Iowa Development of Roller Compacted Concrete

Final Report for Iowa Highway Research Board Project HR-300

March, 1989

Highway Division
Iowa Department of Transportation

FINAL REPORT
for
HR-300 IOWA DEVELOPMENT OF
ROLLER COMPACTED CONCRETE

Presented to the
Iowa Highway Research Board

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DISCLAIMER

ACKNOWLEDGEMENT

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ABSTRACT

Roller compacted concrete (RCC) is a zero slump portland cement concrete mixture that has been used since the early 1970's in massive concrete structures. Iowa Highway Research Board project HR-300 was established to determine if this type mix could be used to pave roads on the Iowa road system. Manatt's Inc. of Brooklyn, Iowa agreed to pave an 800 ft. x 22 ft. x 10 in. section of RCC pavement in their Ames construction yard. This report discusses the construction of the test slab and interprets test results conducted during and after construction.

It was observed that RCC can be placed with conventional asphalt paving equipment. However, there are several problems with RCC paving which must be resolved before RCC can become a viable paving alternative on Iowa's roadway system.

INTRODUCTION

Roller compacted concrete (RCC) is a zero slump portland cement concrete mixture that has been used since the early 1970's in massive concrete structures such as dams and airport runways. Recently, its use has been expanded to include roadway pavements.

Several potential advantages of RCC pavements over portland cement concrete make its development in Iowa desirable. First, RCC is placed using conventional asphaltic concrete paving equipment. This construction method is simple and has the potential for significant savings compared to conventional (slip-form or fixed-form) concrete construction. Also, RCC pavement sets rapidly and can support heavy truck traffic hours after it is placed. Thus, pavements can be open to traffic in one day instead of the 10 to 14 day period normally required for portland cement concrete pavements.

Yet there are aspects of RCC pavement construction which need to be developed before RCC can be used on Iowa's secondary road system. Research project HR-300, "Iowa Development of Roller Compacted Concrete", was initiated in order to find an appropriate construction procedure for, and to study the early age performance of, RCC.

OBJECTIVE

The objective of this research was to construct a test slab using roller compacted concrete and conventional asphalt paving equipment. Specific topics to be investigated include:

1. Develop an appropriate construction procedure for RCC.
2. Determine if the early strength properties of RCC pavement could adequately support heavy wheel loads.
3. Determine the pavement ride quality achievable when compacting RCC with existing pavers and rollers.
4. Determine an appropriate joint spacing.
5. Determine an appropriate curing system that can be used with the early loading concept.

PROJECT LOCATION AND DESCRIPTION

Manatt's, Inc. of Brooklyn, Iowa, agreed to construct an 800' x 22' x 10" RCC test slab in its construction yard located one mile north of Ames on US 69 (Figures 1A and 1B).

Three RCC mix designs were used on the project. A description of each is given in Table I. The cement and fly ash percentages used were based on the total weight of dry aggregate in the mix. The concrete sand was obtained from Hallett's Gravel Pit of Ames and the 3/8 inch minus crushed stone from Martin-Marietta of Ames. A gradation analysis for each aggregate is given in Appendix A.

