IOWA DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS
OFFICE OF MATERIALS

PORTLAND CEMENT CONCRETE UTILIZING RECYCLED PAVEMENT

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ABSTRACT

Many areas in the State of Iowa are presently either in short supply, or entirely void of, high quality coarse aggregate for portland cement concrete pavement. Where adequate quality aggregate does exist, the supply is sooner or later to be exhausted.

A project was conceived to utilize an existing pavement or a reconstruction project. The concept was to crush the old and use as aggregate for the new.

The project selected was 1.5 miles of U.S. 75 in Lyon County, Iowa, located approximately 6 miles south of Rock Rapids. The project consisted of two sections, separated by approximately 4 miles.

The existing roadway was a 10"-7"-10" portland cement concrete, some 18 feet and some 20 feet wide, paved in 1934 and 1936, using gravel as a coarse aggregate. It had been widened with 10 inches of p.c. concrete in 1958 and resurfaced with 3 inches of asphalt concrete in 1963.

Two objectives were involved in this recycling project:

1. To determine if the asphalt concrete surfacing could be removed, the existing portland cement concrete pavement broken, removed, crushed to 1-1/2 inch minus, proportioned through a conventional central mix proportioning plant with the addition of concrete sand,and placed with a conventional slipform paver.

2. To determine if a two course, composite pavement, each course of different mix proportions, could be placed monolithically with conventional slipform equipment after being proportioned and mixed in a conventional central mix plant.

The pavement removal began in March, 1976; the paving was completed in mid-October, 1976.

The project was completed with no major problem. The objectives were satisfactorily met. The project was a success to the degree that the Iowa D.O.T. is proceeding with at least two projects for the 1977 construction season that will utilize the old pavement as aggregate for the new pavement.

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INTRODUCTION

During 1974 and 1975 Iowa became interested and began investigations into uses of "Econocrete". That is, the use of locally available materials, or lower quality materials, in base course construction. Further discussions resulted in considerations of recycling an existing portland cement concrete roadway.

A 1.5 mile project in the northwest corner of Iowa was chosen where such a concept could be attempted. The project was to remove and crush the existing pavement, use the material as it came from the crusher, hopefully without further processing, perhaps add some concrete sand, and to proportion, mix, place, and finish with conventional slip form paving equipment.

PURPOSE

The purpose of this report is to describe Iowa's first experience of recycling an existing portland cement concrete pavement. This was accomplished by crushing the pavement and using the resulting material as aggregate in new concrete pavement construction.

SCOPE

The scope of this report is threefold: 1) to explain the development of the specifications and mix designs for using crushed, or recycled, portland cement concrete paving as aggregate in new concrete pavement, 2) to describe and discuss some of the unique features of the project, and 3) to provide recommendations for future projects involving the utilization of existing concrete pavements as aggregate sources.

PROJECT DEVELOPMENT

Some reasons for considering recycling are:

1. The basic conservation of raw materials. No matter what quantity of raw material (aggregate) is now present in any particular area or state, sooner or later it will be depleted.
2. Many areas are presently either very short of or completely void of locally available aggregates that meet present day requirements for primary paving.
3. To obtain acceptable aggregates in a particular area, one has the cost burden of either the ever increasing expense of transportation or the energy intensive removal of large amounts of overburden to gain access to acceptable material.
4. The increasing difficulty, in terms of environmental considerations, especially in built up urban areas, of disposal of broken concrete that results in reconstruction projects, e.g., landfill restrictions, or even landfill existence.
5. The utilization of what is available and conveniently at hand. In other words, an existing roadway is simply a quarry approximately 24 ft. wide, approximately 8 or 9 inches thick, and X miles long.

Once the staff decision was made to try a recycling project, a reconstruction project with an available detour was sought.

The project chosen was on U.S. 75 in Lyon County, Iowa, in the far northwest corner of the state. This was a 1.476 mile long project consisting of two segments, located approximately four miles apart.

One segment was slightly over one mile in length, the other approximately 0.4 of a mile in length. Each segment consisted of approach paving to new bridges. As mentioned later, two different mix proportions were used in the full depth construction on each 1/2 mile long approach section and composite construction was used on both of the shorter approach sections.

The old pavement was as follows: In the one mile segment of the project, the old pavement was 20 feet wide, constructed of portland cement concrete using gravel coarse aggregate, with a cement content of 658 pounds per cubic yard. It was constructed in 1936, 10 inches thick on the outside, tapering to 7 inches thick in 4 feet. The road was widened to 24 feet with 10 inches of concrete in 1958.

This recycling project had two primary objectives:

1. To determine if the asphalt concrete surfacing could be removed, the existing portland cement concrete pavement broken, removed, crushed to 1-1/2 inch minus, proportioned through a conventional central mix proportioning plant with the addition of concrete sand, and placed with a conventional slipform paver.
2. To determine if a two course, composite pavement, each course of different mix proportions, could be placed monolithically with conventional slipform equipment after being proportioned and mixed in a conventional central mix plant.

MIX DESIGN

The objective of the mix design was to utilize the total crushed material in such a way so as to obtain a satisfactory portland cement concrete mix which could be placed with a slip form paving machine.

Aggregate materials used in this project were crushed portland cement concrete, crushed portland cement concrete and asphalt concrete combined, and natural sand. Cement was Type I. Admixtures consisted of an air-entraining agent and a water reducer.

