, a specially designed paver was used for placing the two layers at the same time. The main reason for the two-layer construction was stated to be economics. This allowed the use of very high quality durable aggregates in the top layer and the use of more locally available aggregate in the lower layer.

PCC pavements have been routinely recycled into the upper portion of the granular blanket layer and the lean concrete or cement bound base. They have recently been used as part of the coarse aggregate in the lower portion of the PCC slab. The recycled material in the 0 to 10 mm (0 to 0.4 in) size range is not used in the concrete mix. No ASR concrete has yet been used as recycled material on the autobahn system.

6. Equipment and Construction

The major equipment innovation was the two-layer paver. This equipment was observed on most of the projects visited. A mobile crusher, which is also available in the U.S., was observed near Leipzig. On two projects, two very short pavers were used in tandem to place the concrete. The major advantage claimed was that these could easily be hauled over the road and set up in three hours. This is a considerable saving in time over the larger U.S.-type equipment. This is important because the average German project is only 5 to 6 km (3 to 3.5 miles) long. The lighter weight of the short pavers combined with the stiff concrete used raised some unanswered questions about the ride quality actually being obtained. The T-shaped vibrators used only on the top lift of the concrete also were unique. It was believed that these vibrators were designed to prevent settlement of the dowels and tie bars when the upper layer of concrete was consolidated. As noted previously, dowel bar inserters have been used routinely since 1975. The type of concrete mixer (believed to be a twin shaft mixer with a clam gate dump with a capacity of about 220 M^3/hr) observed near Leipzig also was unique compared with the type of large dual drum mixers typically used in the U.S.

7. PCC Surface Texturing

Due to the higher population density in Germany, tire noise is a very important issue. A longitudinal burlap drag is used because it was reported to provide a quieter riding surface and adequate friction properties compared to dense graded asphalt pavements. The initial friction values obtained and the reduction in friction values over time were not available. The use of only a longitudinal burlap drag does not agree with U.S. practice. It also is contrary to the results of recent Australian research, which showed that a longitudinal burlap drag combined with light transverse tining (1.0 to 2.0 mm) was quieter and also had better skid resistance than did the longitudinal burlap drag by itself. *The current U.S. guidelines on surface texturing of portland cement concrete pavement should be reviewed to see if any changes in existing recommendations are appropriate based on recent research results and innovations such as the exposed aggregate surface treatment being used in Austria and other European countries.* As part of a European study to standardize surface texture requirements, a German research study is underway. An exposed aggregate surface treatment was to be constructed in 1993 to compare this treatment with other surface texture treatments constructed on A7 near Garlstorf in 1991 and 1992. Also, friction measurements on the autobahn system were made in 1992 that would make it possible to compare the properties of existing pavement surfaces. *The results of this research effort should be available in late 1993 or 1994 and should be very valuable to the United States in addressing this issue, which seems to be a concern in urban areas.* The U.S. emphasis on high friction properties to improve safety rather than on small changes in the tire/pavement noise level is considered appropriate. It also should be noted that in Europe the heavy commercial vehicle exhausts are under the frame and are not vertical like they are in the United States. This needs to be considered when evaluating the tire/pavement noise level contribution to the overall highway noise level and makes a large difference in the height of noise walls needed to mitigate the highway noise impact. A more detailed description of both German and Austrian noise practices is included in appendix C.

III. TOUR OF AUSTRIA

A. General

The major reason for visiting Austria was to observe the construction of a project with an exposed aggregate surface treatment designed to reduce tire/pavement noise while providing very high friction characteristics. Due to the lateness of the season, no other projects of this type were underway in Europe. The actual construction was completed the week prior to our visit. However, all of the construction equipment for the exposed aggregate surface treatment and the concrete pavers used were inspected on October 13 at the construction site in the vicinity of Villach near the Italian border. In addition, other recently constructed exposed aggregate surface treatment projects on A1 from St. Polten to Boheimkirchen and earlier experimental sections near Vienna were reviewed on October 14.

Also, we reviewed the paving of a refueling apron at the Vienna airport using a new Wirtgen paver that constructs two layers of the pavement slab with one piece of equipment. We also met with Mr. Andreas Moser, the equipment developer who now works with Wirtgen, in the Vienna airport on October 14.

After the trip, we received additional information from various sources. From Dr. Sommer of the Austrian Cement Association, we received the proceedings of the February 22 to 24, 1992 PIARC Tyre Noise Workshop held in Vienna. From Dr. Zitzka, Technical University of Vienna (as a result of a subsequent discussion at TRB), we received a summary of the Austrian Design Catalog (in English), information on the Austrian Plate Bearing Test, and some information on compaction. And from Wirtgen, we received additional technical information on their new paver and on concrete pavement design and construction in Austria from some of the projects where the exposed aggregate surface treatment was used.

Romain Buys, General Manager of ROBUCO, helped make arrangements and provided transportation for the team in Austria. Due to the short time frame for planning the trip, the appropriate government transportation officials in Austria could not be reached to coordinate the visit. Mr. Buys' assistance was extremely helpful.

B. Construction Project Near Villach, Austria

The mainline concrete paving was completed the week of October 3. In this mountainous terrain, a temporary asphalt concrete surface was constructed and settlement allowed to occur for seven years before the final concrete surface was constructed. Based on discussions with the Austrian engineer, it was noted that on projects such as this where the asphalt has aged, every second or third joint in the concrete pavement forms initially. On projects where the concrete is constructed over fresh AC, only every sixth joint cracks initially. This is similar to recent experience in the U.S. and has a major effect on the performance of the joint sealant used.

The concrete pavement design is quite similar to Germany except that in Austria a 5 cm (2 in) asphalt concrete separator layer is constructed instead of bonding the surface to the lean concrete or cement bound base (if used). The concrete mix design is developed by certified testing laboratories. Cores from older projects have had compressive strengths as high as 90 N/mm^2 (13,000 psi). Relatively thin 22 cm (9 in) pavement surfaces are constructed in two layers although the legal single axle load is 10 t (22,000 lbs). *The exposed aggregate surface treatment has been constructed on all concrete projects since 1989 to reduce tire noise and provide a surface with excellent friction characteristics.* The noise level is comparable to an open graded asphalt friction course which has been subjected to one year of traffic. The concrete surface is expected to retain its high friction characteristics and low noise level for 30 to 40 years now that studded tires have been banned in Austria. There are only four concrete contractors in Austria, and costs are reportedly about 10 percent higher than they are in Germany. The exposed aggregate surface treatment costs $2 to $3 per square meter (yard) in Austria.

A detailed report on noise considerations including Austria is provided in appendix A. Extensive research involving 18 different countries is underway to harmonize European standards including concrete pavement surface texture. This effort is expected to be completed by 1994. An excellent summary of interim research results on tire/pavement noise is included in the February 1992 PIARC Workshop proceedings. A more general meeting on surface characteristics was held in June 1992 in Berlin. A number of these papers also were presented at the Fifth International Conference on Concrete Pavement Design and Rehabilitation held at Purdue University on April 20 to 22, 1993, and are available in the published proceedings of the conference.

C. Vienna Airport Refueling Apron Concrete Pavement Construction

The newly developed Wirtgen paver (using a CMI mainframe) was observed. For this application, the same concrete mix was being used for both layers of the 40 cm (16 inch) concrete slab as tire noise was not an issue. This paver was developed to efficiently place the two concrete layers with one machine. This was done to overcome a problem with mixing of layers on earlier two-layer highway construction projects in Austria using the exposed aggregate surface treatment process and also to prevent possible delamination of the layers when separate pavers are used. This paver included a dowel bar inserter and was similar to some of the equipment observed in Germany. While the power plant and mainframe were obtained from CMI, the other accessories were manufactured in Europe for Wirtgen.

D. Summary of Austrian Visit

The high quality of concrete in Austria has resulted in very durable surfaces for 30 to 40 years even with 20 to 22 cm (9 inch) pavement thicknesses. A revised design catalog was adopted in 1986 and was based on a combination of previous experience, German or Austrian research, and mechanistic analysis.[(6)] It is also based on high quality subgrade and aggregate subbase support verified by project level plate bearing tests. Older projects have had concrete with compressive strengths as high as 90 N/mm^2 (13,000 psi).

Since 1989, Austria has used the exposed aggregate surface treatment to improve surface friction and reduce tire/pavement noise. Dr. Sommer, has been actively involved in the development of this proprietary process.

Greater U.S. participation in international conferences such as the PIARC sponsored Tyre/Noise Workshop held in Vienna in February 1992 and the upcoming Seventh International Symposium on Concrete Roads planned for Vienna, Austria, on October 3 to 5, 1994, would be very beneficial in keeping track of new European designs; materials; construction techniques and equipment; and maintenance materials, equipment and procedures. Greater cooperation also would minimize duplication of research and/or facilitate more cooperative research in critical areas.

IV. SUMMARY

A. Michigan Experimental Section

A one-mile section of northbound I-75 in Detroit, Michigan, will be constructed August through October 1993 using the German pavement design typical section and an exposed aggregate surface treatment similar to that used in Austria. It will provide a direct comparison of the performance of the hybrid German/Austrian pavement design section with the standard jointed reinforced concrete pavement with a permeable base design used routinely in Michigan. This also will allow a direct comparison of the tire/pavement noise generated by the exposed aggregate surface treatment and the transverse tined (with a longitudinal burlap or artificial carpet drag) texture which is Michigan's standard surface treatment.

The main modifications to the German design are 15 ft (not 5 m) slab lengths, 1¼ in (not 26 mm) dowels, epoxy coated (not plastic coated) dowels and tie bars, and an exposed aggregate surface treatment (not a longitudinal burlap drag). An underdrain in a trench filled with untreated permeable material will be constructed under the shoulder/outside widened lane joint to provide pavement subdrainage. The underdrain outlets will be connected to the catch basin manholes. This section of I-75 has more than 5,000 trucks a day in the design lane. A copy of the report prepared by the Michigan DOT representatives on this trip is included in appendix C. A copy of the specifications used to construct the experimental section in Michigan is included in appendix D.

B. Noise Considerations

In summary, it can be stated that the Europeans are very noise conscious. In some areas of the United States, pavement noise is becoming an important issue. However, it is important to provide adequate friction characteristics while minimizing tire pavement noise. The exposed aggregate surface treatment can provide high quality, low-noise concrete pavements and the Germans also have accepted it on trial basis. *The technology is patented and it would be desirable to use and evaluate it on a few projects.* The friction provided by the longitudinal burlap drag texturing is not likely to be sufficient to satisfy safety requirements in the United States. The longer lasting, more durable friction characteristics of portland cement concrete pavements should result in a reduction in wet weather accidents which outweighs a slight [2 to 3 dB(A)] increase in automobile tire/pavement noise, even if the exposed aggregate surface treatment is not used. It should be noted that the accident rate in Germany is about 1½ times that of the accident rate in the United States.(3) This could be due in part to their high or unrestricted speed limit, the lower pavement surface friction characteristics, and the presence of steeper slopes and more guardrail. Noise considerations alone are not sufficient justification to require a specific pavement type. Safety, durability, and economy also must be considered.

C. Design Considerations

This tour of Germany and Austria provided a unique opportunity to reevaluate some of our design procedures and assumptions and to look at some other techniques that are being used. There are a number of alternate designs or combinations of design features that could result in similar life cycle costs. It is apparent that the German and Austrian engineers have made extensive use of U.S. research. They also have refined some existing design procedures as well as developed unique ways to address improved design features such as the base/subbase/subgrade support for the pavement structure. Only construction of experimental sections for comparisons of the performance of the various alternative designs and of expected construction costs (including material availability if this were to become a standard design in a particular area) will allow determination of which of the various approaches will likely be the most cost effective. *Close monitoring of these experimental sections also will give an early indication of their performance long before the expected 30 to 40 year design life period is over. Construction of some of these European sections as supplements to the Strategic Highway Research Program Special Studies Sections (SPS-2) or as experimental projects is recommended. Supplemental SPS-2 sections are currently being proposed in Colorado and would allow a direct comparison of various designs under a much more controlled set of conditions. This would also minimize the evaluation effort necessary. Further investigation of this approach by the FHWA LTPP staff and the various State highway agencies is recommended.*

D. Expansion of International Outreach

It is apparent that much can be learned by greater sharing of information by engineers through exchange of information. However, due to the lack of uniform definitions and evaluation procedures, much of this information has not been directly transferable. The increased international cooperation generated by the FHWA International Outreach Program and SHRP should be continued and expanded. This effort addressed new pavement design. The opportunities for expanded cooperation are much greater in the area of timing and in the selection of cost effective preventive maintenance and rehabilitation efforts that are even more challenging. *More effective ways of sharing technical information and greater opportunity for engineers in the U.S. to travel to conferences and review new materials, equipment, and techniques for construction and maintenance are needed if we are to maintain our highway infrastructure in a satisfactory condition in the most cost effective manner.*

A summary of information about Austrian roads was obtained from a PIARC report that advertised the 1994 Winter Roads Meeting to be held in Seefeld, Austria, in March 1994 and the Seventh International Symposium on Concrete Roads, which will be held in Vienna, Austria, in October 1994. It should be noted that when the Sixth International Symposium on Concrete Roads was held in Madrid, Spain, in 1990 there were less than half a dozen participants from the U.S. None were from government agencies. This illustrates the low level of involvement from the U.S. in major international conferences held in Europe compared to the good European participation in international conferences held in the U.S. This is in addition to their substantial participation at the annual TRB meetings. For example, there were about 100 foreign visitors at the Fifth International Conference on Concrete Pavement Design and Rehabilitation held in April 1993 in West Lafayette, Indiana, at Purdue University.

Also, many of the proceedings of major international technical conferences (even those available in English) are not being routinely obtained by the U.S. DOT Library in a timely manner (for example, the Proceedings of the Sixth International Symposium on Concrete Roads held in Madrid and a PCC Theoretical Design Workshop held in Siquenza, Spain, just prior to the Madrid meeting). *As part of our international outreach, we need to increase technical representation at these workshops and conferences and obtain sufficient copies of the proceedings to make them available to technical specialists and researchers in the U.S.*

The team approach utilized on this and previous tours has demonstrated the advantage of having members with different backgrounds involved. The issues are so complex it is impossible for one person to adequately recognize and address the many details that may be critical to the success or failure of a new technique or approach. On similar trips, the addition of an engineer well versed in the foreign language would greatly expedite implementation of new ideas. The temporary reassignment of one person full-time to complete the trip report and pursue the many promising approaches would significantly speed sharing of the results with others. The opportunity to explore, in depth, certain of these technical areas has shown that there is a lot of information available that has not been obtained and used. A big improvement in international technology exchange would be a more structured approach to obtaining English versions of major conference proceedings, attendance of more U.S. technical experts at international conferences, and expanded accessibility to translation services for foreign publications and articles.

E. Summary of Recommendations

The following is a summary of the recommendations made in the above report:

1. We should pursue obtaining results of the European effort to harmonize standards in the pavements area.

2. English translations should be obtained for a number of the technical publications obtained during this review including the German reconstruction standard catalog and the 1988 French design catalog. These documents would allow us to take advantage of information on the performance of various rehabilitation options not routinely used in the U.S. Efforts particularly in the rehabilitation and maintenance area should be expanded. Increased opportunities to study foreign languages and attend international conferences by U.S. technical experts should be encouraged.

3. FHWA should expedite efforts to evaluate European COPES data obtained as a result of cooperative efforts with the PIARC Committee on Concrete Roads. Evaluation of this detailed performance data has been proposed to be included in

an existing FHWA research contract on the performance of experimental concrete pavement test sections in the U.S.

4. It is recommended that we purchase the German plate bearing test equipment to compare the support values that they have found to perform well with the results obtained with the SHRP Protocol P59, Deflection Testing of Base and Subgrade Layers, which was dated January 1993 and was developed under the SHRP. Efforts to revise existing design procedures to address improved slab support should be increased. This should be accompanied by corresponding guidance on the maximum slab thickness needed for highway loadings. It appears existing design procedures result in substantially greater slab thicknesses than found necessary in Europe even though significantly higher axle loads and a large number of multiple axles with super single tires are used.

5. The pavement structure geometry should be evaluated to consider the trade-offs of increased cross slopes to 2½ percent for the pavement surface and 4 to 4½ percent for the base and subgrade surfaces to improve surface and subsurface drainage.

6. The guidelines for the design and construction of pavement joints and joint sealing material should be revised to recognize that all joints do not open equally. Greater consideration of this information would greatly improve the long-term performance of joint sealant materials.