STORY COUNTY
IOWA

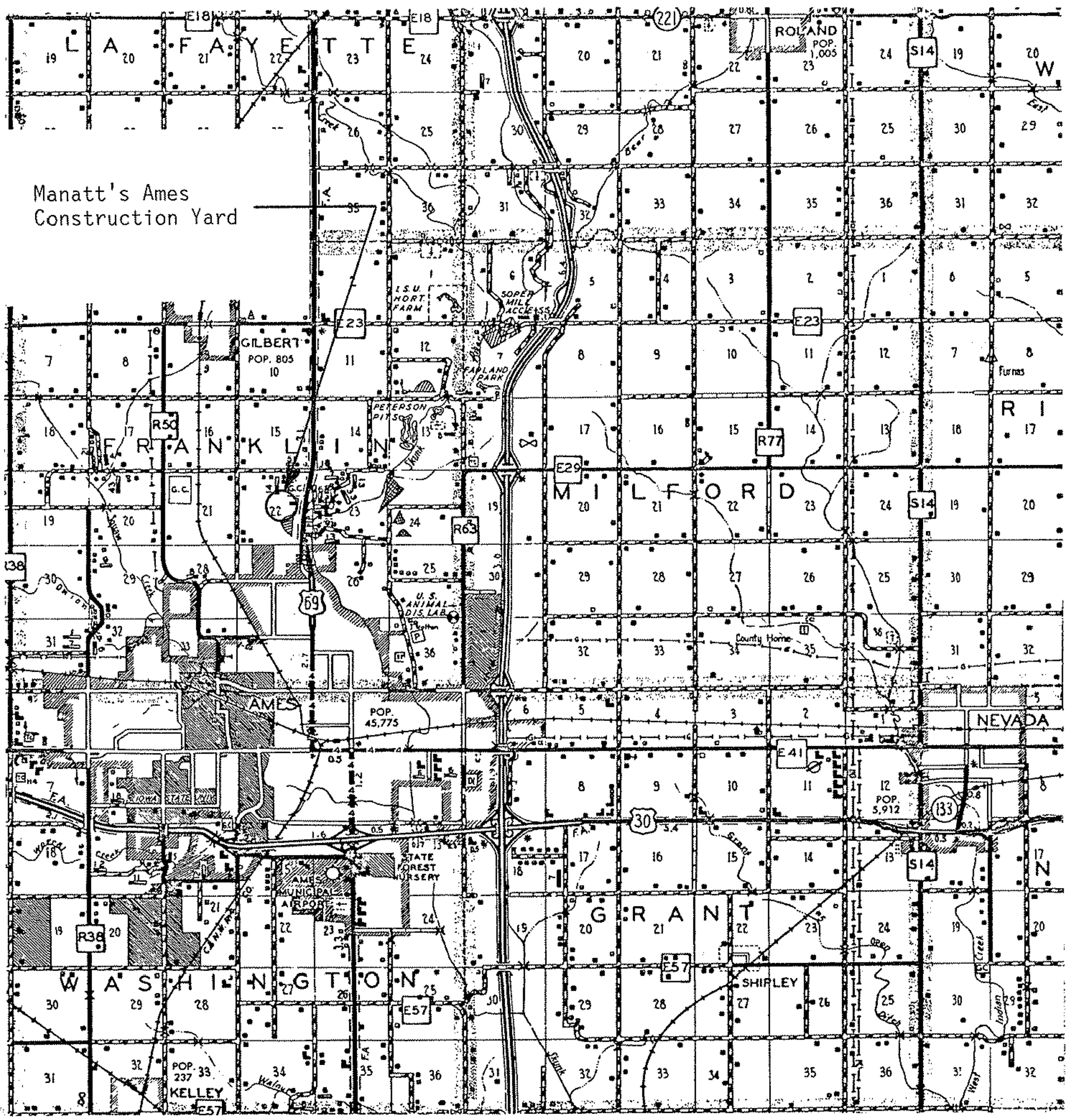

Figure 1A
Project Location

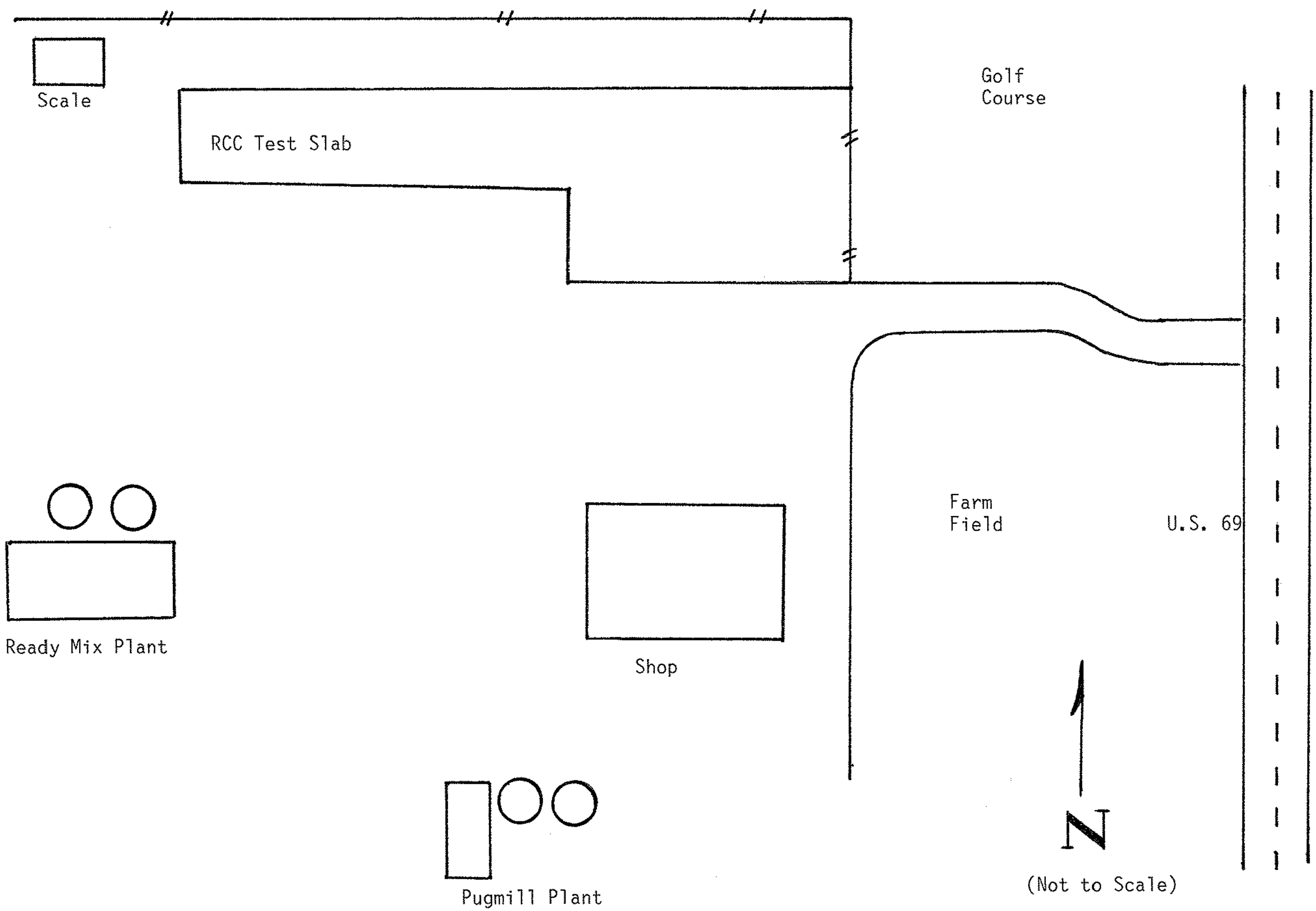

Figure 1B Project Location - Manatt's Construction Yard

Table I
Roller Compacted Concrete
Mix Designs

Mix No.	Description
1	60% 3/8" minus crushed stone 40% concrete sand 7% Type I cement 7% Class C fly ash
2	40% 3/8" minus crushed stone 60% concrete sand 7% Type I cement 7% Class C fly ash
3	70% 3/8" minus crushed stone 30% concrete sand 7% Type I cement 7% Class C fly ash

The RCC test slab was divided into eight sections. Variations in lift thickness and mix design were used to construct each section. A description of the individual sections is given in Table II. Section locations are shown in Figure 2.

TABLE II
RCC Test Section Description

Section	Mix	Construction Technique
1	1	Two 5 inch lifts
2	1	One 10 inch lift
3	1	Two 5 inch lifts
4	1	Two 5 inch lifts
5	1 & 2	Two 5 inch lifts Mix 2 used on bottom lift Mix 1 used on top lift
6	1	Two 5 inch lifts
7	3	Two 5 inch lifts
8	3	One 7 inch lift on bottom One 3 inch lift on top