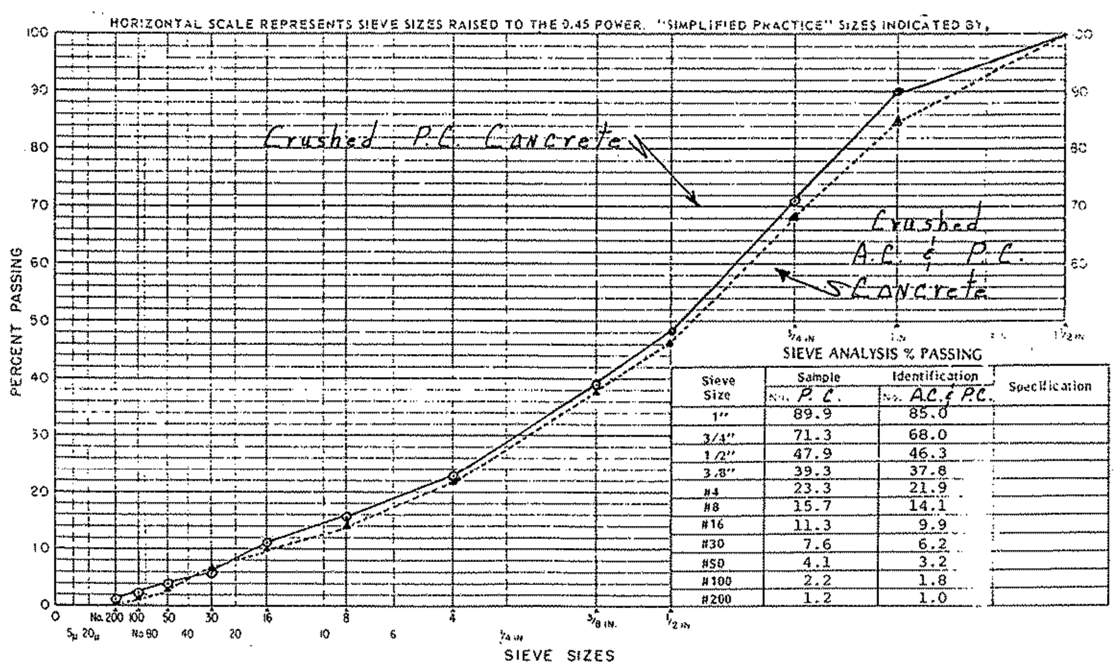
Studies were conducted in 1975 in the laboratory to determine the feasilibity of producing a satisfactory concrete using these materials. From the initial study, pieces of both asphalt and portland cement concrete from maintenance stockpiles in the area of the proposed project were sent to the laboratory where they were crushed and preliminary mixes were made and evaluated. The quantity of material available was insufficient to make a thorough evaluation, but enough information was developed to warrant further investigation. Arrangements were made to have enough material crushed, by a crusher operating in the general vicinity of the proposed project, to make a proper evaluation. Using this material, mixes were made and tested in the laboratory. After evaluation, it was decided that satisfactory results could be obtained and the project concept should continue.

When the material from the project crushing operation became available, it was analyzed in the laboratory. The gradation of the crushed product was as follows:

Crushed Concrete	Lab. No. AAC6-272	Sp.G.	2.457
Crushed A.C. & P.C. Concrete	Lab. No. AAC6-273	Sp.G.	2.445
Sand	Lab. No. AAS6-268	Sp.G.	2.68

	AAC6-272		AAC6-273	
Sieve	% Ret'd.	% Passing	% Ret'd.	% Passing
1"	10.1	89.9	15.0	85.0
3/4"	18.6	71.3	17.0	68.0
1/2"	23.4	47.9	21.7	46.3
3/8"	8.6	39.3	8.5	37.8
#4	16.0	23.3	15.9	21.9
#8	7.6	15.7	7.8	14.1
#16	4.4	11.3	4.2	9.9
#30	3.7	7.6	3.7	6.2
#50	3.5	4.1	3.0	3.2
#100	1.9	2.2	1.4	1.8
#200	1.0	1.2	0.8	1.0
Pan	1.2		1.0	
	100.0		100.0	

GRADATION CHART



The mixes shown in Specification 776 were based on gradations resulting from initial crushing done in the field. It was found that the crushed PC and ACPC from that preliminary crushing had 42 percent and 45 percent respectively, passing the No. 4 screen. When the actual project crushing was done, these same materials had 24 percent and 22 percent respectively, passing the No. 4. Since the initial mix proportions were based on samples crushed only for laboratory evaluations, a change in the mix proportions was required in order to conform with actual field crushed gradations.

A major objective to be considered was to make full utilization of all of the crushed material produced from the old pavement. It could be expected that some old concrete might crush in such a way that sufficient fine aggregate would not be available. Another consideration was the availability of a good concrete sand source near the proximity of the work. In most areas in Iowa, sufficient quantities of concrete sand are available. It was also desirable to learn how workability would be affected by varying the proportions of coarse and fine aggregate. The proportion of coarse to fine was based on a material split passing the No. 4 screen. In view of this, different mix proportions were used in this project.

Two different mixes containing crushed PC concrete were used in the two full depth sections. One mix had 35 percent coarse and 65 percent fine aggregate while the other was 50-50 percent coarse and fine. The wearing course in the composite section was crushed PC, 35% coarse aggregate. To use all of the crushed PC concrete and balance out the material, sand was added to each mix, with the exception of the ACPC in the lower course.

Mixes for each of the two full depth sections contained 564 pounds (6 bags) of portland cement per cubic yard while the lower course in the composite section had 470 (5 bags) pounds. In an effort to keep the water requirements as low as possible, a water-reducing admixture was used in each mix. Air entrainment was obtained through the use of an air-entraining agent (AEA). Very little AEA was required in the two mixes containing crushed PC and sand. However, it was very difficult to get sufficient air entrainment in the concrete containing crushed AC and PC combined.

Mix proportion data for the mixes used on the project are shown in Appendix B. The basis of the mix design was by absolute volume.

PAVEMENT SECTION DESIGN

Based on the preliminary strength data derived from initial laboratory trial mixes with the crushed product, the Office of Road Design concluded that the section thickness should be nine (9) inches for the single course pavement and a total of eleven (11) inches for the composite pavement.

The nine (9) inch thickness was the same as was required using Iowa's standard design method (PCA Method) with standard paving mix proportions and aggregates. It was felt that durability would not be a problem in the "A" and "B" mixes. Since the gravel aggregates in the original paving are considered to be very sound and highly durable, it was not necessary to place a wearing course of conventional concrete on top of concrete made from crushing the old portland cement concrete.

The eleven (11) inch composite section consisted of a seven (7) inch thick lower course and a four (4) inch upper course. In the lower course it was desired to utilize the crushed product of the existing pavement, both the asphalt and portland cement concrete, Mix "C" with no additional aggregates. This was to take advantage of the "Econocrete" concept of using what's available. The upper course was designed to be of the same "A" mix proportions as used on another portion of the project.

Results of strength tests from laboratory trial mixes using the crushed combination of asphalt and portland cement concrete pavement and considering the availability of each, indicated that a 5 bag (470 lbs. of cement) mix should be used in the lower course.

The composite pavement design method used was based on the studies done by Robert G. Packard, Principal Paving Engineer, Portland Cement Association, Paving and Transportation Department. This method basically is based on ratios of Modulii of Elasticity and flexural or compressive strengths.

It was decided by the designer that a 4 inch upper course was needed using the "A" mix design. Applying this to the design criteria results in a lower course of 7 inch thickness or a composite thickness of 11 inches. This was compatible with available crushed material for aggregate and also provides a pavement section equivalent to a 9 inch standard design thickness or to a 9 inch thickness using the "A" or "B" mixes.

After the 7 inch lower course-4 inch upper course section was decided by Road Design, the initial section called for an incapsulated section, i.e., approximately 2-1/2 feet on either side of the 24 foot slab would be constructed of the upper course material with the lower course being approximately 19 feet wide.