7. A study of the adequacy of consolidation of the concrete under dowels in baskets or placed by a dowel bar inserter should be undertaken. This is potentially a greater problem in the U.S. due to the use of thicker pavements, larger diameter dowels, and in most cases, the use of one-layer construction.

8. Efforts should be continued to develop an improved method to quickly verify the accuracy of dowel bar placement directly behind the paver so any necessary adjustments can be immediately made.

9. The existing guidelines for tie bar spacing and size should be reevaluated. For shoulders constructed separately, for ramps used by high volumes of heavy trucks, and for truck climbing lanes, there is considerable evidence that many existing designs are not performing satisfactorily.

10. The freeze-thaw durability test procedures used in Germany (including test procedures developed in former East Germany) to assure high quality concrete should be examined in more detail to see if an improved test procedure is being used or if the quality criteria is higher there than in the U.S. Their procedures are

obviously more effective than those used in most areas in the midwest portion of the U.S. in assuring high quality, durable concrete surfaces.

11. A reevaluation should be made of PCC surface texturing guidelines to determine if revised guidelines are appropriate based on available U.S. research, evaluation of experimental sections previously constructed, and the results of the large amount of European research underway and nearing completion. The cost effectiveness of the exposed aggregate surface treatment should be included in this evaluation.

12. Close monitoring of the Michigan experimental section should be conducted to get an early indication of the long-term performance of the hybrid German/Austrian design compared to the drainable pavement systems now being constructed under concrete pavements by most States in the U.S. Additional supplemental sections should be added to the SHRP SPS-2 sections to evaluate the bonded pre-notched lean concrete base (German design) and the asphalt separator layer between the slab and the stabilized base used by a number of other European countries like Austria and Belgium. Other promising European concrete pavement sections should be constructed on an experimental basis to further evaluate the technology. This would allow a more comprehensive evaluation of the cost effectiveness of these approaches compared to the drainable bases being widely adopted in the U.S. It also would allow the development of guidelines for selecting the most cost effective approach for various combinations of truck loading and climatic conditions.

13. The routine use of widened outside lanes (with or without tied concrete shoulders) with the paint stripe placed at the standard lane width should be encouraged. A significant improvement in performance can be obtained with a minimum of additional cost. Where substantial volumes of heavy trucks are present it is also recommended that the tied shoulder be increased to 3.1 m (10 ft) to accommodate traffic during emergencies such as accidents or during maintenance or rehabilitation activities.

14. Efforts to improve concrete mix design procedures should be expanded. The benefits of higher quality, more durable concrete do not appear to be adequately addressed by many highway agencies. The performance of the higher strength test sections included in SPS-2 will provide valuable information in this regard. In Austria, however, the routine mix design approval by a certified testing laboratory has resulted in a higher quality of concrete without significant increases in the cement content. This approach should be investigated.

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APPENDIX A

NOISE CONSIDERATIONS IN GERMANY AND AUSTRIA

1. GENERAL

Pavement noise reduction (particularly for concrete pavements) is a major issue in European countries including Austria, Germany, Holland, Belgium, Spain, and France. The Europeans are more noise conscious than Americans, and the motorists and property owners along the highways demand smooth, low-noise surfaces. During the tour of Germany and Austria the tour members learned and observed that the highway agencies and the concrete paving industry do their utmost to provide top quality low-noise (tire-pavement) concrete pavements. Substantial research and implementation activities in this area are underway in several European countries. A large number of research documents have been published and presented at PIARC and other international meetings.

The low-noise levels for the concrete paving are achieved by using various techniques. Transverse brooming or transverse tining combined with a longitudinal drag are considered to produce high-noise levels and therefore have fallen out of favor in Germany, Austria and several other countries. The longitudinal texturing with burlap drag is favored in several countries including Germany. The Germans claim that the tire-noise produced on the concrete paving textured with the longitudinal burlap drag is about the same as that generated on dense asphalt pavements. Diamond grooving on existing concrete surfaces has been used in a few countries. Epoxy surface dressings and slurries also have been used successfully for rehabilitation. One of the most promising low-noise concrete paving technologies has been developed in Belgium and is called "exposed aggregate surface treatment." Dr. Sommers (Vienna) has done substantial research and experimentation to develop the patented process in partnership with a Belgian firm, "ROBUCO." The details of the process are provided later in this section.

The team visited several project sites in Germany and Austria and discussed the noise related issues with Government agencies and contractors. There are differences in the state-of-the-art, state-of-practice and design considerations in both countries; therefore, a separate of summary of findings for each country is provided. Dr. Sommers subsequently provided a copy of the proceedings of the PIARC Workshop "Noise reducing concrete surfaces," held in Vienna, Austria, on February 24 and 25, 1992. This report, generally in English, is an excellent summary of current European practices and research related to surface texturing of concrete pavements.

2. AUSTRIAN EXPERIENCE

Mr. Romain Buys, General Manager of ROBUCO, accompanied the team for construction site visits in Austria. Mr. Buys provided information on the exposed aggregate treatment methodology and shared the experiences gained from projects in Belgium, Holland, and Austria. The team visited a major highway near Villach where an epoxy resin and bauxite (chromium) slurry was used to repair concrete pavement rutted by studded tires. The slurry application seems to provide a smooth, low-noise producing surface and is in good condition even after several years of service. The cost of slurry placement was approximately $13 per square meter.

Recently completed projects in the vicinity of Villach (Highway A-2) and Vienna (Highway A-1) were visited on October 13 and 14, 1992, to observe exposed aggregate concrete surface treatment. Some of the sections of the Highway A-1 were constructed two years ago, and the exposed aggregate surface does not show any wear and is in excellent condition. The pavement design life is estimated to be 30 years, and driving experience on these projects indeed confirms the claims about low-noise levels and high-skid resistant surfaces.

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 four dB(A) when compared with longitudinal tined surface treatment. The noise level of the exposed aggregate surface treatment is comparable to that of a porous asphalt surface after one year of traffic. The friction characteristics are comparable to a transverse tined surface due to the aggregate surface roughness and a high resistance to polishing because of the durable coarse aggregates used.

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 remove the mortar from the coarse aggregate particles. Wet brushing has been used in the past, but slurry disposal became a problem. Wet brushing allows for aggregate exposure deeper than 1.5 mm (0.06 in). However, this does not appear to be desirable (from noise standpoint) or necessary (to increase skid resistance). A maximum texture depth of 0.9 to 1.2 mm (0.035 to 0.05 in) is considered adequate. According to Dr. Sommers, a deeper texture does not improve friction characteristics or reduce tire/pavement noise. Hydroblasting has 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 desirable condition. Disposal of the material removed also was a problem.

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. This results in about a 10 percent increase in cost of the concrete pavement.

The retarder 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 is about 500 grams per square meter (0.9 lb per sq yd) for the sugar-based retarder and 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 retarder does not act as a curing compound. When using the sugar-based retarder, a geotextile must be placed over the cut after the joints are saw cut through the plastic in order for desirable concrete curing to continue.

The Austrians use noise walls extensively to further reduce noise levels for the residents along the highways. The Austrian noise walls are attractive and constructed of various materials, colors and shapes. The materials include wood, steel, concrete, brick, and aluminum. Great effort is made to use maintenance free noise wall materials and to avoid monotonous designs.

3. GERMAN EXPERIENCE

The German experience with concrete pavements is substantial since the early autobahn construction in late 1920s and early 1930s. In former West Germany, concrete pavements lost ground to asphalt pavements, due partly to noise considerations. Therefore, the Germans have a great deal of interest in reducing noise on concrete pavements. Substantial highway reconstruction is underway in former East Germany; and much new construction includes concrete paving since, historically, East Germany has favored concrete paving over asphalt paving. The German standard concrete paving texturing practice requires the use of the longitudinal burlap drag. Transverse tining or texturing is not used because of noise considerations. Information on skid resistance provided by the burlap drag texturing could not be obtained, but the Germans claim that adequate skid resistance is provided by this method. A study of skid resistance of concrete pavements was planned to be completed in November 1992, as part of an inventory of the entire autobahn system. The team visited several project sites in the Bremen, Berlin, Leipzig, and Stuttgart areas. The surface texturing practice used on all the projects was the longitudinal burlap drag. At the Bremen project sites, the team saw laboratory experiments being conducted to evaluate the exposed aggregate surface treatment. The Germans will be using the patented ROBUCO process for a test project during 1993. This information will be used to harmonize European standards for skid resistance and tire-pavement noise levels (BRITE program). A report on the results of this German study is expected to be available in July 1993.

The team visited BASt (German Federal Highway Research Institute) in Cologne. During the visit, the team met with Dr. Ullrich who is a noise specialist at BASt. The purpose of the meeting was to obtain information regarding policy on noise issues, the noise measurement techniques used, existing concrete paving practices to reduce noise, and related research activities. The following information was provided by Dr. Ullrich:

- Longitudinal burlap drag is a preferred concrete pavement texturing method. On some projects transverse tining and brushing is used. Exposed aggregate concrete surface texturing has not yet been used but research is underway at the Technical University in Berlin. Concrete paving construction utilizing the patented ROBUCO process will be underway on a project in the near future.

- Noise is measured by using microphones at a distance of 7.5 meters from the middle of outside lane.

- Separate measurements for tire noise, automobile engine noise and automobile body noise had been made in the past, but now only combined noise is measured.

- Typically, noise measurements are performed for 70 to 100 cars and trucks separately. Statistical analysis is then used to estimate general noise levels.

- Noise walls are required if noise levels at abutting properties are higher than 49 dB(A) at night and 59 dB(A) during the day. The noise wall heights are usually two to five meters.

- BASt is interested in measuring the noise levels outside the automobile only.

- Older concrete pavements generate two to three dB(A) higher noise levels than asphalt pavements, and the concrete texturing practices and joints are the causes for higher noise levels. The newer techniques, which include longitudinal burlap drag texturing, produce smoother concrete pavements; and there is no discernable difference between concrete and asphalt pavement noise levels. Transverse tining produces two to three dB(A) higher noise levels and is not acceptable in Germany. Longitudinal tining has a lower noise level than transverse tining but has not been used in Germany.

- Noise walls cannot be eliminated completely by using exposed aggregate treatment or any other concrete pavement texturing techniques because any noise reduction achieved will be only 2 to 3 dB(A).

- Noise reduction of at least 10 dB(A) would be needed to eliminate noise walls, and this level of reduction is not possible with any texturing techniques for concrete or asphalt pavement.

- Germany uses noise walls constructed of aluminum, concrete, wood and transparent materials e.g. glass and plastic. Steel was used until 1982. Repainting of walls is usually not required.

- If construction of buildings is done after highway construction, the noise walls are not required. For houses built before highway construction, either funding is provided to owners to install better windows for noise reduction or, if necessary, noise walls are built.

- BASt is following noise reducing pavement research work underway in Berlin by Professor Huschek and in Belgium, Holland, and Spain.

APPENDIX B

MATERIALS ASPECTS AND SELECTED RESEARCH RELATED TO RIGID PAVEMENTS IN GERMANY AND AUSTRIA

MATERIALS

One of the objectives of this trip was to evaluate the construction materials used by our European counterparts to determine if there was a materials aspect to the apparent better performance of European pavements. For instance, are the European aggregates in general "better" than those available in the U.S.? This and other related issues will be briefly discussed below.

First, *are* the European aggregates, in general, of better quality than those found in the U.S.? The answer is, most likely, "no". Without very detailed study, a definitive answer to this question is impossible. Europe has a range of aggregate quality depending on the geologic setting just as we do here in the United States, so there is probably little inherent advantage. Geography on the other hand, may often be an advantage because a better quality aggregate can be imported, even across country borders, at distances much less than those often facing U.S. construction agencies within a given State. Recycling of old pavements as aggregate in new pavements also is being practiced there.

A better answer to materials superiority may lie in the overall European approach to building pavements. Briefly, as has been noted elsewhere here and in previous European "tour" reports, in Europe new and recently built pavements are constructed with a common philosophy: give higher priority to design, construction and materials excellence, and lower priority to cost. This is not to say that cost is not a concern; rather, it is often not the deciding parameter.

With this approach, the advantage of the European design and construction practice with regard to aggregates and other materials, lies in closely matching the quality needs of the pavement layer being considered to the quality level of the aggregate (or other materials) being used. Thus a premium quality aggregate is not used in an unbound frost blanket layer. Nor, on the other hand, is a recycled portland cement concrete aggregate used in a surface layer.

Test procedures and their application do not appear to be an advantage, in that tests used to evaluate the suitability of a given aggregate for a particular use are for the most part similar to, or some variation on, tests run in this country. Follow-up tests are then run on in-place material or trial mixes to verify that the target properties are being achieved.

Do pavement designs unique to Europe take advantage of certain aspects of aggregate characteristics that we don't currently fully exploit? This is another possibility. Such features as exposed aggregate surfaces for portland cement concrete, with carefully controlled gradation and frictional properties to provide concrete pavements with both low-noise generation and adequate frictional resistance, may fit in this category. These design variations are currently being studied and will be evaluated in field trials of pavement sections in this country. Results of these field trials will give us further insight as to the benefits of these designs.

RIGID PAVEMENT RESEARCH

Current German research in the area of concrete pavements, particularly at the Munich Technical University by Drs. Eisenmann, Zachlehner, and others, is concentrating on the early age response of the pavement to heat generated during hydration and to the environmental conditions.

As are American researchers, these researchers are concerned with the development of stresses in the pavements in response to these factors. In his dissertation work under Dr. Eisenmann, Dr. Zachlehner evaluated the stresses in concrete pavements due to the combined effect of traffic and temperature, and he also considered the elastoplastic properties and response of the soil. A follow-up study concentrated on the early age pavement deformations independent of external loading and the restraint stresses associated with these deformations. Causes of these strains include shrinkage, expansion, and temperature effects due to the heat of hydration and daily heating and cooling cycles.

Full-scale testing was conducted to determine these effects. Based on his outdoor experiments, he concluded that concrete placed on a warm sunny day, which is then followed by a cool night where air temperature drops by more than 15 degrees C, induces high bending stresses in the slabs in both longitudinal and transverse directions. These stresses exceed the concrete strength at that early age and result in cracking at relatively short spacing. On the other hand, if the concrete is placed on a cloudy day with little temperature drop over night, only slight bending stresses, which are not enough to cause cracking, are induced. In this case cracking is caused by contraction at a later time, due to overall cooling of the slab and subbase friction. A temperature drop of 10 to 20 degrees C in the concrete will usually cause this cracking, which has much greater spacing than the first example, of several slab lengths. He found that lifting of the edges of the slabs resulted from drying shrinkage and temperature gradients during the "hydration" phase. This induced shape in the slabs was found to remain for a long period of time. The space at the edges was eventually found to be compensated for by a plastic deformation of the "subsoil."

In order to control the location of cracks at the joints, it was found that the joint must be 0.3 the slab depth for transverse joints and 0.3 to 0.45 the slab depth for longitudinal joints. This agrees with their current specifications.

In addition, a model was developed for estimating the time-dependant stresses in early age pavements. The model uses temperature distribution, elastic modulus, and split tensile test results as input. The model distinguishes between stresses due to internal restraint (non-linear) and those due to external restraint (linear). The two types of stresses are combined to assess the risk of cracking and to estimate the time of cracking. The model indicates that the cracking is greatly dependant on the temperature at the time of placement as well as on the time period immediately following placement, as indicated by the field experiments conducted. Depth of joint formation in order to control crack location also is evaluated.

The BASt (Federal Highway Research Institute) facility is located near Cologne. The operation was started in 1951, and the current facility was completed in 1983. They employ approximately 400 people at the Cologne site, with additional employees at a branch facility in Berlin that was opened in 1990. The broad subject areas investigated at BAST include pavement surface friction, pavement noise generation, accelerated loading of pavements for fatigue, durability of concrete and steel, crash tests, and traffic counts and management. They have a circular track facility for pavement durability testing and an acoustic laboratory for modeling noise and studying noise control, which is one of their big concerns. They are currently experimenting with porous concrete for use in the portion of the base layer that is under the shoulder in concrete pavements. In their petrographic laboratory we saw them working with fluorescent epoxy impregnated concrete specimens, which are used to enhance identification and study of microscopic features in the concrete. It was noted however, that they don't do their own analyses of air void systems in hardened concrete. Rather, they send them out to commercial laboratories for economic reasons.