However, it was felt that this potential vertical plane, located in a wheel track, could reflect through the surface and possibly result in a maintenance problem. The design was changed to retain the encapsulated effect for protection of the perhaps less durable concrete by designing the lower course to be approximately 23 feet wide with approximately 6 inches on either side to be constructed with surface course concrete.

As the project was divided into several well defined segments, it was decided to utilize Mix "A" and Mix "B" proportions in the longer segments, of the project. The Mix "A"-Mix "C" composite section was to be placed in both of the shorter segments.

DEVELOPMENT OF SPECIFICATION

The development of the specification for this project involved many people both inside and outside the Iowa Division of Highways. It was a cooperative effort between various individuals within the Offices of Road Design, Construction, and Materials as well as between paving contractors, and other people experienced in breaking concrete and producing aggregate.

Several meetings were held to discuss project concepts, specifics of crushing, handling crushed material, etc. As a result of the combined input and after several meetings with The Specification Committee, the specification for the project was developed (See Appendix C).

The specification was written to cover both aspects of the project, i.e., the single course, full-depth pavement and the two courses composite pavement.

Because of the project design concept for the lower course of the composite section, the contractor was expected to crush the asphalt concrete resurfacing with the portland cement concrete in the same proportions as they existed in the old roadway. The contractor could remove the existing pavement in tact, or remove the asphalt concrete first and introduce both materials into the crusher in the same proportion that they existed in the old roadway.

The asphalt concrete was required to be removed as well as possible from the pavement that was intended to be used in Mix "A" or "B".

Isolated areas of adhering asphalt concrete up to 1 inch in thickness were allowed. It was not considered economically feasible to require 100 percent removal of the asphalt concrete. All reinforcing steel was to be removed and to be diposed of by the contractor.

The specification required the contractor to remove the pavement in a manner that minimized the amount of fines in the material. It was anticipated that fines from the subgrade could be a problem in the crushed product. From laboratory evaluations, a maximum of 5 percent passing the No. 200 sieve was considered tolerable. In order to minimize costs, washing the aggregate was not required. However, to provide some control, the contractor was required to use processing equipment having the capability to remove fines passing the No. 8 screen in order to comply with the minus No. 200 requirement.

It was decided, during the mix evaluation, that the top-size coarse aggregate would be 1-1/2 inch. The specification required that all material be crushed to 100 percent passing the 1-1/2 inch screen.

The specification was developed using the normal requirements for proportioning and mixing equipment used in conventional concrete paving. However, there were some additional placing and finishing equipment requirements that applied to the composite section. It was assumed that the lower course would need a roughening or scarifying of the surface in order to achieve adequate bond between the two courses. Equipment capable of scarifying to a depth of 1 inch was required, subject to the approval of the engineer, and to be used at his direction. Since the second course was intended to be placed while the first course was still plastic, no finishing was required on the first course. Further, to keep the design concept intact, the surface of the first course was limited to the design elevation prior to scarifying, with a tolerance of plus 1/2 inch. The second course was required to be placed, finished, and cured in accordance with normal paving specifications.

The single lift, full-depth sections were to be measured in square yards, in accordance with normal paving specifications. The composite section was to be measured as follows: The first course was to be measured on a volume basis, in cubic yards, using a batch count of concrete incorporated. By measuring on the basis of volume and paying only for the concrete incorporated, with no payment for that in excess of the design volume, the contractor was forced to carefully control the thickness of the first course. The second course was to be measured and paid for on a square yard basis. All of the completed pavement was to be cored and measured for thickness compliance. If there was a thickness deficiency in the composite section, the price adjustment was to be applied to the surface course.

To provide for the possibility of insufficient crushed product to make the necessary concrete, a provision for payment for additional coarse aggregate was included in the specification.

DISCUSSION OF PROJECT

The project was let on November 12, 1975. In mid March, 1976 breaking and removal of the old pavement was started.

A pneumatic hammer mounted on the rear of a John Deere back hoe/ loader was used to punch holes in the old pavement on approximately 2 to 3 foot centers. (Figure 1) This caused weak points so that the old slab would more readily break. The existing asphalt pavement was easily removed. A back hoe, a Cat 225 Excavator, was used to remove the 3 inch resurfacing mat. It came off in large, 3 to 4 foot sized pieces. (Figure 2) The surface was cleaned with a loader bucket and this essentially completely removed the asphalt.

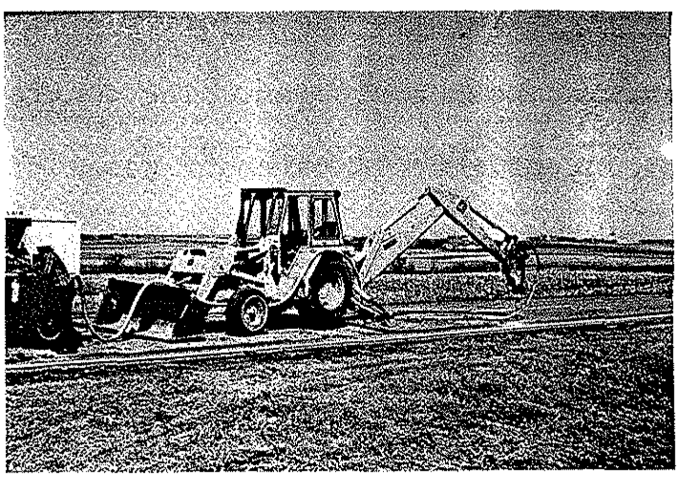


Figure 1
Punching Holes in Old Pavement

Figure 2
Removing 3 in. A.C. Resurfacing

After the asphalt was removed, the back hoe picked up the slab in approximately 2 to 3 foot square sections and loaded dump trucks for transport to the crushing site. (Figure 3) A hydraulically operated shear cut the slabs free that were tied together by the reinforcing steel. The asphalt was also hauled to the crushing site and stockpiled separately.

Only a very small amount of the subgrade soil stuck to the slabs in dry weather conditions. During wet weather the subgrade tended to adhere to the old pavement. The contractor limited his removal operations to dry weather conditions. By taking care, the back hoe operator was able to leave most of the fine material on the grade.

The contractor made no attempt to recover any of the broken concrete smaller than approximately 6 to 8 inch size from the grade. (Figure 4) By doing so, he was able to effectively eliminate the majority of fines at the crusher that could have otherwise been a problem. The contractor estimated that approximately 12 percent of the old pavement was left on the grade.

At the crushing site, the contractor charged a Pioneer 3042, 42-inch jaw crusher with an end loader. This primary crushing operation reduced the material to a 6 inch maximum size.