They have a separate laboratory for the accelerated load testing of new pavement designs to evaluate their effectiveness. The laboratory consists of a concrete pit 40 m x 8 m x 4 m (depth) in which the complete proposed pavement section can be constructed. They employ thick blocks of styrofoam to simulate a soft subgrade in the section. Supporting equipment for the laboratory includes several hydraulic rams on movable bridges which span the pit and can apply a load of up to six tons. Once a test has been designed and started, the rams are completely controlled by computer including their movement, magnitude and frequency of load application, and location of load application.

APPENDIX C

MICHIGAN DEPARTMENT OF TRANSPORTATION
M•DOT

EUROPEAN CONCRETE PAVEMENT TOUR

Roger D. Till, P.E.
Randy VanPortfliet, P.E.

Materials and Technology Division
Construction Division

Lansing, November 1992

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EXECUTIVE SUMMARY

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.

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, %	7.1	5.0
Voids per Inch	9.3	8.8
Specific Surface, in^2/in^3	525	689
Spacing Factor, in.	0.008	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

R. W. Muethel

RWM:kat

cc: R. Till
D. L. Smiley
S. P. Beck

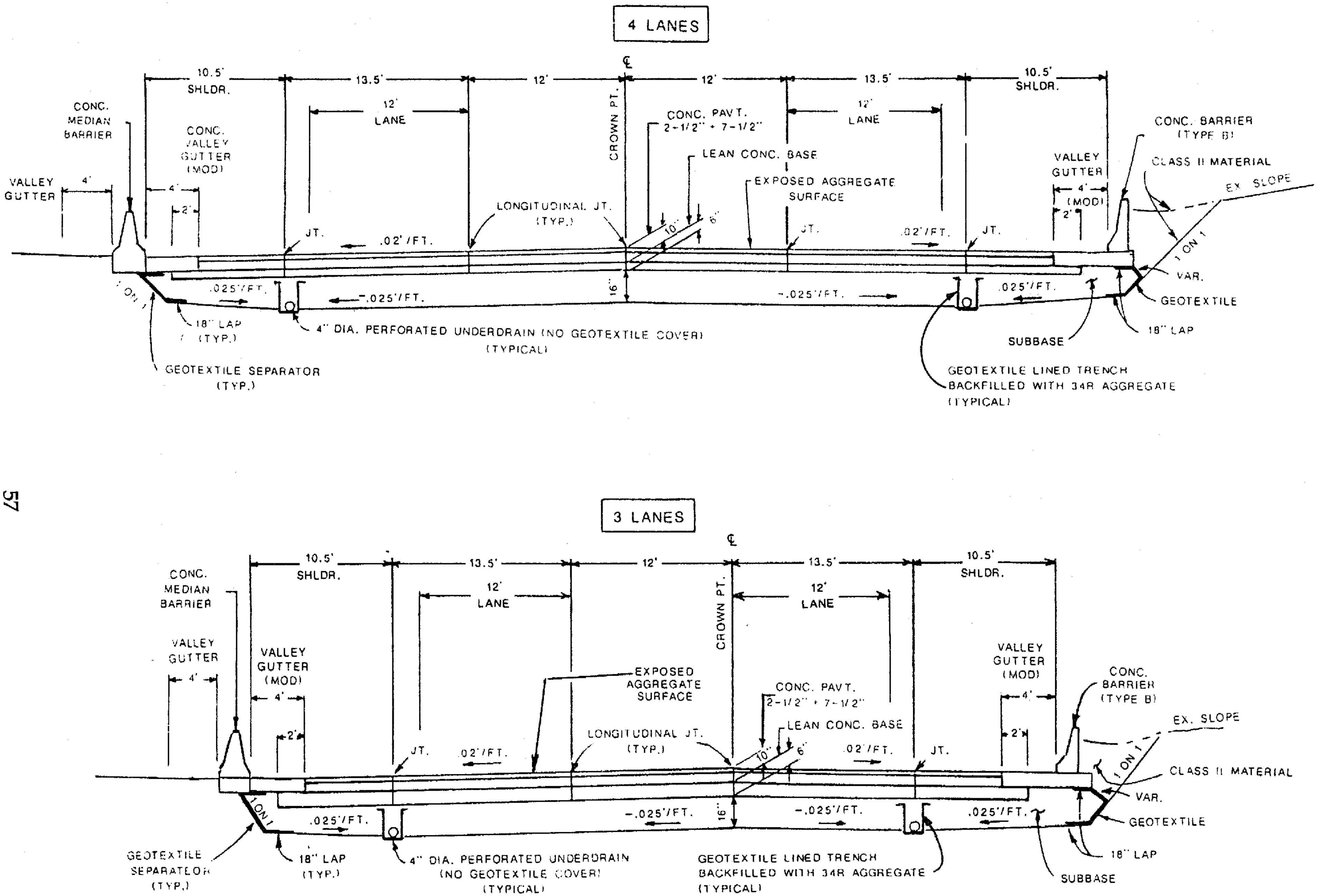

Figure 1. Typical cross-sections trial project.

APPENDIX D

MICHIGAN DEPARTMENT OF TRANSPORTATION
M•DOT

Specifications
for
European Concrete Pavement

Demonstration Project
Control Section IM 82251
Job Number 30613A
Letting Date June 14, 1993

Michigan Transportation Commission
Barton W. LaBelle, Chairman;
Richard T. White, Vice-Chairman;
Jack L. Gingrass, Robert M. Andrews,
Irving J. Rubin, John C. Kennedy
Patrick M. Nowak, Director
Lansing, August 1993

MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION FOR EXPOSED AGGREGATE SURFACE TREATMENT OF CONCRETE PAVEMENTS (EUROPEAN PAVEMENT)

a. Description.-This work shall consist of the removal of the surface mortar from the top of a concrete pavement to produce an exposed aggregate finish. This finish shall be achieved with the help of a setting retarder sprayed on to the surface of the concrete pavement immediately after it has been placed. The retarded mortar shall be removed by wet or dry brushing with steel wire brushes no sooner than 20 hours after placing the concrete pavement.

The process required by this specification is patented by Robuco, Ltd. located in Buggenhout, Belgium (see note 1). Robuco, Ltd. is being represented in the United States by Robuco U.S.A. (see note 2). The Contractor is responsible for making all the necessary arrangements and payments for the use of the patent on this project.

The Contractor shall make arrangements to have a representative from Robuco, Ltd. on site during the exposed aggregate surface treatment operation. Robuco's representative shall advise the Contractor regarding the exposed aggregate surface treatment operation.

b.Materials.-Curing compound materials shall be in accordance with Section 8.24 of the Standard Specifications.

The composition and viscosity of the surface retarder shall be such that it can be spread at an adequate and uniform rate over the surface of the concrete pavement in order to ensure effective and adequate aggregate exposure during the subsequent wire brushing operation.

The surface retarder shall contain a pigment, other than white, in sufficient quantity to give an even and uniform color after it has been sprayed onto the pavement surface at an acceptable rate. The retarder shall be non-hazardous. Material Safety Data Sheets shall be provided to the Engineer before starting this work.

The Contractor shall submit to the Engineer information on the type and composition of the retarder intended for use in order to satisfy these requirements. The use of this retarder shall be subject to the approval of the Engineer.

The protective sheeting shall be made of polyethylene or other plastic that is completely waterproof. This waterproof sheeting shall have a thickness of at least 2 mils (50 microns). Splices in the protective sheeting shall be waterproof and shall be accomplished by using a one-foot minimum overlap with two lines of double faced tape, one tape line near each edge.

c. Construction Methods and Equipment.-The process for the exposed aggregate surface finish includes spraying retarder on the concrete surface, covering the surface with plastic sheeting, removing the plastic sheeting, wire brushing the retarded surface, and applying a curing material to the moistened exposed aggregate surface.

c.1. Application of the Retarder.-The retarder shall be sprayed onto the surface of the wet concrete pavement as soon as possible after the concrete has been placed and shall be sprayed onto the surface within 30 minutes after the final smoothing operation. The rate of application of the retarder shall be determined by the Contractor's trial sections as required in Section f.

The spraying system shall operate in an automated manner that ensures that the retarder is spread evenly in both the transverse and longitudinal directions. To achieve this uniformity of application, the spraying system shall consist of a spray bar, provided with nozzles, mounted on a machine spanning the concrete pavement.

Before commencing work, the height of the spray bar, the rate of retarder delivery from the nozzles of the spray bar, and the forward speed of the machine shall be adjusted so as to achieve the required rate of application.

A manual spraying system shall always be available on the site for emergency use in case of a breakdown of the automated spraying system. The manual spraying system is subject to approval by the Engineer.

c.2. Protection of the Surface After the Application of the Retarder.-Total protection of the applied retarder and concrete shall be provided by covering with waterproof sheeting that is unrolled evenly onto the full width of the concrete surface. This protective sheeting shall be placed over the concrete pavement immediately after the application of the surface retarder.

The laying of the sheeting shall not affect the finish of the concrete surface or the even distribution of the retarder in any way. Air bubbling or blistering under the sheeting shall be eliminated to the extent possible.

This sheeting shall exceed the width of the concrete pavement by a minimum of 18 inches on each side of the newly placed concrete pavement. The sheeting shall be kept in place by ballast that shall be laid only on the extra width overlaps on both sides of the concrete pavement.

When transverse and longitudinal joints in the concrete pavement are saw cut through the protective sheeting, an equivalent protective sheeting shall be immediately placed over the saw cut holes in the sheeting with 6-inch minimum lap each side of the saw cut and held in place by a suitable means.

c.3. Unrolling of the Waterproof Sheeting.-To minimize the effect of wind on the protective waterproof sheeting, the system of unrolling shall be so arranged that the sheeting is released directly above and as close as possible to the concrete surface.

The unrolling system shall include a burlap drag 10 to 15 feet long and shall be attached to the system for the full width of the concrete pavement and towed forward over the laid protective sheeting so that the sheeting is pressed against the concrete surface. This burlap drag shall be sprinkled with water to keep it moist so that it maintains pressure on the waterproof protective sheeting.

c.4. Removing the Waterproof Sheeting and Exposing the Aggregate by Brushing.-Removing the waterproof sheeting and brushing the concrete surface shall be carried out not less than 20 hours after placing the concrete pavement. Wet or dry wire brushing to remove the retarded surface mortar shall be used. In addition, the concrete must have gained sufficient strength for the brushing machine to travel on the slab without causing any damage to the concrete.

The Contractor shall take all necessary steps to complete the aggregate exposure before the retarder used becomes ineffective.

The waterproof sheeting shall be removed in advance of the machining at the same rate as the brushing machine proceeds in successive sections of 250 foot maximum length in order for the protection to remain in place as long as possible.

The waste waterproof protective sheeting and mortar removed from the surface shall be disposed of at a site outside the project limits on a daily basis.

c.5. Brushing System.-The brushing machine shall be equipped with one or two rotary brushes fitted with twisted steel wires having a diameter of 0.02 to 0.04 inches. The rotary brushes shall be shrouded to eliminate mortar dust from being discharged into the air.

The length of the brush wires, when new, shall be at least 10 inches, exclusive of the length of attachment. A brush shall be discarded as soon as any of its wires become shorter than 4 inches, exclusive of the length of attachment.

The brushing machine shall be capable of maintaining a brush rotational speed, which in conjunction with the forward travel speed, is sufficient to remove the surface mortar to the desired depth in two or three passes, while leaving the aggregate exposed in place.

If the wet brushing method is used, each brush shall be equipped with a front spray bar for sprinkling water. An additional spray bar shall be mounted at the rear of the machine.

The inclination and height of the brush(es), as well as the extension on both sides of the machine to at least 12 inches outside the tire track, shall be adjustable from the operator's seat.

To help meet the requirement of Section C.4 relating to avoidance of damage to the concrete, the wheels of the brushing machine shall be fitted with wide tires having a low inflation pressure and a shallow tread.

c.6. Protection of the Exposed Aggregate Surface After Brushing.-Within four hours after removing the waterproof sheeting and within one hour of completing the brushing operation, a curing compound shall be sprayed mechanically onto the entire exposed aggregate surface of the concrete pavement. The surface shall be cleaned of all foreign material and moistened with water before spraying the curing compound onto the exposed aggregate surface. The application of the curing compound shall be in accordance with Section 4.50 of the Standard Specifications.

d. Surface Texture Depth.-The texture depth of the concrete pavement shall be measured by the sand patch test method indicated herein. The average texture depth determined for each 150 foot section of roadway lane tested shall be 1.3 mm ± 0.20 mm (0.05 in. ± 0.008 in.). Surfaces not meeting this texture depth shall be repaired by the Contractor using a method approved by the Engineer.

The Contractor shall be responsible for quality control testing at the rate specified herein to ensure this surface texture is attained. The Department will conduct quality assurance tests at the rate specified herein for acceptance of the surface.

e. Sand-Patch Test Method.-The basis of this test method is British Standard BS598 Part 105.

Sand meeting the gradation of Table 1 and 90 percent roundness requirement is available from U. S. Silica, Gradation AFS 50-70 (Phone 800-635-7363).

e.1. Apparatus.-Measuring cylinder of 50 ± 1 mL total capacity and 30 mm maximum internal diameter.

A flat, hard disk approximately 25 mm (1 in.) thick and 60 to 75 mm (2.5 to 3.0 in.) in diameter. The bottom surface or face of the disk shall be covered with a hard rubber material and a suitable handle may be attached to the top surface of the disk. An ice hockey puck is considered suitable for use as the hard rubber material.

Washed and dried silica sand with a 90 percent roundness in accordance with ASTM D 1155 and conforming to the grading given in Table 1. Gradation of sand shall be certified by supplier.

Table 1 Grading of Sand for Sand-Patch Test

Sieve Size	Percent Passing, By Weight
600 µm (#30)	100
300 µm (#50)	90 to 100
150 µm (#100)	0 to 15

A standard steel scale 300 mm (12 in.) or greater in length and having 1 mm (0.04 in.) divisions.

e.2. Measurement of the Surface Texture.-Measure the surface texture depth as soon as possible after the surfacing has been completed and before the surfacing has been opened to traffic. Curing compound shall be removed from the surface before conducting the test and shall be reapplied to the surface if the concrete has not attained at least 70 percent of its required strength.

The test shall not be carried out on wet or sticky surfaces.

Make test measurements on 150 foot lane lengths randomly spaced along the section. The total length of the 150 foot lane lengths tested shall not be less than one-third of the section length being represented by the tests.

On each 150 foot lane length, take 10 individual test measurements of the texture depth at approximately 15 foot spacing along a diagonal line across the roadway lane width. Do not take measurements within 12 inches of the longitudinal edge of the roadway.

e.3. Procedure for Carrying out a Single Measurement.-If necessary, dry the surface to be measured and remove any foreign matter by sweeping.

Fill the cylinder with sand and, taking care not to compact the sand by any vibration, strike off the sand level with the top of the cylinder. Shield from wind if necessary.

Pour the sand into a heap on the surface to be tested and spread the sand over the surface using the disc. Carefully work the disc with its face kept flat to the road surface, in a rotary motion so that the sand is spread into a circular patch with the surface depressions in the road filled with sand to the level of the peaks. The procedure is complete when no further distribution of sand outward is achieved. Shield from wind if necessary.

Measure the diameter of the sand patch to the nearest 1 mm at 4 diameters approximately 45° apart using the steel scale.

e.4. Calculation and Expression of Results.-Calculate the average diameter of the sand patch to the nearest 1 mm.

Calculate the average texture depth (in mm) from the following formula:

$$\frac{63{,}660}{D^2} = T$$

Where

D is the average diameter of the sand patch.
T is the average texture depth in mm.

Determine the average texture depth for each section of roadway lane tested and the average of each set of 10 individual measurements to the nearest 0.1 mm.

e.5. Test Report.-The report shall state that the texture measurements were made in accordance with this section and shall include the following:

(1) The name and address of the testing organization;
(2) A unique serial number for the test report;
(3) The name of the client and project numbers;
(4) Clear identification of the individual test locations, along with the location of each lane length tested;
(5) The individual test results of texture depth and the average texture depths for each 150 foot lane length comprising each section together with the average value for the section;
(6) A statement saying the road surface was newly laid;
(7) The signature of the person accepting technical responsibility for the test report;
(8) The date of each test;
(9) The date of the report.

f. Trial Sections.-The Contractor shall perform exposed aggregate trial sections as described herein under the observation of the Engineer. These trial sections shall form the basis of the production work.

f.1 Test Panels.-Test panels using the top layer concrete, surface retarder, waterproof protective sheeting, and curing compounds that will be used in the production work shall be prepared by the Contractor. These test panels shall demonstrate that the surface retarder, retarder application rate, and elapsed time before mortar removal will provide the desired surface texture. A test panel procedure, including a materials list, shall be submitted to the Engineer for review prior to making the panels. The panels shall be a minimum of 18 inches wide by 18 inches long and shall be 2-1/2 inches thick. Initial spot check measurements of the panel texture depth shall be performed by the Contractor using the sand-patch test method described herein.

f.2 Trial Length and Production Work.-A trial length of concrete pavement shall be constructed by the Contractor in accordance with the Special Provision for Two-Layer Concrete Pavement and Concrete Shoulders (European Pavement). This trial length of concrete pavement shall incorporate the exposed aggregate surface treatment. The same materials and equipment used to construct the trial length shall be used in concrete pavement production. The trial length shall comply with the specifications in all respects. The Contractor shall not proceed with the European concrete pavement production until the trial length has been approved by the Engineer.

During the construction of this trial length of concrete pavement and European concrete pavement production initial spot check measurements of the texture depth shall be carried out by the Contractor as soon as possible after completing the exposure of the aggregate. If, at this stage, the texture depth requirements are not achieved, work shall be stopped immediately and the surface shall be treated by scabbling or other approved methods until the requirements are met. Work shall not be resumed without the approval of the Engineer and until the causes of the observed defects have been investigated and resolved.

Any new observations of inadequate surface texture during the course of the work shall give rise to the same measures of repair and investigation until the required results are achieved.

g. Measurement and Payment.-Payment for the work of EXPOSED AGGREGATE SURFACE TREATMENT OF CONCRETE PAVEMENTS (EUROPEAN PAVEMENT) includes royalty fees and all the necessary materials, labor, and equipment to produce the desired surface texture, along with disposal of the waterproof sheeting and waste mortar. Payment shall be made in accordance with the following contract item (pay item).

Pay Item	Pay Unit
Exposed Aggregate Surface Treatment (European Pavement)	Square Yard

Payment for the exposed aggregate trial sections and test panels will not be paid for separately, but shall be considered in the payment of the Exposed Aggregate Surface Treatment (European Pavement).

Note 1: Robuco, Ltd.
Romain Buys, General Manager
Industriepark Gendhof 4
B-9360
Buggenhout
Belgium (Eur.)
Phone 32-52-33-13-03

Note 2: Robuco U.S.A.
Earl Knott
3800 Maiden
Waterford, MI 48329
Phone 313-623-9567

C/APPR/RVP/RGS 4-27-93

MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

**SPECIAL PROVISION
FOR
TWO-LAYER CONCRETE PAVEMENT
AND CONCRETE SHOULDERS
(EUROPEAN PAVEMENT)**

a. Description.-This work shall consist of constructing two-layer, wet on wet, concrete pavement and concrete shoulders. Fresh concrete for the top layer shall be placed on the fresh concrete for the bottom layer in one continuous operation. The concrete pavement and concrete shoulder shall be non-reinforced and shall be constructed to the dimensions and limits shown on the plans. This concrete pavement shall have a final finish in accordance with the Special Provision for Exposed Aggregate Surface Treatment of Concrete Pavements (European Pavement). Concrete pavement and concrete shoulders shall be constructed in accordance with the Standard Specifications, except as modified herein and by other Special Provisions.

b. Concrete Mix Design.-The Contractor shall be responsible for the concrete mix design as specified in the Special Provision for Furnishing Portland Cement Concrete (Quality Assurance). Concrete properties, characteristics, and acceptance sampling rate shall be as specified herein. Acceptance of the concrete based on these properties and characteristics shall be in accordance with the Special Provision for Furnishing Portland Cement Concrete (Quality Assurance).

This concrete pavement and concrete shoulder is considered a Critical Pay Adjustment Item.

The Contractor shall provide separate and distinct concrete mixtures for the top layer and bottom layer of the two-layer concrete pavement. The Contractor will not be allowed to construct the pavement full depth with the top layer Grade 55P concrete.

b.1. Bottom Layer Concrete.-Concrete for the bottom layer shall meet the following properties and characteristics.

Class Design Strength (28 days, psi)	5000
Verification Strength (28 days, psi)	5500
Retest Limit (28 days, psi)	4500
Maximum Water/Cement Ratio (lb/lb)	0.42
Minimum Cement Content (lb/cyd)	588
Maximum Slump (inches)	3

This concrete is designated as Concrete Grade 50P.

The Initial Sampling Rate for acceptance shall be 5 per lot, the Retest Sampling Rate (minimum) shall be 6 per lot, and the Rejection Limit shall be 10 percent.

Fine aggregate shall meet the requirements of Section 8.02 in the Standard Specifications.

Coarse aggregate shall be a natural gravel or crushed stone and shall meet the requirements of 6AA as stated in the Standard Specifications, with the additional requirement that freeze-thaw dilation (in percent) per 100 cycles shall be 0.008 maximum per MTM 115. Coarse aggregate shall be sampled at the source or dock if the material is shipped to the project by boat and shall be approved before shipment. Each aggregate stockpile shall be sampled by the District as it is constructed at a frequency of 1 sample for each 1000 tons. No material shall be added or removed from a stockpile after a sample is taken until testing is completed. An aggregate source will not be approved by certification for this concrete. All stockpiles shall be clearly identified to this project at both the source and concrete batch plant.

b.2. Top Layer Concrete.-Concrete for the top layer shall meet the following properties and characteristics.

Class Design Strength (28 days, psi)	5500
Verification Strength (28 days, psi)	6000
Retest Limit (28 days, psi)	5000
Maximum Water/Cement Ratio (lb/lb)	0.40
Minimum Cement Content (lb/cyd)	752
Maximum Slump (inches)	3

This concrete is designated as Concrete Grade 55P.

The Initial Sampling Rate for acceptance shall be 5 per lot, the Retest Sampling Rate (minimum) shall be 6 per lot, and the Rejection Limit shall be 10 percent.

Fine aggregate shall meet the requirements of Section 8.02 in the Standard Specifications.

Coarse aggregate shall meet the requirements of 6AA as stated in the Standard Specifications, with the additional requirements that the material shall be 100 percent crushed basalt, the freeze-thaw dilation (in percent) per 100 cycles shall be 0.008 maximum per MTM 115, the maximum size shall be 0.31 inches (8 mm), the maximum percent passing the No. 5 (4 mm) sieve shall be 3 percent, the maximum percent passing the No. 200 sieve shall be 2 percent, the Los Angeles Abrasion Loss (in percent) shall be 20 maximum and the Aggregate Wear Index (AWI) value shall be 300 minimum. The coarse aggregate shall be sampled at the source or dock if the material is shipped to the project by boat and shall be approved before shipment. Each aggregate stockpile shall be sampled by the District as it is constructed at a frequency of 1 sample for each 1000 tons. No material shall be added or removed from a stockpile after a sample is taken until testing is completed. An aggregate source will not be approved by certification for this concrete. All stockpiles shall be clearly identified at both the source and concrete batch plant.

c. **Concrete Production.**-The Contractor shall provide separate concrete mixtures for the top layer and bottom layer of the two-layer concrete pavement. Concrete mixtures for the two-layer concrete shoulder shall be the same as the top layer and bottom layer of the concrete pavement, or each layer shall be placed using the concrete mixture for the bottom layer of the concrete pavement.

d. Equipment.-Slip form pavers shall be used for constructing the concrete pavement and the concrete shoulder. Lane ties may be hand vibrated into place or placed with an automatic lane tie inserter for longitudinal joints. A separate machine including a concrete spreader, consolidator, and screed shall be used for each layer of the concrete. This shall be accomplished by using a separate paver for each layer or by using a combined two-layer paver. All pavers used shall be capable of maintaining proper line and grade.

Concrete finishing equipment for the top layer concrete shall include an oscillating longitudinal float pan moving perpendicular to the centerline of the roadway that has a smoothing action on the surface and removes any irregularities left by the operation of the paving equipment. The length of longitudinal float pan in the direction parallel to the centerline of the roadway shall be a minimum of six feet. Hand finishing will only be allowed at the edges.

Dowel bars may be set using a joint assembly or an automatic inserter. Equipment used to automatically place dowel bars and lane ties shall be capable of accurately inserting the dowel bars and lane ties into plastic concrete at the location shown on the plans without interrupting the forward movement of the pavers. The installing device shall consolidate the concrete around the dowel bars and lane ties such that no voids exist, without the supplement use of handheld vibrators. The Contractor shall provide a work bridge for use by the Department in order to make wet checks on the location of the dowel bars and lane ties.

If basket assemblies are used, they shall be held in place and attached to the lean concrete base by a method approved by the Engineer.

e. Construction.-Concrete pavement and concrete shoulders shall be constructed to the dimensions shown on the plans. Steel reinforcement shall not be placed in the concrete pavement or concrete shoulder. The concrete pavement shall have a final finish in accordance with the Special Provision for Exposed Aggregate Surface Treatment of Concrete Pavements (European Pavement). Concrete shoulders shall be dragged longitudinally with one or two layers of damp burlap or cotton fabric, a stiff fiber artificial grass carpet, or other approved material as soon as the concrete has set sufficiently to maintain texture. This concrete shoulder texturing shall be done in accordance with Subsection 4.50.14 of the Standard Specifications.

Concrete pavement and concrete shoulder shall be placed over a lean concrete base. The surface of the lean concrete base shall be cleaned of all foreign material before placing the concrete pavement or concrete shoulder. Heavy equipment and equipment for concrete paving will not be allowed on the lean concrete base until it reaches a strength of 70 percent of its class design strength.

Transverse joints in the concrete pavement shall be placed within 2 inches from the transverse joint in the lean concrete base. Longitudinal joints in the two-layer concrete pavement shall be placed within 1 inch from the longitudinal joints in the lean concrete base.

If dowel bars and lane ties are placed by an automatic inserter, they shall be inserted into the consolidated bottom layer of concrete prior to placing the top layer of concrete. Tolerances for placing the dowel bars are 3/16 inch in the length of the bar in both the vertical and horizontal planes of the pavement, within 2 inches of the plan longitudinal location, within 1 inch of the plan transverse location, and within 1/2 inch of the plan depth location. Tolerances for placing the lane ties are 1/2 inch in the length of the bar in both the vertical and horizontal planes of the pavement, within 2 inches of the plan transverse location, within 1 inch of the plan longitudinal location, and within 1/2 inch of the plan depth location. All dowel bars and lane ties placed outside these tolerances shall be removed and replaced at the Contractor's expense. The Contractor shall furnish an instrument capable of verifying the final location of the inserted dowel bars and lane ties.

The Contractor shall provide positive control and an approved method of marking the dowel bar locations for correlation to the sawed transverse joints.

Top layer concrete shall be placed within 30 minutes from screeding the bottom layer concrete directly below and within 45 minutes from unloading the bottom layer concrete onto the lean concrete base. The maximum distance during paving between the top layer paver and bottom layer paver shall be 50 feet.

Miscellaneous concrete pavement shall be constructed using the same materials and procedures as used for concrete pavements. Transverse joints in the miscellaneous concrete pavement shall coincide with the adjacent concrete pavement transverse joints.

e.1. Trial Length.-A trial length of concrete pavement, including a final finish in accordance with the Special Provision for Exposed Aggregate Surface Treatment of Concrete Pavements (European Pavement), shall be constructed by the Contractor.

At least one month prior to the construction of the trial length of concrete pavement the Contractor shall submit for the Engineer's approval a detailed description of the proposed materials, plant, equipment, and construction methods. No trials of new materials, plant, equipment, or construction methods; nor any development of them shall be permitted either during the construction of the trial length or in any subsequent paving work, unless they form part of further approved trials.

The Contractor shall demonstrate the materials, plant, equipment, and methods of construction that are proposed for concrete paving by first constructing a trial length of slab at least 500 feet but not more than 1000 feet long. The width of the trial length shall be 12-foot minimum. The trial length shall be constructed in two parts over a period comprising at least part of two separate working days, with a minimum of 250 feet constructed each day. The trial length shall be constructed at a similar rate to that which is proposed for the production paving.

At least two complete transverse joints and one complete longitudinal joint shall be constructed and assessed in the trial length.

The trial length shall comply with the specifications in all respects, with the following additions.

At least 3 cores with a minimum diameter of 4 inches shall be taken at random from the pavement by the Contractor to check the top and bottom layer thickness.

At least 3 cores with a minimum diameter of 4 inches shall be taken at random from the pavement by the Contractor at joints to check the lateral and vertical location of joint grooves and initial saw cut crack inducers.

Alignment of dowel bars shall be checked by the Contractor in any two consecutive transverse joints by drilling cores from the pavement with a minimum diameter of 4 inches. Cores shall be taken at each end of at least 3 dowel bars in each joint. If the position or alignment of the dowel bars at one of these joints does not comply with the tolerances stated herein, but if that joint remains the only one that does not comply after the next three consecutive transverse joints have been inspected, then the method of placing dowels shall be deemed to be satisfactory.

Position and alignment of tie bars shall be checked by the Contractor by drilling cores from the pavement with a minimum diameter of 4 inches. Cores shall be taken at each end of at least one-third of all the tie bars in the trial section.

Approval of the materials, plant, equipment, and construction methods will be given when the trial length complies with the specifications. The Contractor shall not proceed with production work until the trial length has been approved and any earlier defective trial lengths have been removed, unless they can be remedied to the satisfaction of the Engineer. If the Engineer does not notify the Contractor of any deficiencies in any trial length within 10 working days after the completion of that trial length the Contractor may assume that the trial length, and the materials, plant, equipment, and construction methods adopted are all acceptable.

When approval has been given, the materials, plant, equipment, and construction methods shall thereafter not be changed, except for normal adjustments and maintenance of the plant, without the approval of the Engineer. Any changes in materials, plant, equipment, and construction methods shall entitle the Engineer to require the Contractor to construct another trial length as described in this section to demonstrate that the changes will not adversely affect the work.

Trial lengths that do not comply with the specifications, with the exception of areas within the pavement surface that can be remedied to the satisfaction of the Engineer, shall be removed immediately upon notification of deficiencies by the Engineer and the contractor shall construct a further trial length.

f. Measurement and Payment.-Payment for the work of TWO-LAYER CONCRETE PAVEMENT AND CONCRETE SHOULDERS (EUROPEAN PAVEMENT) includes all the materials, labor, and equipment necessary to complete the work as described herein. Payment shall be made in accordance with the following contract items (pay items).

Pay Item	**Pay Unit**
Two-Layer Concrete Pavement - 10-inch Non-Reinforced (European Pavement)	Square Yard
Two-Layer Concrete Shoulder - 10-inch Non-Reinforced (European Pavement)	Square Yard
Miscellaneous Two-Layer Concrete Pavement 10-inch Non-Reinforced (European Pavement)	Square Yard

The cost of furnishing and setting dowel bars and lane ties in two-layer concrete pavement transverse joints is included in the payment for Transverse Contraction Joint (European Pavement) and Longitudinal Joint (European Pavement) as described in the Special Provision for Constructing Longitudinal and Transverse Contraction Joints.

Payment for the trial length of concrete pavement will not be paid for separately, but shall be considered included in the payment for Two-Layer Concrete Pavement - 10-inch Non-Reinforced (European Pavement). Cost for removal and replacement of all failing trial lengths shall be at the Contractor's expense.

Coring the concrete pavement for thickness determination and acceptance will be done in accordance with Section 4.50 of the Standard Specifications. Total pavement thickness will be the basis of application to this section. Top layer thickness of $\pm$1/2 inch from the plan dimension shall be cause for removal and replacement. Depth of reinforcement measurements are not applicable.

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MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION FOR LEAN CONCRETE BASE (EUROPEAN PAVEMENT)

a. Description.-This work shall consist of constructing a lean concrete base over a granular subbase. The lean concrete base shall be non-reinforced and shall be constructed to the dimensions and limits as shown on the plans. Lean concrete bases shall be constructed in accordance with concrete base courses as specified in Section 4.50 of the Standard Specifications, except as modified herein. The two-layer concrete pavement and concrete shoulders shall be placed over the lean concrete base.

b. Concrete Mix Design.-The Contractor shall be responsible for the concrete mix design as specified in the Special Provision for Furnishing Portland Cement Concrete (Quality Assurance). Concrete properties, characteristics, and acceptance sampling rate shall be as specified herein. Acceptance of the concrete based on these properties and characteristics shall be in accordance with the Special Provision for Furnishing Portland Cement Concrete (Quality Assurance). This lean concrete base is considered a Critical Pay-Adjustment Item.

b.1. Concrete Properties and Characteristics.-Concrete for the lean concrete base shall meet the following properties and characteristics.