Figure 3
Removing Broken Concrete

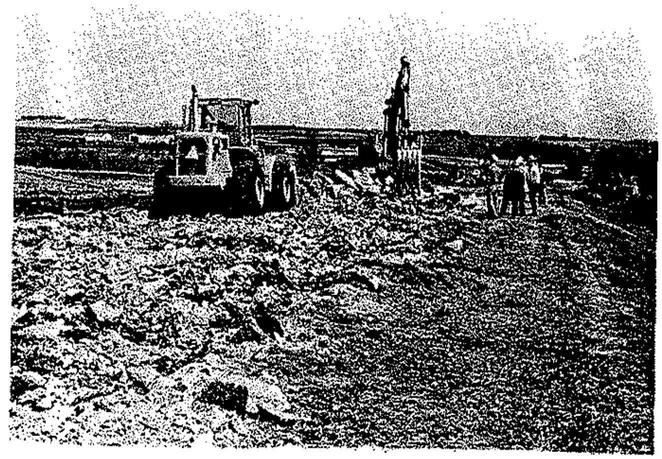


Figure 4
Grade Condition After
Concrete Removal

The conveyor below the jaw crusher was positioned several feet below the jaws to prevent damage to the belt by pieces of the reinforcing steel. Two laborers, positioned on either side of the belt conveyor, removed the reinforcing steel from the stream of crushed material. (Figure 5) Approximately 53 tons of steel were recovered at the crushing site, most of it during the primary crushing operation.

The jaw crusher was very effective in breaking the concrete away from the smooth, reinforcing steel bars. Present day concrete pavements, using deformed re-bars, may cause a problem in this operation.

The minus 6-inch material was stockpiled, and after a considerable quantity was on hand, a Hewitt-Robins Apache Twin portable crushing and screening plant was brought to the crushing site. (Figure 6) This plant, fed with a front-end loader, further crushed the product to 100 percent passing the 1-1/2 inch screen. This plant had the prescreening capability to reject the minus No. 8 material, as required by the specification, but was not used.

Figure 5
Laborers Removing Reinforcing Steel

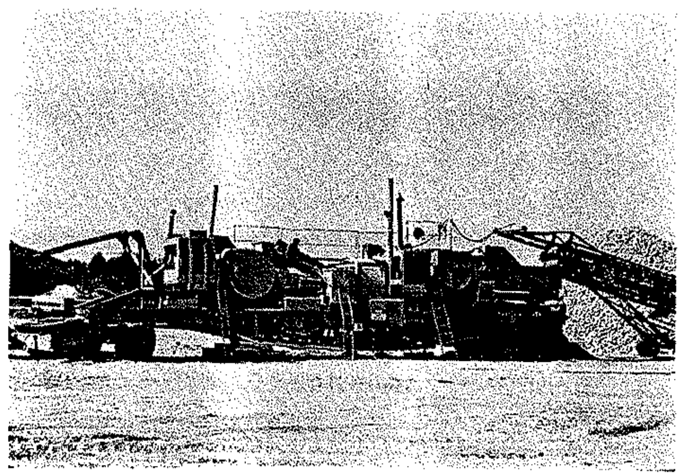


Figure 6
Secondary Crushing & Screening Plant

The combined PC and AC was produced by crushing the 6 inch crushed PC and AC together in approximately the same proportions the two materials existed in the old pavement. The blend was controlled by the feed to the secondary crusher from separate stockpiles.

Small pieces of reinforcing steel were removed, again by hand, from the feed point to the secondary crusher as well as from the resulting stockpile. Even with this conscientious effort, a few pieces of steel were observed in the concrete when delivered to the grade.

The paving operation began in early September, 1976. The contractor first placed the "B" mix segment, followed by the "A" mix segment, using a Rex slip form paver.

The "B" mix (50% coarse aggregate - 50% fine aggregate) was similar to conventional concrete in placing and finishing characteristics. The mix was considered a little harsh because of the amount of minus No. 4 material in the crushed concrete. The surface exhibited dimples ranging from 1/2 to 3/4 inch in diameter that required the use of an aluminum float and a straight edge to close the surface. These dimples generally seemed to be over a piece of coarse aggregate. This mix held an edge as well as conventional paving.

The "A" mix (35% coarse aggregate - 65% fine aggregate) was considered to be too heavily sanded. The surface exhibited a few of the dimples as described above but less frequently. An aluminum float was used to close the surface.

The surface texture of both segments was accomplished by a longitudinal astrograss drag. It is felt that, if a transverse wire tine texturing machine would have followed the astrograss drag, (which is now required by Iowa Specification) the aluminum float would not have been needed on the "A" mix concrete. Some hand finishing would have been required on the "B" mix, however, because of the extent of the dimples.

In placing the composite section, a Rex belt placer was used to deposit the lower course, Mix "C", on the grade. A Rex slip form paver consolidated and struck off the "C" mix to the design thickness of 7 inches. The width was held to 23 feet 6 inches to facilitate the passage of the second paving machine. (Figure 7) For the second course, 4 inches of "A" mix was placed with a Rex Town and Country slip form paver. The second paver followed the first by approximately 100 to 200 feet. As soon as the complete paving train was in operation, the contractor produced the two mixes in 60/40 ratio, i.e., 3 batches of Mix "C" to 2 batches of Mix "A". The trucks carrying Mix "C" were identified with a red flag tied to the outside mirror. This prevented the contamination of mixes on the grade.

The lower course was very harsh and difficult to handle. Because of the deficiency in fines (approximately 25 percent passing the No. 4) and having no natural sand, the mix was extremely unworkable. Workmen could easily walk on the surface of this mix. (Figure 8) The mix was so stiff, the mixers in the Agitor trucks could not be operated.

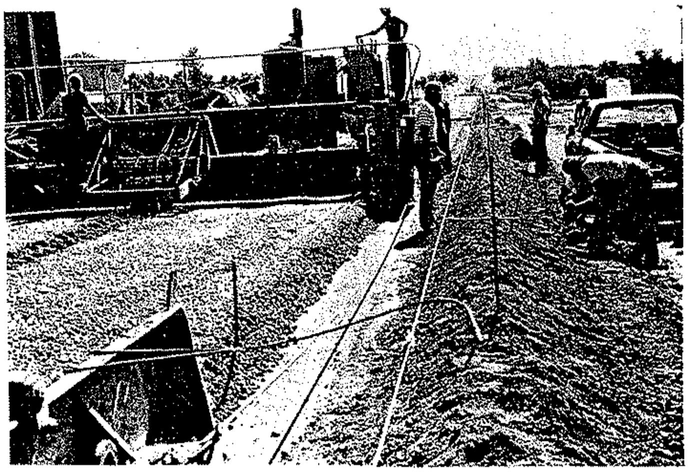


Figure 7
Placing Lower Course in
Composite Section

Figure 8
Harsh Concrete in Lower Course
of Composite Section

For approximately one half of the composite segment, 15 percent concrete sand was added to "C" mix proportions (see mix C-3 in Appendix B). This addition of fines to the mortar greatly increased the workability of the lower course. The contractor also felt the "C-3" mix was easier to consolidate.