Class Design Strength (28 days, psi)	2500
Verification Strength (28 days, psi)	3000
Retest Limit (28 days, psi)	2000
Maximum Water/Cement Ratio (lb/lb)	0.70
Minimum Cement Content (lb/cyd)	400
Maximum Slump (inches)	3

This concrete is designated as Concrete Grade 25P.

The Initial Sampling Rate for acceptance shall be 5 per lot, the Retest Sampling Rate (minimum) shall be 6 per lot, and the Rejection Limit shall be 10 percent.

Fine aggregate shall meet the requirements of Section 8.02 in the Standard Specifications.

Coarse aggregate shall be a natural gravel or crushed stone and shall meet the requirements of 6AA as stated in the Standard Specifications, with the additional requirement that freeze-thaw dilation (in percent) per 100 cycles shall be 0.008 maximum per MTM 115. No recycled concrete pavement will be allowed in the lean concrete base mixture. Coarse aggregate shall be sampled at the source or dock if the material is shipped to the project by boat and shall be approved before shipment. Each aggregate stockpile shall be sampled by the District as it is constructed at a frequency of 1 sample for each 1000 tons. No material shall be added or removed from a stockpile after a sample is taken. An aggregate source will not be approved by certification for this concrete. All stockpiles shall be clearly identified to this project at both the source and concrete batch plant.

c. Construction.-The lean concrete base shall be non-reinforced and shall be constructed over a granular subbase to the dimensions shown on the plans. The two-layer concrete pavement and concrete shoulders shall be placed over the lean concrete base. Equipment used to place the lean concrete base shall be capable of screeding and consolidating the concrete mixture to the proposed line and grade. Transverse and longitudinal plane of weakness joints with a depth of at least 0.4 to 0.45 percent of the thickness shall be placed in the lean concrete base within 24 hours of placing the concrete. These joints shall be made by a vibrating panel placed in the fresh concrete or by saw cutting the hardened concrete. Transverse joints in the lean concrete base shall be placed within 2 inches from the transverse joint in the two-layer concrete pavement. Longitudinal joints in the lean concrete base shall be placed within 1 inch from the longitudinal joint in the two-layer concrete pavement. Load transfer bars shall not be placed in the lean concrete base at the transverse or longitudinal joints.

As soon as the concrete has set sufficiently to maintain texture, the concrete surface shall be dragged longitudinally with one or two layers of damp burlap or cotton fabric, a stiff fiber artificial grass carpet, or other approved material. This texturing shall be done in accordance with Subsection 4.50.14 of the Standard Specifications.

Lean concrete base surfaces shall be kept free of curing compound. These surfaces shall be cured by being kept continuously moist until the concrete has reached an age of at least 7 days. The moist curing shall be started as soon as the concrete has hardened sufficiently to prevent significant marring or water damage.

Heavy equipment, including slip form pavers, will not be permitted on the lean concrete base until the concrete has attained a strength of 70 percent of its class design strength.

The Contractor shall remove and replace all sections of lean concrete base that have full depth cracks between the transverse joints at no cost to the project.

The surface of the lean concrete base shall be cleaned of all foreign material before placing the two-layer concrete pavement or concrete shoulder.

d. Measurement and Payment.-Payment for the work of LEAN CONCRETE BASE (EUROPEAN PAVEMENT) includes all the materials, labor, and equipment necessary to complete the work as described herein. Payment shall be made for the following contract item (pay item).

Pay Item	Pay Unit
Lean Concrete Base - 6-inch Non-Reinforced (European Pavement)	Square Yard

Coring the lean concrete base for thickness determination and acceptance will be done in accordance with Section 4.50 of the Standard Specifications. Depths of reinforcement measurements are not applicable.

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MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION FOR AGGREGATE SUBBASE (CIP) (European Pavement)

a. Description.-This work shall consist of furnishing and placing an aggregate on a prepared subgrade in accordance with the details shown on the plans and as specified in Sections 2.08, 2.11, and 8.02 of the 1990 Standard Specifications with the exceptions and additions specified herein.

b. Materials.-The materials shall meet the requirements specified herein. The aggregate for the subbase shall be a natural aggregate meeting the following grading and physical requirements:

Grading Requirements

MI Series & Class	Sieve Analysis, Total Percent Passing 1-3/4"	1"	1/2"	#8	#30	%Loss by Washing
Euro-A1	100	65-95	40-65	20-42	8-30	7.0 Max.

Physical Requirements

MI Series & Class	Euro-A1
Crushed Material, min.	90%(*)
Loss, max., Los Angeles Abrasion (AASHTO T96)	45%

*The percentage of crushed material will be determined on that portion of the sample retained on all sieves down to and including the No. 4 sieve.

c.Construction Methods.-Prior to placing the aggregate subbase, the subgrade shall be prepared in accordance with Section 2.08.

The aggregate material shall be placed in accordance with Section 2.11, except as modified herein. The aggregate material shall be placed and compacted in two layers of approximately equal thickness. Each layer shall be compacted to not less than 100 percent of its maximum unit weight.

The surface of the Aggregate Subbase shall be finished to the specified grade and cross-section within a tolerance of ±3/4 inch. The finished surface shall be smooth and uniform in appearance, and be free of holes, depressions, ruts, and ridges.

d.Testing and Acceptance.-The material will be sampled and tested for gradation acceptance and physical requirements prior to placing and compacting. The Contractor shall make adequate allowance for degradation or segregation of the aggregate so that it will meet specification requirements after being compacted-in-place.

e.Measurement and Payment.-The completed work as measured for AGGREGATE SUBBASE (CIP) will be paid for at the contract unit price for the following contract item (pay item).

Pay Item	Pay Unit
Aggregate Subbase (CIP) (European Pavement)	Cubic Yard

Aggregate subbase (CIP) will be measured by area in cubic yards in place in accordance with the methods specified for measuring sand subbase in Subsection 2.11.04 of the 1990 Standard Specifications. Payment for the item Aggregate Subbase (CIP) includes payment for furnishing, placing, spreading, shaping, compacting, and maintaining the new aggregate material.

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MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION
FOR
CONSTRUCTING LONGITUDINAL AND
TRANSVERSE CONTRACTION JOINTS
(EUROPEAN PAVEMENT)

a. Description.-This work shall consist of constructing longitudinal and transverse contraction joints in the two-layer European concrete pavement and associated shoulders and miscellaneous pavement in accordance with the plans and Section 4.50 of the 1990 Standard Specifications with the exceptions contained herein. Both joints shall be sealed with a PHOENIX EPDM joint seal in place of the hot-poured rubber asphalt longitudinal sealant, and in place of the 1-1/4 inch preformed neoprene transverse seal.

b.Materials:

Joint Sealant.-The longitudinal joint seal shall be a Phoenix EPDM type M 214-66. The transverse joint seal shall be a Phoenix EPDM type M 214-45. No other manufacturer for these joints will be allowed. The manufacturer shall provide Type D certification on the EPDM material, as defined in the Michigan Materials Quality Assurance Manual. PHOENIX North America, Inc. shall be notified one week in advance of the pending sealing operation. A representative of Phoenix will be on hand to assist in the installation procedure. The PHOENIX contact person is:

Mr. Scott Poyner
PHOENIX North America,Inc.
1 minue Street
Carteret, New Jersey 07008-9984
Ph: (908) 969-0319

Dowel Bars.-The dowel bars for transverse contraction joints shall meet the requirements of 8.16.08 except as noted. The dowel bars shall be twenty inches long with a diameter of one and one quarter inch (1 1/4"). The transverse dowel spacing shall be as shown on the plans. The dowels are to be inserted in the pavement by a mechanical dowel bar inserter or by dowel basket assemblies. The dowel bar coating shall be Type A for the inserted dowel bars.

Lane Ties.-Lane ties for longitudinal pavement joints shall meet the requirements of Subsection 8.16.10-a of the 1990 Standard Specifications except that the lane ties shall be an epoxy coated, deformed, number seven bar (seven-eighths inch in diameter), thirty two inches in length. The spacing for the lane ties shall be as shown on the plans.

c. Joint Groove Sawing.-The joint grooves shall be sawed to the dimensions shown on the plans and as specified in Subsection 4.50.17 of the 1990 Standard Specifications, except that the first stage saw cutting on all joints will be performed within twenty four hours after concrete placement. No sawing shall be permitted until the concrete has obtained sufficient strength to support the saw without damage. After the initial saw cut, a continuous plastic band or tubing shall be inserted into the saw cut to a depth just below the subsequent saw cut that shapes the joint for the Phoenix seal. This plastic band is inserted to prevent slurry, resulting from the second stage saw cutting, from infiltrating into the crack cavity below the joint seal. The diameter of the solid plastic band should be approximately 10% greater than the width of the initial saw cut or if hollow tubing is used, approximately 25% greater. The exposed ends of the plastic band or tubing should be tied or knotted to prevent the band or tubing from contracting into the exposed ends of the saw cut. The saw and saw blade used for cutting the required bevel, as shown on the plan detail, will be supplied by the joint seal manufacturer (Phoenix). Immediately after the final stage sawing, the joint groove shall be cleaned with water having sufficient pressure to remove all slurry and debris from the joint faces and reservoir. The final stage sawing shall follow the completion of work for the aggregate surface treatment.

d. Joint Repair.-Prior to sealing, all spalls or voids in the joint area shall be repaired as specified in Subsection 4.50.19 of the 1990 Standard Specifications. Prior to sealing the joint, the repaired areas shall be sandblasted to clean and texture the surface.

e. Joint Preparation.-Immediately prior to sealing, the joint shall be cleaned to remove all dust and contamination from the joint faces and reservoir. Cleaning shall consist of abrasive blasting followed by a final cleaning with compressed air, free of oil and water and having a minimum nozzle pressure of 90 psi.

f. Joint Sealing.-The EPDM seal shall be installed in accordance with Subsection 4.50.22-b of the 1990 Standard Specifications with the following exceptions. The transverse joint seal shall be installed prior to installing the longitudinal seal. No lubricant-adhesive shall be used. The joint seal shall be installed by a machine supplied by the joint seal manufacturer. The installation operation shall be carried out in such a manner that the longitudinal elongation of the seal does not exceed 5%. The joint seal shall be wiped clean with a water and soap solution as it is being inserted into the installation device. After the transverse joint seals are installed, a U-shaped notch shall be cut into the seals. This cut, at the intersection between the transverse and longitudinal joints, shall be two-thirds of the profile height of the transverse joint. The device used to notch the transverse seals shall be the same machine that bevels the joint edge. The longitudinal seal shall be installed in a similar manner as the transverse joint. The surface contacts for the overlap between the transverse and longitudinal seals shall be glued with Sikaflex 221. Alternatives to this adhesive shall be approved only by the joint seal manufacturer. The placement of any glue shall not extend more than three transverse joints ahead of the longitudinal seal installation.

g. Joint Seal Splicing.-No splicing of the transverse joint seals will be allowed. Splices in the longitudinal joint shall be made only at mid-panel locations to avoid the intersecting point with the transverse joint. At the splice locations, the ends of the abutting members shall be trimmed square and be joined with an application of Sikaflex 221. Both sections of the seal shall then be inserted into the groove using a hammer and flat ended chisel butting the ends tightly together. Hammer and chisel installation of the longitudinal seal will continue for an additional three feet either side of the splice location, before continuing the installation of the seal with the installation machine.

h. Measurement and Payment.-The completed work as measured for CONSTRUCTING LONGITUDINAL AND TRANSVERSE CONTRACTION JOINTS (EUROPEAN PAVEMENT) will be paid for at the contract unit price for the following contract items (pay items).

Pay Item	Pay Unit
Transverse Contraction Joint (European Pavement)	Linear Foot
Longitudinal Joint (European Pavement)	Linear Foot

The payment for Transverse Contraction Joint will include all items provided for in this provision to construct and seal the transverse joints. This pay item includes such items as furnishing and installing dowel bars, all transverse EPDM joint seals required, adhesives, sawing, forming, and cleaning the joints; furnishing and installing the plastic bands; repairing spalls or voids; and furnishing special installation and sawing equipment. The pay item for Longitudinal Joint will include those similar materials and work for constructing transverse joints, as described in this provision, necessary to construct and seal the longitudinal joint.

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MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION FOR HIGH DURABILITY COARSE AGGREGATE FOR CONCRETE PAVEMENTS AND CONCRETE SHOULDERS

M&T:RDT:RVP **03-18-93**

a. Description.-The coarse aggregate furnished for Grade 35P and Grade 30P concrete for pavements and shoulders on northbound I-75, within the project limits, shall meet the requirements of 6AA as specified in the Standard Specifications, except as modified herein.

Coarse Aggregate 6AA shall be a natural gravel or crushed stone and shall have a maximum freeze-thaw dilation of 0.008 percent per 100 cycles per MTM 115. Coarse aggregate shall be sampled at the source or dock if the material is shipped to the project by boat and shall be approved before shipment. Each aggregate stockpile shall be sampled by the District as it is constructed at a frequency of 1 sample for each 1000 tons. No material shall be added or removed from a stockpile after a sample is taken. An aggregate source will not be approved by certification for this concrete. All stockpiles shall be clearly identified at both the source and concrete batch plant.

In cases where this Special Provision is in conflict with another Special Provision, this Special Provision will prevail.

b. Measurement and Payment.-Separate payment will not be made for providing this coarse aggregate. All costs associated therewith shall be included in the applicable unit price for the concrete item.

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MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION FOR FURNISHING PORTLAND CEMENT CONCRETE (QUALITY ASSURANCE)

a. Description.-This specification sets forth the requirements for furnishing portland cement concrete and the procedures that will be used for acceptance of the concrete product. All concrete furnished for pavements, structures (except prestressed concrete), and appurtenant highway items that are concrete will be governed by this specification. Provisions for furnishing concrete shall be in accordance with the appropriate sections of the 1990 Standard Specifications for Construction, except as modified herein. Latex modified concrete, concrete repair mixtures, concrete patching mixture, mortar, grout, and concrete grade 35HE are not covered by this specification. In cases where this Special Provision is in conflict with another Special Provision, this Special Provision will prevail.

b. Mix Design Proportioning and Verification.-It is the responsibility of the Contractor to provide a concrete mix design such that the specified temperature, slump, air-entrainment, and compressive strength of concrete will be attained.

b.1. Mix Design Proportioning.-The designs shall be computed and set up in accordance with ACI Standard 211.1 as applicable. The mix design basis for bulk volume, dry loose or dry rodded method, of coarse aggregate per unit volume of concrete shall be between 65 and 75 percent, inclusive. Dry loose or dry rodded unit weight of coarse aggregate shall be determined in accordance with ASTM C 29 shoveling procedure and rodding procedure, respectively. The material shall be dried before testing.

b.2. Mix Design Verification.-The Contractor shall submit mix designs for the various grades of concrete required to the Engineer for review, along with documentation indicating that the proposed mix design will meet the verification strength requirements listed in Table 1. Compressive strength of concrete at an age of seven days that equals or exceeds 90 percent of the verification strength listed in Table 1 will be considered an acceptable mix design. The documentation may be from past experience with the same materials and the same mix design, past experience with similar materials and a similar mix design, or from trial batches.

Mix design documentation using the same materials and the same mix design shall include traceable test results of compressive strength and air content.

Mix design documentation based on past experience with similar materials and similar mix design shall be restricted to changes of aggregate sources. Coarse aggregate sources will be allowed to be substituted provided the new source is within the same source type as the original aggregate, that is, natural gravel, quarried stone, and slag. Substitution of the fine aggregate source will be permitted. Proportions of the proposed mix design shall be adjusted based on the differences in specific gravity and absorption of the fine and coarse aggregate to produce a theoretical yield of 100 percent. This mix adjustment shall be done by an approved testing laboratory. Traceable test results of compressive strength and air content shall be included in the documentation for the original mix design, along with calculations showing how the mix proportions were adjusted.

Mix design documentation using trial batches shall be based on the same materials and proportions proposed for use on the project. Trial batches shall be prepared at least 30 days prior to the start of concrete placement. Tests on the trial batch shall be performed by an approved testing laboratory.