PROJECT TEST RESULTS

Test results from beam and cylinder specimens prepared on the project, as well as project control test data, are as follows:

Mix Description		
Mix A	564 lb. cement	35% CA - 65% FA
Mix B	564 lb. cement	50% CA - 50% FA
Mix C	470 lb. cement	AC-PC 100%
Mix C3	470 lb. cement	AC-PC with 15% sand

Concrete Compression - 28 day - Average Results	
Mix A	4413 psi
Mix B	4292 psi
Mix C	2250 psi
Mix C3	2290 psi

Modulus of Rupture - 28 day - Average Results	
Mix A	799 psi
Mix B	811 psi
Mix C	586 psi
Mix C3	560 psi

Durability testing was performed using crushed material from the project in concrete specimens made in the laboratory. Under Iowa Standard Specifications for coarse aggregate durability, test specimens using the aggregate in question must exhibit a durability factor of at least 80 when tested according to ASTM C666, Procedure B, and moist-room cured for 90 days. Test results at 300 cycles are shown below.

Durability

Mix	Cement (LB)	Aggregate Type	Aggregate Proportion %	Sand Added	Durability Factor
1	564	Cr. PC	60 C.A.-40 F.A.	633	88
2	564	Cr. PC	50 C.A.-50 F.A.	1043	94
3	470	Cr. ACPC	66 C.A.-34 F.A.	486	79

Slump and air tests were taken at the jobsite with the following results:

	Slump Ave.	Range	Air Ave.	Range
Mix A	2.4	1.6 - 3.5	6.4	5.0 - 7.8
Mix B	1.6	1.5 - 1.7	6.7	6.2 - 7.2
Mix C	1.9	1.7 - 2.0	3.6	3.5 - 3.6
Mix C3	0.75	0.25- 1.5	5.0	4.7 - 5.2

Water Cement Ratio

	Design	Max. Allowable	Actual Job Ave.
Mix A	0.54	0.613	0.514
Mix B	0.49	0.556	0.456
Mix C	0.54	0.613	0.550
Mix C3	0.54	0.613	0.500

OBSERVATIONS AND RECOMMENDATIONS

By stockpiling the total crushed product from the secondary crusher into a single stockpile, much segregation resulted. In addition to the obvious mix problems caused by material segregation, the crushed product was difficult to batch. The feed through the bin gates was inconsistent, causing abnormal difficulties in setting the automatic gate closure operation.

To help remedy the segregation problem, future projects involving crushing the old pavement should require splitting the crushed product at about the 3/8 inch screen size. By providing the crushed aggregate in both coarse and fine fractions, the mix proportioning should be easier to control. Separating the crushed product would also facilitate mix design. An economical and workable mix design should be readily attainable by considering a three-aggregate mix of uniform coarse and fine crushed product plus concrete sand.

Project inspection personnel reported having difficulty in performing specific gravity and moisture content determinations on the crushed AC-PC concrete using the pycnometer. It was difficult to deal with the fines in the combined material. These problems did not exist with the crushed PC concrete. The asphalt would tend to soften when being dried in a pan over a burner and continued to lose weight when drying.

Present field lab procedures and equipment need revising for dealing with a crushed asphalt. Microwave ovens could perhaps be considered for any future project that might incorporate crushed asphalt into a concrete mix.

Because of the adherence of fines to the coarse particles in the crushed AC-PC, the project personnel felt that their gradation results for that material were probably incorrect, especially on the No. 8 thru the No. 200 screens.

It was discovered that Mixes "A" and "B" needed less air entraining agent than conventional concrete to attain the desired 6-1/2 percent ± 1-1/2 percent air entrainment. Project personnel advised that they would begin paving with no air-entraining in the mix and then introduce a small amount of air-entraining agent as the ambient temperature warmed up. They further advised that three to four fluid ounces of air-entraining agent per seven cubic yards was adequate for the "A" mix.

The "C" mix (crushed AC-PC with no other aggregare) also exhibited entrained air problems, but of a different nature than mentioned above. An entrained air content of 3 to 3-1/2 percent was obtained without any air entraining admixture. Air entraining agent dosages up to 48 fluid ounces per 7 cubic yards were used with no significant change in the measured air entrainment. However, in the "C-3" mix (15 percent sand added) the entrained air was measured at 4-1/2 to 5 percent, with no air entraining agent in the mix.

Although the contractor was required to have equipment available to scarify the surface of first course in the composite section, none was necessary. It was felt the open, porous surface exhibited by both the "C" and "C-3" mixes would afford adequate bond between the two courses.

Occasionally, "slick" spots, 1 to 2 square yards in size, would appear on the surface of the "C" mix. These areas seemed wet and were probably the result of segregation in the aggregate. The areas were less frequent in the "C-3" mix concrete. The contractor scarified these isolated areas with a 3-tined fork.

The following are observations by the paving contractor:

(1) For composite paving, he would use a belt spreader in front of both pavers. If a lower course would be as harsh as the lower on this project, he would install vibrators on the front spreader to aid in consolidation.

(2) He would probably use two proportioning plants to produce separate mixes for a composite section. The independence of two plants would assist in keeping the batch trucks separated thus preventing mix contamination. This would also prevent contamination of stockpiles at the plant site. A larger than usual plant site would be required, however.

(3) For future use of crushed aggregate, such as the "A" and "B" mixes, he would prefer the crushed product to be in two fractions. He further felt that proportioning a three-aggregate mix would cause no problem with his existing equipment.

(4) Checking for depth of the slab in the plastic concrete in the composite section was a definite problem. The harshness of the lower course was difficult to penetrate with various types of probes and get an accurate measurement. They often resorted to digging holes. A similar situation existed in measuring the top course. The openness of the surface of the first course made it difficult to probe in the conventional manner and get an accurate measurement. Project inspection personnel also felt that some other method of depth checking would be advisable. Digging or cutting holes in the surface course was suggested.

(5) For future projects involving composite sections, if the lower course was expected to be difficult to place and finish, the contractor suggested a specification provision to allow the more workable surface course to be placed, full-depth, in construction gaps, headers, etc., in lieu of the composite section. As this would facilitate the paving operation, and would provide for substituting a higher quality concrete, the suggestion would certainly seem acceptable.

The project engineer recommends that any crushed product remaining from future projects be provided to the contractor for use as aggregate for shoulders, driveway surfacing, etc. Also, any concrete culverts, bridges, etc. from a reconstruction project that sometimes present a disposal problem, should be considered for crushing on future recycling projects.

The pavement crushing contractor suggests the following for future projects:

(1) That the removal and crushing be included in the same contract to enable the crusher to have control of the method of removal. This is felt necessary to maintain control of the fines that could result from the pavement removal operation.

(2) That the removal and crushing be measured in square yards rather than tons to facilitate quantity determination.

(3) That project designers can plan on about 75 to 80 percent recovery of an old pavement to a crushed product.

(4) He would prefer removing larger pieces, 10 to 12 feet in size, hauling in larger trucks to the crushing site, and breaking the pieces down to a smaller size with a drop ball. This would facilitate the removal of the reinforcing steel, a labor sensitive operation.

Due to some of the project problems mentioned herein with the crushed asphalt concrete when included as an aggregate, as well as its questionable durability, it is recommended that any asphalt concrete resurfacing not be considered as a paving aggregate. It is suggested that any existing resurfacing be removed, crushed separately, and stockpiled for later use by the contracting authority. This material could be expected to be excellent for various maintenance operations.

The total bid cost of this grade and pave project was $671,505.82. The bid price of some of the individual items related to the recycling and paving portion of the project are as follows:

Item	Quantity w/unit	Unit Price	Range of Unit Bid Prices Low	High	Ave.
Removal and Crushing of Pavement	24,159 sq.yds.	$4.30	$4.30	$6.00	$5.15
Pavement, Standard or Slipform P.C. Conc., Special Class, 9 in.	19,932 sq.yds.	$8.84	$8.84	$14.50	$10.69
Pavement, Std. or Slip-form Special Class P.C. Composite, 4"	5,415 sq.yds.	$7.51	$4.40	$8.09	$6.98
Pavement, Std. or Slip-form Special Class P.C. Composite, 7"	1,053 sq.yds.	$9.81	$9.81	$60.00	$30.45

CONCLUSIONS

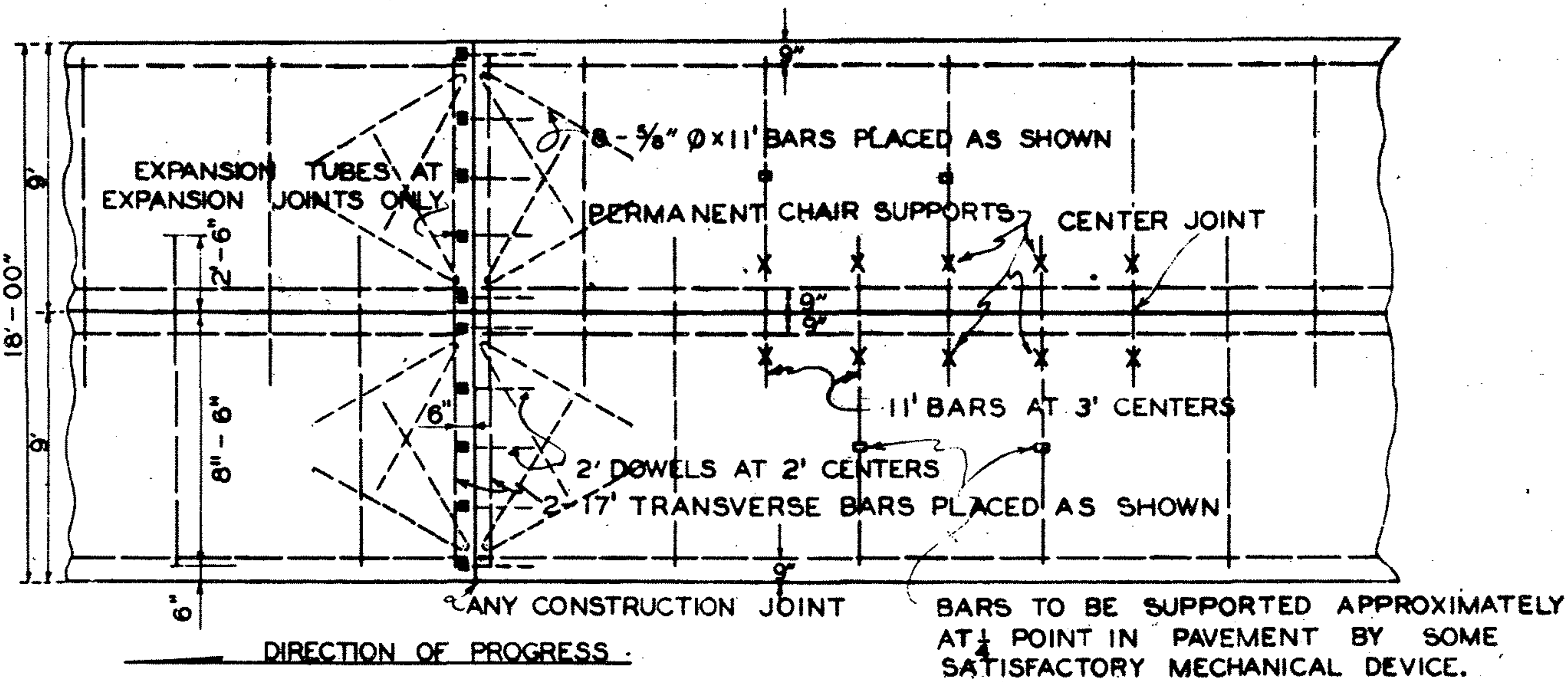
From all experiences on this project, it appears that recycling old portland cement concrete pavements into new pavements is a viable reconstruction alternative. Removal of the old pavement, reinforcement removal, crushing, and reusing as aggregate for paving was proven possible and feasible by this project. In addition, composite paving, using two separate mix proportions, through a conventional plant at the same time and placed with conventional slip form paving equipment was achieved with few problems.

The latter provides designers with another option, i.e., to use a locally available aggregate of a lessor than normal paving quality in a lower course and cover it with concrete using high quality, more expensive aggregates. Further research into such areas as composite design, thickness, mix design, effects of lower durability aggregates in the lower course, and placing and consolidating very harsh mixes is needed to fully utilize the composite pavement design concept.