At the Department's option, verification may be done on an annual basis for a concrete plant rather than on a project-to-project basis provided the properties and proportions of the materials do not change. If the job is the continuation of work in progress during the previous construction season and written verification is submitted that the same source and character of materials are to be used, the Engineer may waive the requirement for the design and verification of previously approved mixes.

b.3. Mix Designs Using Fly Ash.-If fly ash is added to concrete, the restrictions cited in Subsection 7.01.04 of the Standard Specifications regarding the maximum weight of cement replaced by fly ash and the maximum substitution ratio do not apply. If the Contractor elects to use concrete containing a separate addition of fly ash, the Contractor shall provide a concrete mix design as described herein, except that fly ash shall not be greater than 30 percent of the cementitious material. The combined weight of fly ash and cement content shall be used to determine compliance with the cement factor and water-cement ratio requirements listed in Table 1.

b.4. Laboratory Requirements.-Private testing laboratory shall conform to ASTM C 1077 and must demonstrate that they are equipped, staffed, and managed so as to be capable of batching and testing portland cement concrete in accordance with the applicable ASTM/AASHTO methods of testing. A means of demonstrating such ability of the laboratory is by submission of a copy of their latest report of inspection by the Cement and Concrete Reference Laboratory, National Institute of Standards and Technology, along with a letter detailing the actions taken to correct any deficiencies noted therein.

b.5. Review of Mix Designs.-Each mix design shall be submitted on portland cement concrete mix design forms acceptable to the Department, giving the source of materials, specific gravity of constituents, aggregate absorption, dry weights used, dry loose or dry rodded unit weight of coarse aggregate (whichever one is used as basis for design), batch weights, and test data. The test data shall include compressive strength, concrete age at the time of strength testing, and air content. When trial batches are used, the test data shall also include the slump of the concrete and the compressive strength of at least two molded cylinders. The average strength of these cylinders must meet the verification strength requirements.

When mix design documentation is based on past experience with similar materials and similar mix design the above information shall be submitted for the original mix design and the proposed mix design, along with calculations showing how the mix proportions were adjusted to produce a theoretical yield of 100 percent.

b.6. Changes in Materials and Proportions.-Concrete furnished on the project shall conform to the approved mix design. If another previously approved mix design is to be used, the Engineer shall be notified prior to such change.

Changes in the sources, types, or proportions of materials shall not be made until the requirements for the verification strengths specified herein have been satisfied. Minor adjustments in the approved mix design proportions will be permitted in accordance with Section 7 of the Standard Specifications. The requirement to verify a new design as a result of a change in the type of portland cement may be waived only by the Engineer.

Concrete may be designed to achieve early strength requirements by increasing the cement content. Alternatively, an existing approved mix design may serve as a high-early-strength mix.

c. **Concrete Production.**-The Contractor shall provide quality control measures for the concrete in accordance with the Special Provision for Contractor Quality Control for Concrete.

d. **Acceptance Testing Procedures for Temperature, Slump, and Air-Entrainment.**-The Engineer will perform sampling and testing for temperature, slump, and air-entrainment.

Concrete temperature shall be in accordance with the Standard Specifications and is a basis of acceptance.

Slump and air-entrainment tests are at the rate specified for strength tests in Table 2 and are performed on the same samples of material from which the compressive test cylinders are molded. The Engineer may perform additional unscheduled slump and air-entrainment tests. These tests will be a basis of acceptance. While these tests are being performed, discharge from the truck is to be halted.

Concrete must pass temperature, slump, and air-entrainment tests before cylinders for strength tests are molded.

e. **General Acceptance Testing Requirements for Strength.**-The Contractor shall be responsible for sampling, molding, 28-day curing, and transporting the concrete cylinders for testing, under the observation and direction of the Engineer. The 28-day, fully cured concrete cylinders shall be transported to the District Testing Laboratory to which the project is assigned. These fully cured concrete cylinders shall be delivered to the Testing Laboratory 28 days after molding the specimens. Metal tags will be inserted a maximum of 1/2-inch into the top surface of the molded cylinders by the Engineer for identification purposes. The air content and slump of the concrete represented by the cylinders will be noted on these tags. Random sampling techniques will be used by the Engineer to determine the samples selected for testing. Any high early strength concrete used intermittently on a project shall not be included in the sampling of that grade of concrete to determine acceptance of a lot. High early strength concrete shall not be used for critical pay adjustment items unless written permision from the Engineer is received. The Engineer reserves the right to sample and test any high early strength concrete used on the project to determine acceptance of that concrete.

The Department will cap the fully cured concrete cylinders and perform the strength tests. Metal tags for identification will be clipped off the cylinders by the Department prior to strength testing. Results of the strength test, along with the recorded slump and air content, will be provided to the Contractor and concrete supplier.

Curing of concrete test cylinders for 28 days, as required by ASTM C31, shall be provided by the Contractor.

The Contractor shall furnish a sufficient number of 6-inch by 12-inch cylinder molds to permit making the number of test specimens required for the volume of concrete produced. A shortage of molds will result in a stoppage in the placement operations.

The Contractor shall be responsible for making additional cylinder or beam specimens required for form removal and opening to traffic strengths. Curing of these specimens shall be provided by the Contractor and shall be in the same environment as the concrete item that they represent. These work progress test specimens shall be tested by the Contractor on the project site and the testing shall be witnessed by the Engineer.

An initial strength test result is defined as the average of two 6-inch by 12-inch compression test cylinders, cured for 28 days in accordance with applicable ASTM Standards, and tested in the Department's Laboratory. The required rate of sampling and the acceptance testing criteria of Table 2 must be met. If a batch of concrete is rejected because it fails to meet the temperature, slump, or air-entrainment requirements of this specification, the cylinders for strength tests shall not be molded.

The Engineer may direct additional unscheduled compression cylinders to be taken. These cylinders will be included with the regularly scheduled compression cylinders and the lot will be evaluated on the basis of the increased number of tests.

f. Acceptance Testing for Strength for Critical Pay-Adjustment Items.-The list of critical concrete pay items that are subject to pay adjustment and their base prices may be found in the Special Provision for Pay Adjustments.

The amount of pay adjustment in dollars is the product of the item base price times the lot quantity times the percent pay adjustment. The percent pay adjustment is given by Equation (1).

Equation (1):

$$PPA = 2.0 - 0.2\ PD$$

In which

PPA = Percent Pay Adjustment
PD = Percent Defective (Estimate of percent of lot below the class design strength by the use of Equation (2) and Table 3

Equation (2):

$$Q = (\text{Average Lot Strength} - \text{Class Design Strength}) \div S$$

In which

Q = Quality index for pay adjustment computations
S = Standard deviation of the strength test results for the lot as computed by Equation (3)

Equation (3)

$$S = \left[\frac{\Sigma(Xi - ALS)^2}{(N - 1)}\right]^{1/2}$$

In which

Σ = Summation
Xi = Individual test result (Average strength of a test cylinder pair)
ALS = Average lot strength
N = Number of test results for the lot

NOTE - When only a single test result is available, the standard deviation is assumed to be S = 400 psi.

When it is necessary to estimate the percentage of material below the retest limit to check the rejection criteria in Table 2, Equation (4) is used with Table

3. All other terms are as previously defined.

Equation (4)

$$Q_{reject} = (\text{Average Lot Strength} - \text{Retest Limit}) \div S$$

Provided that no initial test result (average strength of two test cylinders) falls below the retest limit (psi) listed in Table 2, the acceptability of a lot is based upon the estimated percentage of concrete having a 28-day compressive strength less than the class design strength specified in Table 1. To be eligible for 100 percent payment, a lot must have no more than 10 percent of the material below the class design strength.

For lots with percent defective levels less than 10 percent, Equation (1) awards positive pay adjustments to be added to the contract price. For lots having percent defective levels greater than 10 percent (when the percent defective is determined using Equation (2) and class design strength) but not exceeding the rejection limit in Table 2 (when the percent defective is determined using Equation (4) and the retest limit), Equation (1) assesses pay adjustments to be subtracted from the contract price.

Whenever an initial test result falls below the retest limit in Table 2, the concrete will be re-evaluated by coring or non-destructive testing.

When re-evaluation is accomplished by a method other than coring, the results will be used only to determine what further action is to be taken. If any non-destructive test results are below the class design strength, the Engineer has the option to core. If this option is waived, the Contractor may elect to core, at no cost to the Department, or to accept the pay adjustment computed from the initial cylinder tests. If the Contractor elects to core, the coring shall be performed as directed and must be submitted to the Department within 45 days from the concrete placement. Cores shall not be taken within two feet of transverse joints, within two feet of longitudinal joints, or within two feet of free edges for critical pay-adjustment items, one-foot clearance in all other cases. The Department will test the cores. If none of the non-destructive test results is below the class design strength, the Engineer may elect either to core or to accept the lot at 100 percent payment.

When cores are taken, final disposition of the lot is based on the core results. Pay adjustment will be computed using the core test results provided that the percentage of material below the retest limit does not exceed the rejection limit percentage in Table 2. If this maximum allowable percentage is exceeded, the Engineer may:

(1) Require the Contractor to remove and replace the defective lot at no cost to the Department. New initial tests shall be obtained and the evaluation procedure repeated.

(2) Allow the Contractor to leave the defective lot in place and receive a percent pay adjustment (PPA) of minus 50 percent, or

(3) Allow the Contractor to submit a plan, for approval, for corrective action to be performed at no cost to the Department. If the plan for corrective action is not approved, either Option (1) or (2) may be applied.

g. Acceptance Testing for Strength for Non-Critical Pay-Adjustment Items.-This section applies to all other concrete items, which are subject to pay adjustment, not covered in Section (f), and that are not accepted on the basis of Certificates of Compliance. The lot is eligible for 100 percent payment provided that all initial test results equal or exceed the retest limit for non-critical pay-adjustment items in Table 2. Whenever one or more individual test results fall below the retest limit, the lot will be re-evaluated by coring or other suitable means and is subject to pay adjustment and all other provisions in accordance with Section (f), except that the amount of pay adjustment is the product of the unit bid price times the lot quantity times the percent pay adjustment given by Equation (1).

h. Combined Pay Adjustments.-When a contract price requires adjustment for reasons other than strength, the lot of concrete accepted based on strength requirements may have varying contract price adjustments (for other reasons) within that lot. The total pay adjustment for the item shall be calculated using the summation of the pay adjustments involved. The base price or unit bid price, whichever case applies, shall be used in determining the pay adjustment for strength.

i. Sampling and Testing.-Sampling and testing will be performed in accordance with the following:

ASTM
C29 Unit Weight and Voids in Aggregate
C31 Making and Curing Concrete Test Specimens in the Field
C39 Compressive Strength of Cylindrical Concrete Specimens
C42 Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C127 Specific Gravity and Absorption of Coarse Aggregate
C128 Specific Gravity and Absorption of Fine Aggregate
C138 Unit Weight, Yield and Air Content (Gravimetric) of Concrete
C143 Slump of Hydraulic Cement Concrete
C172 Sampling Freshly Mixed Concrete
C173 Air Content of Freshly Mixed Concrete by the Volumetric Method
C192 Making and Curing Concrete Test Specimens in the Laboratory
C231 Air Content of Freshly Mixed Concrete by the Pressure Method

The Department's established procedures for sampling are considered acceptable alternatives.

The Contractor's personnel performing designated sampling and testing shall be certified as a Concrete Technician Michigan Level I or II through a program certified by the Michigan Concrete Association. The Contractor shall furnish the name(s) of the concrete technician(s) to the Engineer prior to sampling and testing.

j. Measurement and Payment.-The completed work as measured for FURNISHING PORTLAND CEMENT CONCRETE (QUALITY ASSURANCE) will be paid for at the contract unit price for the following contract item (pay item).

Pay Item	**Pay Unit**
Concrete Quality Assurance Cylinders	Each

Payment for Concrete Quality Assurance Cylinders includes all the necessary materials, labor, and equipment necessary to furnish each fully cured concrete cylinder to the Department for acceptance testing. An initial strength test result consists of the average of two test cylinders, and will be paid for as two Concrete Quality Assurance Cylinders.

Separate payment will not be made for the work required to provide an acceptable concrete mix design, for providing work progress tests, or for providing and maintaining an effective concrete quality control program. These costs shall be considered included in the applicable unit price for the concrete item.

Table 1
Mix Design Requirements

Grade of Concrete

	45D	40S	35T	35P 35S	30P 30S
Class Design Strength (28 days, psi)	4500[1]	4000	3500	3500	3000
Verification Strength (28 days, psi)	5000	4500	4500	4000	3500
Maximum Water/Cement Ratio lb/lb	0.44	0.50	0.50	0.50	0.50
Minimum Cement Content lb/cy	650	600[2]	550[2]	550[2]	500[2]

Note 1 - Water reducing or water reducing retarding admixtures shall be used.

Note 2 - Cement content may be decreased by five percent if a water reducing or water reducing retarding admixture is used.

Table 2
Lot Sizes, Sampling Rates, Retest and Rejection Limits

	Grade of Concrete				
	45D	40S	35T	35P 35S	30P 30S
Lot Size, Maximum	One Day's Production				
Critical Pay-Adjustment Items					
Initial Sampling Rate	6/Lot	5/Lot	4/Lot	5/Lot	4/Lot
Retest Limit, psi	4000	3500	3000	3000	2500
Retest Sampling Rate, Min.	6/Lot	6/Lot	6/Lot	6/Lot	6/Lot
Rejection Limit, percent	10	10	10	10	15
Non-Critical Pay-Adjustment Items					
Initial Sampling Rate	3/Lot	3/Lot	3/Lot	3/Lot	3/Lot
Retest Limit, psi	4500	4000	3500	3500	3000

Note 1 - The lot sizes are maximums and, at the option of the Engineer, any lot may be subdivided into two or more smaller lots. When such a subdivision is made, the specified sampling rate applies to each of the smaller lots.

Note 2 - A retest result is defined as the strength of an individual test result obtained by coring or other suitable means.

Note 3 - The specified sampling rates shall apply except that no more than one test per truckload or batch of concrete will be required. At the option of the Engineer, lots consisting of fewer than three truckloads or batches, or containing 20 cubic yards or less, may be accepted without strength tests.

Note 4 - No lot shall include more than one grade of concrete, nor include concrete of the same grade having different specified levels of slump or air-entrainment, nor include concrete of the same grade having a different mix design.

Table 3
Estimation of Lot Percent Defective

Variability-Known Procedure — Standard Deviation Method

Sample Size
1

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	48.98	47.96	46.94	45.92	44.90	43.88	42.86	41.84	40.82
0.1	39.80	38.78	37.76	36.73	35.71	34.69	33.67	32.65	31.63	30.61
0.2	29.59	28.57	27.55	26.53	25.51	24.49	23.47	22.45	21.43	20.41
0.3	19.39	18.37	17.35	16.33	15.31	14.29	13.27	12.24	11.22	10.20
0.4	9.18	8.16	7.14	6.12	5.10	4.08	3.06	2.04	1.02	0.00

Note 1 - Numbers in the body of the table are estimates of lot percent defective corresponding to specific values of Q, the Quality Index. For values of Q greater than or equal to zero, the estimate of percent defective is read directly from the table. For values of Q less than zero, the table value must be subtracted from 100.

Note 2 - This empirically derived table is suitable only for use with this specification.

Variability-Unknown Procedure — Standard Deviation Method

Sample Size
2

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	49.66	49.33	48.99	48.66	48.32	47.99	47.65	47.32	46.98
0.1	46.64	46.31	45.97	45.64	45.30	44.97	44.63	44.30	43.96	43.62
0.2	43.29	42.95	42.62	42.28	41.95	41.61	41.28	40.94	40.60	40.27
0.3	39.93	39.60	39.26	38.93	38.59	38.26	37.92	37.58	37.25	36.91
0.4	36.58	36.24	35.91	35.57	35.23	34.90	34.56	34.23	33.89	33.56
0.5	33.22	32.89	32.55	32.21	31.88	31.54	31.21	30.87	30.54	30.20
0.6	29.87	29.53	29.19	28.86	28.52	28.19	27.85	27.52	27.18	26.85
0.7	26.51	26.17	25.84	25.50	25.17	24.83	24.50	24.16	23.83	23.49
0.8	23.15	22.82	22.48	22.15	21.81	21.48	21.14	20.81	20.47	20.13
0.9	19.80	19.46	19.13	18.79	18.46	18.12	17.79	17.45	17.11	16.78
1.0	16.44	16.11	15.77	15.44	15.10	14.77	14.43	14.09	13.76	13.42
1.1	13.09	12.75	12.42	12.08	11.75	11.41	11.07	10.74	10.40	10.07
1.2	9.73	9.40	9.06	8.72	8.39	8.05	7.72	7.38	7.05	6.71
1.3	6.38	6.04	5.70	5.37	5.03	4.70	4.36	4.03	3.69	3.36
1.4	3.02	2.68	2.35	2.01	1.68	1.34	1.01	0.67	0.34	0.00

Note 1 - Numbers in the body of the table are estimates of lot percent defective corresponding to specific values of Q, the Quality Index. For values of Q greater than or equal to zero, the estimate of percent defective is read directly from the table. For values of Q less than zero, the table value must be subtracted from 100.

Note 2 - This empirically derived table is suitable only for use with this specification.

Table 3 (Continued)

Variability-Unknown Procedure Standard Deviation Method

Sample Size
3

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	49.72	49.45	49.17	48.90	48.62	48.35	48.07	47.79	47.52
0.1	47.24	46.96	46.69	46.41	46.13	45.85	45.58	45.30	45.02	44.74
0.2	44.46	44.18	43.90	43.62	43.34	43.05	42.77	42.49	42.20	41.92
0.3	41.63	41.35	41.06	40.77	40.49	40.20	39.91	39.62	39.33	39.03
0.4	38.74	38.45	38.15	37.85	37.56	37.26	36.96	36.66	36.35	36.05
0.5	35.75	35.44	35.13	34.82	34.51	34.20	33.88	33.57	33.25	32.93
0.6	32.61	32.28	31.96	31.63	31.30	30.97	30.63	30.30	29.96	29.61
0.7	29.27	28.92	28.57	28.22	27.86	27.50	27.13	26.76	26.39	26.02
0.8	25.64	25.25	24.86	24.47	24.07	23.67	23.26	22.84	22.42	21.99
0.9	21.55	21.11	20.66	20.19	19.73	19.25	18.75	18.25	17.74	17.21
1.0	16.67	16.11	15.53	14.93	14.31	13.66	12.98	12.27	11.51	10.71
1.1	9.84	8.89	7.82	6.60	5.08	2.87	0.00	0.00	0.00	0.00

Note 1 - Numbers in the body of the table are estimates of lot percent defective corresponding to specific values of Q, the Quality Index. For values of Q greater than or equal to zero, the estimate of percent defective is read directly from the table. For values of Q less than zero, the table value must be subtracted from 100.

Variability-Unknown Procedure Standard Deviation Method

Sample Size
4

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	49.67	49.33	49.00	48.67	48.33	48.00	47.67	47.33	47.00
0.1	46.67	46.33	46.00	45.67	45.33	45.00	44.67	44.33	44.00	43.67
0.2	43.33	43.00	42.67	42.33	42.00	41.67	41.33	41.00	40.67	40.33
0.3	40.00	39.67	39.33	39.00	38.67	38.33	38.00	37.67	37.33	37.00
0.4	36.67	36.33	36.00	35.67	35.33	35.00	34.67	34.33	34.00	33.67
0.5	33.33	33.00	32.67	32.33	32.00	31.67	31.33	31.00	30.67	30.33
0.6	30.00	29.67	29.33	29.00	28.67	28.33	28.00	27.67	27.33	27.00
0.7	26.67	26.33	26.00	25.67	25.33	25.00	24.67	24.33	24.00	23.67
0.8	23.33	23.00	22.67	22.33	22.00	21.67	21.33	21.00	20.67	20.33
0.9	20.00	19.67	19.33	19.00	18.67	18.33	18.00	17.67	17.33	17.00
1.0	16.67	16.33	16.00	15.67	15.33	15.00	14.67	14.33	14.00	13.67
1.1	13.33	13.00	12.67	12.33	12.00	11.67	11.33	11.00	10.67	10.33
1.2	10.00	9.67	9.33	9.00	8.67	8.33	8.00	7.67	7.33	7.00
1.3	6.67	6.33	6.00	5.67	5.33	5.00	4.67	4.33	4.00	3.67
1.4	3.33	3.00	2.67	2.33	2.00	1.67	1.33	1.00	0.67	0.33
1.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note 1 - Numbers in the body of the table are estimates of lot percent defective corresponding to specific values of Q, the Quality Index. For values of Q greater than or equal to zero, the estimate of percent defective is read directly from the table. For values of Q less than zero, the table value must be subtracted from 100.

Table 3 (Continued)

Variability-Unknown Procedure Standard Deviation Method

Sample Size
5

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	49.64	49.29	48.93	48.58	48.22	47.86	47.51	47.15	46.80
0.1	46.44	46.09	45.73	45.38	45.02	44.67	44.31	43.96	43.60	43.25
0.2	42.90	42.54	42.19	41.84	41.48	41.13	40.78	40.43	40.08	39.72
0.3	39.37	39.02	38.67	38.32	37.97	37.62	37.28	36.93	36.58	36.23
0.4	35.88	35.54	35.19	34.85	34.50	34.16	33.81	33.47	33.12	32.78
0.5	32.44	32.10	31.76	31.42	31.08	30.74	30.40	30.06	29.73	29.39
0.6	29.05	28.72	28.39	28.05	27.72	27.39	27.06	26.73	26.40	26.07
0.7	25.74	25.41	25.09	24.76	24.44	24.11	23.79	23.47	23.15	22.83
0.8	22.51	22.19	21.87	21.56	21.24	20.93	20.62	20.31	20.00	19.69
0.9	19.38	19.07	18.77	18.46	18.16	17.86	17.55	17.25	16.96	16.66
1.0	16.36	16.07	15.78	15.48	15.19	14.91	14.62	14.33	14.05	13.76
1.1	13.48	13.20	12.93	12.65	12.37	12.10	11.83	11.56	11.29	11.02
1.2	10.76	10.50	10.23	9.97	9.72	9.46	9.21	8.96	8.71	8.46
1.3	8.21	7.97	7.73	7.49	7.25	7.02	6.79	6.56	6.33	6.10
1.4	5.88	5.66	5.44	5.23	5.02	4.81	4.60	4.39	4.19	3.99
1.5	3.80	3.61	3.42	3.23	3.05	2.87	2.69	2.52	2.35	2.19
1.6	2.03	1.87	1.72	1.57	1.42	1.28	1.15	1.02	0.89	0.77
1.7	0.66	0.55	0.45	0.36	0.27	0.19	0.12	0.06	0.02	0.00

Note 1 - Numbers in the body of the table are estimates of lot percent defective corresponding to specific values of Q, the Quality Index. For values of Q greater than or equal to zero, the estimate of percent defective is read directly from the table. For values of Q less than zero, the table value must be subtracted from 100.

Table 3 (Continued)

Variability-Unknown Procedure Standard Deviation Method

Sample Size
6

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	49.63	49.27	48.90	48.53	48.16	47.80	47.43	47.06	46.70
0.1	46.33	45.96	45.60	45.23	44.86	44.50	44.13	43.77	43.40	43.04
0.2	42.68	42.31	41.95	41.59	41.22	40.86	40.50	40.14	39.78	39.42
0.3	39.06	38.70	38.34	37.98	37.62	37.27	36.91	36.55	36.20	35.84
0.4	35.49	35.14	34.79	34.43	34.08	33.73	33.38	33.04	32.69	32.34
0.5	32.00	31.65	31.31	30.96	30.62	30.28	29.94	29.60	29.26	28.93
0.6	28.59	28.25	27.92	27.59	27.26	26.92	26.60	26.27	25.94	25.61
0.7	25.29	24.96	24.64	24.32	24.00	23.68	23.37	23.05	22.74	22.42
0.8	22.11	21.80	21.49	21.18	20.88	20.57	20.27	19.97	19.67	19.37
0.9	19.07	18.78	18.49	18.19	17.90	17.61	17.33	17.04	16.76	16.48
1.0	16.20	15.92	15.64	15.37	15.09	14.82	14.55	14.29	14.02	13.76
1.1	13.50	13.24	12.98	12.72	12.47	12.22	11.97	11.72	11.47	11.23
1.2	10.99	10.75	10.51	10.28	10.04	9.81	9.58	9.36	9.13	8.91
1.3	8.69	8.48	8.26	8.05	7.84	7.63	7.42	7.22	7.02	6.82
1.4	6.63	6.43	6.24	6.05	5.87	5.68	5.50	5.33	5.15	4.98
1.5	4.81	4.64	4.47	4.31	4.15	4.00	3.84	3.69	3.54	3.40
1.6	3.25	3.11	2.97	2.84	2.71	2.58	2.45	2.33	2.21	2.09
1.7	1.98	1.87	1.76	1.66	1.55	1.45	1.36	1.27	1.18	1.09
1.8	1.01	0.93	0.85	0.78	0.71	0.64	0.57	0.51	0.46	0.40
1.9	0.35	0.30	0.26	0.22	0.18	0.15	0.12	0.09	0.07	0.05
2.0	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note 1 - Numbers in the body of the table are estimates of lot percent defective corresponding to specific values of Q, the Quality Index. For values of Q greater than or equal to zero, the estimate of percent defective is read directly from the table. For values of Q less than zero, the table value must be subtracted from 100.

Table 3 (Continued)

Variability-Unknown Procedure Standard Deviation Method

Sample Size
7

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	49.63	49.25	48.88	48.50	48.13	47.75	47.38	47.01	46.63
0.1	46.26	45.89	45.51	45.14	44.77	44.40	44.03	43.65	43.28	42.91
0.2	42.54	42.17	41.80	41.44	41.07	40.70	40.33	39.97	39.60	39.23
0.3	38.87	38.50	38.14	37.78	37.42	37.05	36.69	36.33	35.98	35.62
0.4	35.26	34.90	34.55	34.19	33.84	33.49	33.13	32.78	32.43	32.08
0.5	31.74	31.39	31.04	30.70	30.36	30.01	29.67	29.33	28.99	28.66
0.6	28.32	27.98	27.65	27.32	26.99	26.66	26.33	26.00	25.68	25.35
0.7	25.03	24.71	24.39	24.07	23.75	23.44	23.12	22.81	22.50	22.19
0.8	21.88	21.58	21.27	20.97	20.67	20.37	20.07	19.78	19.48	19.19
0.9	18.90	18.61	18.33	18.04	17.76	17.48	17.20	16.92	16.65	16.37
1.0	16.10	15.83	15.56	15.30	15.03	14.77	14.51	14.26	14.00	13.75
1.1	13.49	13.25	13.00	12.75	12.51	12.27	12.03	11.79	11.56	11.33
1.2	11.10	10.87	10.65	10.42	10.20	9.98	9.77	9.55	9.34	9.13
1.3	8.93	8.72	8.52	8.32	8.12	7.92	7.73	7.54	7.35	7.17
1.4	6.98	6.80	6.62	6.45	6.27	6.10	5.93	5.77	5.60	5.44
1.5	5.28	5.13	4.97	4.82	4.67	4.52	4.38	4.24	4.10	3.96
1.6	3.83	3.69	3.57	3.44	3.31	3.19	3.07	2.95	2.84	2.73
1.7	2.62	2.51	2.41	2.30	2.20	2.11	2.01	1.92	1.83	1.74
1.8	1.65	1.57	1.49	1.41	1.34	1.26	1.19	1.12	1.06	0.99
1.9	0.93	0.87	0.81	0.76	0.70	0.65	0.60	0.56	0.51	0.47
2.0	0.43	0.39	0.36	0.32	0.29	0.26	0.23	0.21	0.18	0.16
2.1	0.14	0.12	0.10	0.08	0.07	0.06	0.05	0.04	0.03	0.02
2.2	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note 1 - Numbers in the body of the table are estimates of lot percent defective corresponding to specific values of Q, the Quality Index. For values of Q greater than or equal to zero, the estimate of percent defective is read directly from the table. For values of Q less than zero, the table value must be subtracted from 100.

Table 3 (Continued)

Variability-Unknown Procedure Standard Deviation Method

Sample Size
8

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	49.62	49.24	48.86	48.49	48.11	47.73	47.35	46.97	46.59
0.1	46.22	45.84	45.46	45.08	44.71	44.33	43.96	43.58	43.21	42.83
0.2	42.46	42.08	41.71	41.34	40.97	40.59	40.22	39.85	39.48	39.11
0.3	38.75	38.38	38.01	37.65	37.28	36.92	36.55	36.19	35.83	35.47
0.4	35.11	34.75	34.39	34.04	33.68	33.33	32.97	32.62	32.27	31.92
0.5	31.57	31.22	30.87	30.53	30.18	29.84	29.50	29.16	28.82	28.48
0.6	28.15	27.81	27.48	27.15	26.82	26.49	26.16	25.83	25.51	25.19
0.7	24.86	24.54	24.23	23.91	23.59	23.28	22.97	22.66	22.35	22.04
0.8	21.74	21.44	21.14	20.84	20.54	20.24	19.95	19.66	19.37	19.08
0.9	18.79	18.51	18.23	17.95	17.67	17.39	17.12	16.85	16.57	16.31
1.0	16.04	15.78	15.51	15.25	15.00	14.74	14.49	14.24	13.99	13.74
1.1	13.49	13.25	13.01	12.77	12.54	12.30	12.07	11.84	11.61	11.39
1.2	11.17	10.94	10.73	10.51	10.30	10.09	9.88	9.67	9.47	9.26
1.3	9.06	8.87	8.67	8.48	8.29	8.10	7.91	7.73	7.55	7.37
1.4	7.19	7.02	6.85	6.68	6.51	6.35	6.19	6.03	5.87	5.71
1.5	5.56	5.41	5.26	5.12	4.97	4.83	4.69	4.56	4.42	4.29
1.6	4.16	4.03	3.91	3.79	3.67	3.55	3.43	3.32	3.21	3.10
1.7	2.99	2.89	2.79	2.69	2.59	2.49	2.40	2.31	2.22	2.13
1.8	2.04	1.96	1.88	1.80	1.72	1.65	1.58	1.51	1.44	1.37
1.9	1.31	1.24	1.18	1.12	1.07	1.01	0.96	0.91	0.86	0.81
2.0	0.76	0.72	0.67	0.63	0.59	0.55	0.52	0.48	0.45	0.42
2.1	0.39	0.36	0.33	0.30	0.28	0.26	0.23	0.21	0.19	0.17
2.2	0.16	0.14	0.13	0.11	0.10	0.09	0.08	0.07	0.06	0.05
2.3	0.04	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.00

Note 1 - Numbers in the body of the table are estimates of lot percent defective corresponding to specific values of Q, the Quality Index. For values of Q greater than or equal to zero, the estimate of percent defective is read directly from the table. For values of Q less than zero, the table value must be subtracted from 100.

Table 3 (Continued)

Variability-Unknown Procedure | Standard Deviation Method

Sample Size
9

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	49.62	49.24	48.85	48.47	48.09	47.71	47.33	46.95	46.57
0.1	46.18	45.80	45.42	45.04	44.66	44.29	43.91	43.53	43.15	42.77
0.2	42.40	42.02	41.64	41.27	40.89	40.52	40.15	39.77	39.40	39.03
0.3	38.66	38.29	37.92	37.55	37.19	36.82	36.46	36.09	35.73	35.37
0.4	35.00	34.64	34.29	33.93	33.57	33.21	32.86	32.51	32.15	31.80
0.5	31.45	31.10	30.76	30.41	30.07	29.72	29.38	29.04	28.70	28.36
0.6	28.03	27.69	27.36	27.03	26.70	26.37	26.04	25.72	25.39	25.07
0.7	24.75	24.43	24.11	23.80	23.49	23.17	22.86	22.56	22.25	21.94
0.8	21.64	21.34	21.04	20.75	20.45	20.16	19.87	19.58	19.29	19.00
0.9	18.72	18.44	18.16	17.88	17.61	17.33	17.06	16.79	16.53	16.26
1.0	16.00	15.74	15.48	15.23	14.97	14.72	14.47	14.22	13.98	13.73
1.1	13.49	13.26	13.02	12.79	12.55	12.32	12.10	11.87	11.65	11.43
1.2	11.21	10.99	10.78	10.57	10.36	10.15	9.95	9.75	9.55	9.35
1.3	9.16	8.96	8.77	8.59	8.40	8.22	8.04	7.86	7.68	7.51
1.4	7.33	7.17	7.00	6.83	6.67	6.51	6.35	6.20	6.04	5.89
1.5	5.74	5.60	5.45	5.31	5.17	5.03	4.90	4.77	4.64	4.51
1.6	4.38	4.26	4.14	4.02	3.90	3.78	3.67	3.56	3.45	3.34
1.7	3.24	3.14	3.03	2.94	2.84	2.75	2.65	2.56	2.47	2.39
1.8	2.30	2.22	2.14	2.06	1.98	1.91	1.84	1.76	1.70	1.63
1.9	1.56	1.50	1.44	1.37	1.32	1.26	1.20	1.15	1.10	1.05
2.0	1.00	0.95	0.90	0.86	0.82	0.77	0.73	0.70	0.66	0.62
2.1	0.59	0.55	0.52	0.49	0.46	0.43	0.41	0.38	0.36	0.33
2.2	0.31	0.29	0.27	0.25	0.23	0.21	0.20	0.18	0.17	0.15
2.3	0.14	0.13	0.11	0.10	0.09	0.08	0.08	0.07	0.06	0.05
2.4	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01
2.5	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note 1 - Numbers in the body of the table are estimates of lot percent defective corresponding to specific values of Q, the Quality Index. For values of Q greater than or equal to zero, the estimate of percent defective is read directly from the table. For values of Q less than zero, the table value must be subtracted from 100.