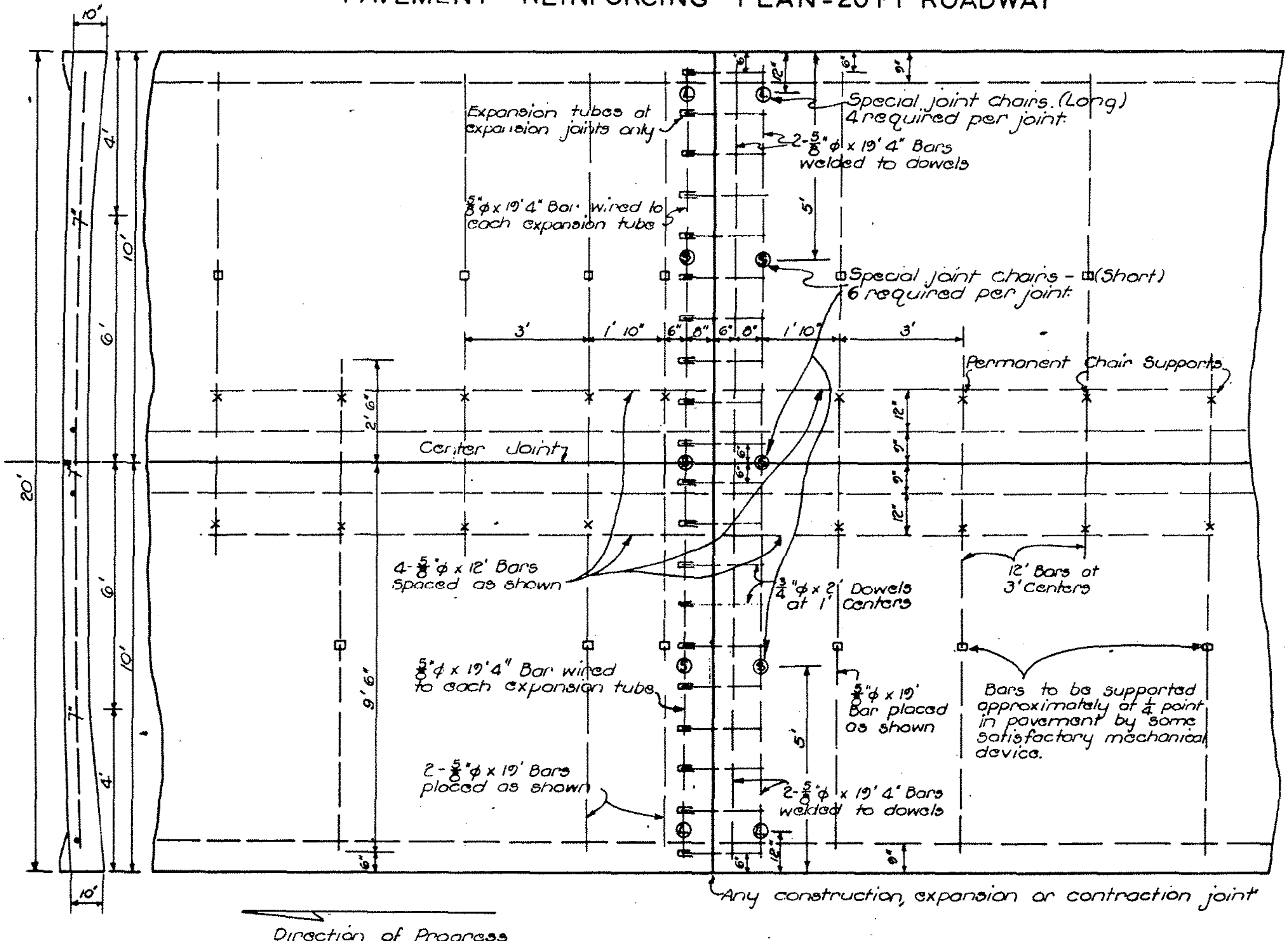
From the experience gained on this project, Iowa plans to consider using the existing concrete on reconstruction projects as an aggregate source. It would be expected to be used in subbases as well as in pavements.

Based on the resulting gradation of the crushed concrete in this project, the addition of natural sand in the neighborhood of 20 to 25 percent would seem to provide a very workable, easy to finish mix proportion. It is felt that a mix in which approximately 50 to 55 percent of the total aggregate passes the No. 4 screen would be most desirable from the placing and finishing standpoint.

PAVEMENT REINFORCING



PAVEMENT REINFORCING PLAN - 20 FT ROADWAY



APPENDIX B

PROJECT MIX PROPORTIONS

	Basic Abs. Vol.	Quantities/cu. yd.
Mix "A": 35% C.A. - 65% F.A.		
Cement	.106611	564 lb.
Water	.181030	305 lb.
Air	.060000	
Agg. (Crushed PCC)	.300429	1244 lb.
F. Agg. (Sand)	.351930	1589 lb.
w/c = 0.54 lb./lb.	Max. s/c - 0.613 lb./lb.	
Mix "B": 50% F.A. - 50% C.A.		
Cement	.106611	564 lb.
Water	.164411	277 lb.
Air	.060000	
Agg. (Crushed PCC)	.440117	1822 lb.
Agg. (Sand)	.228861	1033 lb.
w/c = 0.49 lb./lb.	Max. 2/c = 0.556 lb./lb.	
Mix "C": Crushed A.C. & P.C.		
Cement	.088842	470 lb.
Water	.150760	254 lb.
Air	.060000	
Aggregate	.700398	2885 lb.
w/c = 0.54 lb./lb.	Max. w/c = 0.613 lb./lb.	
Mix "C3": 85% A.C. & P.C. - 15% Sand		
Cement	.088842	470 lb.
Water	.150760	254 lb.
Air	.060000	
Crushed A.C. P.C.	.595338	2452 lb.
Aggregate (Sand)	.105060	474 lb.
w/c = 0.54 lb./lb.	Max. w/c = 0.613 lb./lb.	

The above quantities are based on the following:

Specific gravity of cement	3.14
Specific gravity of fine aggr. (sand)	2.68
Specific gravity of crushed P.C. Conc.	2.457
Specific gravity of crushed A.C.P.C. conc.	2.445

Approx. 24% of crushed P.C. conc. will pass No. 4 screen.
Approx. 22% of crushed A.C.P.C. conc. will pass No. 4 screen.

APPENDIX C

Specification 776

IOWA DEPARTMENT OF TRANSPORTATION

Ames, Iowa

SUPPLEMENTAL SPECIFICATIONS
FOR
PORTLAND CEMENT CONCRETE PAVING UTILIZING RECYCLED PAVEMENT

November 12, 1975

THE STANDARD SPECIFICATIONS, SERIES OF 1972, ARE AMENDED BY THE FOLLOWING MODIFICATIONS, ADDITIONS, AND DELETIONS. THESE ARE SUPPLEMENTAL SPECIFICATIONS AND THEY SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

Section 2301 shall apply with the following modifications:

776.01 DESCRIPTION. Concrete pavement shall consist of a single-course, or a monolithic, composite, two-course, portland cement concrete pavement, as indicated on the plans.