Table 3 (continued)

Variability-Unknown Procedure Standard Deviation Method

Sample Size
10

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	49.62	49.23	48.85	48.46	48.08	47.70	47.31	46.93	46.54
0.1	46.16	45.78	45.40	45.01	44.63	44.25	43.87	43.49	43.11	42.73
0.2	42.35	41.97	41.60	41.22	40.84	40.47	40.09	39.72	39.34	38.97
0.3	38.60	38.23	37.86	37.49	37.12	36.75	36.38	36.02	35.65	35.29
0.4	34.93	34.57	34.21	33.85	33.49	33.13	32.78	32.42	32.07	31.72
0.5	31.37	31.02	30.67	30.32	29.98	29.64	29.29	28.95	28.61	28.28
0.6	27.94	27.60	27.27	26.94	26.61	26.28	25.96	25.63	25.31	24.99
0.7	24.67	24.35	24.03	23.72	23.41	23.10	22.79	22.48	22.18	21.87
0.8	21.57	21.27	20.98	20.68	20.39	20.10	19.81	19.52	19.23	18.95
0.9	18.67	18.39	18.11	17.84	17.56	17.29	17.03	16.76	16.49	16.23
1.0	15.97	15.72	15.46	15.21	14.96	14.71	14.46	14.22	13.97	13.73
1.1	13.50	13.26	13.03	12.80	12.57	12.34	12.12	11.90	11.68	11.46
1.2	11.24	11.03	10.82	10.61	10.41	10.21	10.00	9.81	9.61	9.42
1.3	9.22	9.03	8.85	8.66	8.48	8.30	8.12	7.95	7.77	7.60
1.4	7.44	7.27	7.10	6.94	6.78	6.63	6.47	6.32	6.17	6.02
1.5	5.87	5.73	5.59	5.45	5.31	5.18	5.05	4.92	4.79	4.66
1.6	4.54	4.41	4.30	4.18	4.06	3.95	3.84	3.73	3.62	3.52
1.7	3.41	3.31	3.21	3.11	3.02	2.93	2.83	2.74	2.66	2.57
1.8	2.49	2.40	2.32	2.25	2.17	2.09	2.02	1.95	1.88	1.81
1.9	1.75	1.68	1.62	1.56	1.50	1.44	1.38	1.33	1.27	1.22
2.0	1.17	1.12	1.07	1.03	0.98	0.94	0.90	0.86	0.82	0.78
2.1	0.74	0.71	0.67	0.64	0.61	0.58	0.55	0.52	0.49	0.46
2.2	0.44	0.41	0.39	0.37	0.34	0.32	0.30	0.29	0.27	0.25
2.3	0.23	0.22	0.20	0.19	0.18	0.16	0.15	0.14	0.13	0.12
2.4	0.11	0.10	0.09	0.08	0.08	0.07	0.06	0.06	0.05	0.05
2.5	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01
2.6	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00

Note 1 - Numbers in the body of the table are estimates of lot percent defective corresponding to specific values of Q, the Quality Index. For values of Q greater than or equal to zero, the estimate of percent defective is read directly from the table. For values of Q less than zero, the table value must be subtracted from 100.

C/APPR/RVP/RGS 2-4-93

MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION FOR PAY ADJUSTMENTS

M&T:RDT **1 of 1** **01-27-93**

a. Description.-This specification sets forth the base price of critical concrete items as referenced in the Special Provision for Furnishing Portland Cement Concrete (Quality Assurance). This base price is used in determining the pay adjustment for these items.

b. Base Prices.-The following pay items and corresponding base price are critical pay-adjustment items:

Pay Item	Item Code Number	Unit	Base Price
Concrete Pavement Reinforced 11"	4500025	Syd	$ 16.00
Miscellaneous Concrete Pavement-Reinforced 9"	4500075	Syd	$ 22.00
Miscellaneous Concrete Pavement-Reinforced 10"	4500080	Syd	$ 24.00
Miscellaneous Concrete Pavement-Reinforced 11"	4500085	Syd	$ 26.00
Substructure Concrete	5030023	Cyd	$ 300.00
Superstructure Concrete	5030024	Cyd	$ 140.00
Two-Layer Concrete Pavement 10-inch Non-Reinforced (European Pavement)	4507001	Syd	$ 34.00
Miscellaneous Two-Layer Concrete Pavement 10-inch Non-Reinforced (European Pavement)	4507004	Syd	$ 44.00
Two-Layer Concrete Shoulder 10-inch Non-Reinforced (European Pavement)	4507002	Syd	$ 30.00
Lean Concrete Base 6-inch Non-Reinforced (European Pavement)	4507003	Syd	$ 12.00

C/APPR/RVP/RGS 2-9-93

SPECIAL PROVISION
FOR
CONTRACTOR QUALITY CONTROL FOR CONCRETE

a. Description.-The Contractor shall provide quality control for concrete adequate to produce work of acceptable quality. The Contractor shall perform quality control sampling, testing, and inspection during all phases of the concrete work at the rate specified herein.

The Engineer will not sample or test for quality control or assist in controlling the Contractor's production operations. The Contractor shall provide the personnel and testing equipment capable of performing the specified tests for quality control. Continual production of nonconforming work at a reduced price, in lieu of adjustments to bring work into conformance, will not be allowed.

Acceptance tests on the concrete products will be performed in accordance with the Special Provision For Furnishing Portland Cement Concrete (Quality Assurance).

b. Quality Control Plan.-The Contractor shall provide and maintain a quality control plan, including all the personnel, equipment, supplies, and facilities necessary to obtain samples, perform tests, and otherwise control the quality of the product to meet specified requirements. The quality control plan shall contain a system for sampling that assures all material being produced has an equal chance of being selected for testing and must specify what actions will be taken when test results identify concrete that is not in compliance with the specifications. The Engineer shall be provided the opportunity to witness all sampling and testing. The Contractor shall certify in writing to the Engineer that the testing equipment to be used is properly calibrated.

The quality control plan shall be administered by a qualified individual. The individual administering the plan must be a full-time employee of or a consultant engaged by the Contractor. The individual shall have full authority to institute any and all actions necessary for the successful operation of the quality control plan.

The Contractor shall maintain complete records of all quality control tests and inspections. These records shall indicate what action was taken to correct deficient concrete when quality control tests indicate the concrete was not in compliance with the specifications. The original and one copy of these records shall be furnished to the Engineer within 24 hours after the date covered by the record. Forms shall be in a format acceptable to the Engineer. Failure of the Contractor to provide properly documented quality control test results in a timely manner will be justification for withholding acceptance of the concrete product.

The Contractor shall submit the quality control plan for the appropriate items to the Engineer for approval a minimum of ten working days prior to the start of related work. The Contractor shall not start work on the subject items without an approved quality control plan.

When directed by the Engineer, the Contractor shall sample and test any material which appears inconsistent with similar material being sampled, unless such material is voluntarily removed and replaced or corrected by the Contractor.

c. **Qualifications.**-The Contractor's personnel administering the quality control plan shall be a Professional Engineer registered in the State of Michigan, or shall be certified by the National Institute for Certification of Engineering Technologies (NICET) at Level III or above for concrete, or shall be certified as a Concrete Technician Michigan Level II through a program certified by Michigan Concrete Association Board of Examiners.

The Contractor's personnel performing designated tests shall be certified as a Concrete Technician Michigan Level I or II through a program certified by Michigan Concrete Association Board of Examiners.

The Contractor shall furnish the names and credentials of the quality control staff to the Engineer prior to sampling and testing.

d. **Sampling and Testing.**-Sampling and testing shall be performed in accordance with the following minimum frequencies and specifications.

d.1. Concrete Yield Determination.-After the start of the first concreting operation for each mix design and immediately after the specified slump and entrained air have been attained, unit weight determinations shall be made by the Contractor, under the direction of the Engineer. The average of the three determinations from different batches shall be considered the unit weight of the concrete. The actual yield shall be determined from the average unit weight and the design mix shall be adjusted as required to correct the actual yield to correspond to the theoretical.

During the progress of the work, the actual yield may be verified and, if the yield based on a single unit weight determination should differ from the theoretical (adjusted for differences in air content) more than plus or minus two percent, two additional unit weight determinations shall be made by the Contractor and the average of the three determinations shall be considered the unit weight of the concrete. The actual yield shall be determined from the average unit weight, and the design mix shall again be adjusted as required to correct the actual yield to correspond to the theoretical.

d.2. Concrete Slump Determination.-The Contractor shall determine the concrete slump on the first load of the pour, the next load after this test is completed and a third load immediately after the second test is completed, then once every hour of continuous production, or more often as directed by the Engineer.

d.3. Concrete Air-Entrainment Determination.-The contractor shall determine the concrete air content on the first load of the pour, the next load after this test is completed and a third load immediately after the second test is completed, then once every two hours of continuous production. Additional tests shall be made whenever there is a change in air-entraining admixture dosage, or as directed by the Engineer.

d.4. Concrete Strength Determination.-The Contractor shall determine the concrete strength on samples taken at least once every 200 cubic yards of that class of concrete, except that no more than four samples need to be taken for one day's production. Compressive strength or modulus of rupture may be used for strength determination. A single strength test shall consist of two cylinders or two beams. The Contractor is responsible for proper curing of the cylinders.

d.5. Concrete Containing Fly Ash.-For concrete grade 45D containing fly ash, a qualified Concrete Technician Michigan Level II inspector provided by the Contractor as cited in Subsection 7.04.01 is required. Concrete from each batch, each load shall not be placed in the bridge deck until the air content has been determined and found to be within the specified range.

d.6. Test Procedure Specifications.

ASTM

C31	Making and Curing Concrete Test Specimens in the Field
C39	Compressive Strength of Cylindrical Concrete Specimens
C78	Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C138	Unit Weight, Yield and Air Content (Gravimetric) of Concrete
C143	Slump of Hydraulic Cement Concrete
C172	Sampling Freshly Mixed Concrete
C173	Air Content of Freshly Mixed Concrete by the Volumetric Method
C231	Air Content of Freshly Mixed Concrete by the Pressure Method
C293	Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)

The Department's established procedures for sampling and testing are considered acceptable alternatives.

e. Measurement and Payment.-Separate payment will not be made for providing and maintaining an effective quality control program, and all costs associated therewith shall be included in the applicable unit prices for the concrete item.

C/APPR/RVP/RGS 3-18-93

NOTICE TO BIDDERS

LETTING OF JUNE 9, 1993

ADDENDUM NO. 1

This Addendum changes the terms of the Bid Proposal. By submitting a bid you accept all changes included in this Addendum.

The following paragraphs and the attached pages will instruct you as to the changes made and how to make them.

CHANGES TO BID ITEM PRICES

When you are instructed to **ADD, DELETE, OR MAKE CHANGES** to a BID ITEM PAGE OR PAGES, these additions, deletions, or changes MUST be made on the bid item pages you submit with your bidding proposal, whether handwritten or computer generated.

CHANGES TO OTHER PAGES

When you are instructed to **DELETE** something which is **NOT** on a Bid Item Page, you may line through the text diagonally and/or print or write the word "DELETE" on the text being deleted. Physically removing the page(s) is not necessary.

When you are instructed to **ADD A** NON-BID ITEM PAGE(S), OR PORTIONS THEREOF, you **MUST CONSIDER** it/them in developing your bid, but the physical insertion of the new page(s) into the proposal is not necessary.

FAILURE TO CARRY OUT THE INSTRUCTIONS IN THIS ADDENDUM MAY RESULT IN THE REJECTION OF YOUR BID.

THIS ADDENDUM IS FOR THE FOLLOWING LISTED PROJECTS:

ITEM	PROJECT	JOB NO.	PARTS	FED NO.	FED ITEM
9306 083	IM 82251	30613A		IM 75-1(420)	NP 1417
	IM 82111	30614A		IM 75-1(420)	NP 1417

Prospective bidders on the above noted project are hereby advised of the following changes:

Proposal

1. On Cover Sheet of the proposal, **revise** the following paragraph "BIDS WILL BE OPENED AT 10:30 A.M., E.D.T., ON WEDNESDAY, JUNE 9, 1993 AT THE HOLIDAY INN SOUTH/CONVENTION CENTER 6820 S. CEDAR ST., LANSING, MICHIGAN" **to read** "BIDS WILL BE OPENED AT 2:00 P.M., ON MONDAY, JUNE 14, 1993 AT THE SOUTH TRAINING CENTER OF THE TRANSPORTATION BUILDING, 425 WEST OTTAWA, LANSING, MICHIGAN."

2. **Replace** pages 1 thru 22, titled "BID ITEMS" with pages 1 Revised thru 22 Revised, titled "BID ITEMS."

3. On page 50 **revise** the following paragraph of the "Progress Schedule:" "**1993 Construction Season:** The Contractor . . . the full day. See Notice to Bidders."

to read "1993 Construction Season: The Contractor will construct the NB I-75 and I-375 roadway during the 1993 construction season (Traffic Stages I and II). The Contractor will be required to schedule the paving of the European concrete pavement section on Saturday, October 23 and Monday, October 25, 1993, during the National AASHTO Convention in Detroit. The concrete paving on October 23 and 25 shall consist of at least one lane of main line paving and it shall last for the full day. See Notice to Bidders."

4. **Add** pages 69A and 69B, titled "Typical Sign Sequence For A Single Lane Closure On A Divided Highway Using Statutory Speed Limit" and "Typical Sign Sequence For A Double Lane Closure On A Divided Highway Using Statutory Speed Limit & Attenuators."

5. **Add** page 69C, "Special Provision For <u>Vehicle Mounted Attenuator</u>."

6. On page 115, **revise** the first paragraph in "Section b. Concrete Mix Design" of the "Special Provision For Two-Layer Concrete Pavement And Concrete Shoulders (European Pavement):" The Contractor shall . . . for Furnishing Portland Cement Concrete (Quality Assurance)."

to read

"**b. Concrete Mix Design.**-The Contractor shall be responsible for the concrete mix design as specified in the Special Provision for Furnishing Portland Cement Concrete Quality Assurance). Concrete properties, characteristics, and acceptance sampling rate shall be as specified herein. Acceptance of the concrete based on these properties and characteristics shall be in accordance with the Special Provision for Furnishing Portland Cement Concrete (Quality Assurance). The Engineer will evaluate the concrete of each individual layer separately for acceptance. Rejection of an individual layer will be cause for rejecting the entire thickness. The percent pay adjustment applied to the lot quantity will be a weighted average based on plan thickness of the layers and the corresponding percent pay adjustment for that layer. The bottom layer will account for 75 percent and the top layer will account 25 percent of the percent pay adjustment applied to the lot quantity. If cores from the concrete are taken, the strength of each layer will be determined and the results evaluated for acceptance."

7. On page 118, titled "Special Provision For Two-Layer Concrete Pavement And Concrete Shoulders (European Pavement)" under "Section e. Construction" fourth paragraph **delete** the last sentence reading "Contractor shall furnish an instrument capable of verifying the final location of the inserted dowel bars and lane lies" and **add** the following paragraph:

> "The Contractor shall furnish an instrument capable of verifying the final location of the dowel bars and lane ties regardless of the installation method."

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