776.02 MATERIALS. All materials shall meet the requirements for the respective items in Part IV of the Standard Specifications, except the aggregate derived from crushing the existing pavement.

776.03 REMOVAL AND CRUSHING. All existing portland cement concrete shall be removed and crushed, except as noted on the plans. All removed and crushed pavement shall be the property of the contracting authority.

A. Where the plans indicate single-course construction, if asphaltic concrete resurfacing is present, the asphaltic concrete shall be removed before the portland cement concrete is crushed, and each shall be crushed separately. It is intended that all of the asphaltic concrete be removed from the portland cement concrete. Isolated areas of adhering asphaltic concrete up to one inch in thickness will be considered acceptable, including patches of asphaltic concrete.
B. Where the plans indicate two-course, composite construction and asphaltic concrete resurfacing is present, the contractor may break and remove the two materials together or separately. Both materials shall be introduced into the crusher at the same time and in the same proportion as they existed in the old pavement. Other means of combining the crushed product of the portland cement concrete and the asphaltic concrete in their original in-place proportions may be used with the approval of the engineer.
C. All reinforcing steel shall be removed from the existing pavement prior to or during the crushing operation and shall be disposed of by the contractor.
D. The contractor shall remove the pavement in a manner which does not develop a large amount of fines in the pavement material and which excludes subgrade and subbase material to the maximum extent practicable.
E. The pavement material shall be crushed to pass a 1½-inch sieve. Processing equipment shall include a screen by which excessive fines in the product can be controlled by removal of fines passing the No. 8 screen. Control will be as directed by the engineer, and his target will be 5 percent passing the No. 200 sieve. Aggregate washing will not be required.
F. Any excess material and fines removed during processing shall be disposed of as shown on the plans.

776.04 CONCRETE MIX PROPORTIONS. The following three (3) mix proportions will be used where indicated on the plans:

<u>Mix A</u>: (35% C.A. - 65% F.A.)

Basic Absolute Volumes:

Cement	.106611
Water	.180769
Air	.060000
Aggregate (crushed p.c. concrete)	.393822
Fine Aggregate (4110)	.258798
	1.000000

Approximate quantities of materials per cubic yard of concrete:

Aggregate (crushed p.c. concrete)	1652 lb.
Fine Aggregate (4110)	1155 lb.
Cement	564 lb. (6 bags)
Water	305 lb.
Design Water/Cement Ratio = 0.54	

<u>Mix B</u>: (45% C.A. - 55% F.A.)

Basic Absolute Volumes:

Cement	.106611
Water	.180769
Air	.060000
Aggregate (crushed p.c. concrete)	.506334
Fine Aggregate (4110)	.146277
	1.000000

Approximate quantities of materials per cubic yard of concrete:

Aggregate (crushed p.c. concrete)	2124 lb.	
Fine Aggregate (4110)	653 lb.	
Cement	564 lb.	(6 bags)
Water	305 lb.	
Design Water/Cement Ratio = 0.54		

Mix C:

Basic Absolute Volumes:

Cement	0.088842
Water	.181327
Air	.060000
Aggregate (crushed p.c. and a.c. concrete)	.669831
	1.000000

Approximate quantities of materials per cubic yard of concrete:

Aggregate	2765 lb.	
Cement	470 lb.	(5 bags)
Water	306 lb.	
Design Water/Cement Ratio = 0.65		

Notes: The above quantities are based on the following assumptions:

Specific gravity of cement	3.14
Specific gravity of fine aggregate (4110)	2.65
Specific gravity of crushed P.C. concrete	2.49
Specific gravity of crushed P.C. and A.C. concrete	2.45
Approximately 42% of the crushed P.C. concrete will pass the No. 4 screen	
Weight of one cu. ft. of water	62.4 lb.

An approved water reducing admixture will be required with each of the above mixes.
Gradation of the crushed material will be evaluated at the time of processing, and changes in proportions may be required.

776.05 EQUIPMENT. Equipment used shall be subject to approval of the engineer and shall comply with the following:

A. Proportioning and Mixing Equipment shall meet the requirements of 2301.06.

B. Placing and Finishing Equipment for the first lift of composite sections shall be capable of spreading the mixture to the full width and depth of the lift and consolidation of the mixture equivalent to that specified for pavement. In addition, equipment may be required that is capable of roughening or scarifying the surface of the first lift of a composite section to a depth of 1 inch. This equipment is subject to approval of the engineer and shall be used as he directs. Placing and finishing equipment for the second lift of composite sections and for single-lift construction shall meet requirements of 2301.07.

776.06 PLACING AND FINISHING. Pavement sections requiring single-lift construction shall be placed, finished, and cured in accordance with requirements of Section 2301.

A. Composite Section. Where indicated on the plans, composite sections shall be placed and finished in accordance with Section 2301 with the following modifications:

Composite sections shall be constructed monolithically. The first lift shall be consolidated by vibration before the second lift is placed.

The surface of the first lift shall have a roughened or scarified finish to facilitate a monolithic bond with the second lift. It is not intended that any hand finishing be performed on the first lift. The surface of the first lift shall not be higher than the design elevation prior to scarifying.

The second lift shall be placed while the first lift is in a plastic condition. The second lift shall be placed, finished, and cured in accordance with Section 2301.

776.07 LIMITATIONS. The pavement may be opened for use in accordance with 2301.36 with both the single-lift sections and the composite sections considered as Class A concrete.

776.08 METHOD OF MEASUREMENT. The single-lift pavement sections will be measured by the engineer in accordance with 2301.39. Composite pavement sections will be measured as follows:

A. The first lift will be measured on a volume basis, in cubic yards, using a count of batches incorporated.

B. The second lift will be measured in accordance with 2301.39.

C. The entire composite section will be considered in the determination of pavement thickness.

D. One core will be taken for approximately each 1000 square yards of composite pavement constructed.

776.09 BASIS OF PAYMENT. Payment for single-lift pavement will be in accordance with 2301.40. Payment for composite pavement will be as follows:

A. Payment for the first lift will be at the contract unit price per cubic yard for the number of cubic yards incorporated, and no payment will be allowed for concrete in excess of the design volume.

B. Payment for the second lift will be in accordance with 2301.40 using only the percentage rates indicated for 6-inch designed depth. These percentage rates will be applied only to the second lift in the composite section.

Measurement and payment for the removal and crushing of old pavement will be as shown on the plans.

Additional coarse aggregate necessary to complete the paving operation, as ordered by the engineer, will be paid for as extra work.