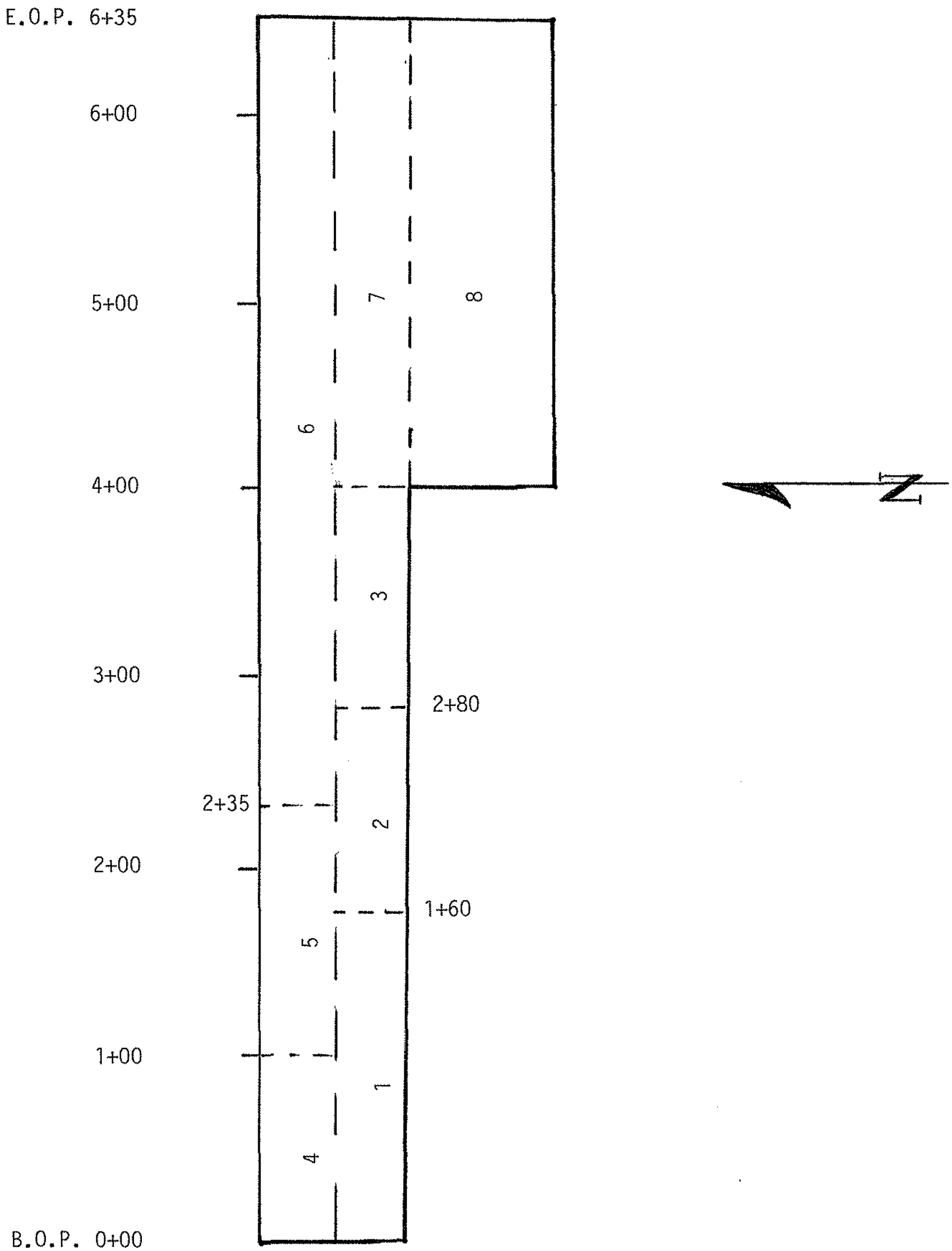

Figure 2
Test Section Layout

CONSTRUCTION

Manatt's construction crew began subgrade preparation the morning of Thursday, April 16, 1987. Ten inches of asphalt and base material were removed from an 800 ft. x 22 ft. area in the northeast portion of Manatt's construction yard (Figure 1B). The area was then compacted using a vibratory steel drum roller. Subgrade preparation was completed and ready for the first load of RCC mix that afternoon. Manatt's started producing RCC using Mix No. 1 shortly thereafter.

The RCC was mixed in a Borgman twin shaft pug mill continuous mixer and hauled in regular dump body trucks. The mix was placed with a Blaw Knox PF500 track type asphalt paver. A Pav-Saver screed, specially designed to compact RCC, was attached to the paver. The screed compacted the mix to over 80% of proctor density. Further compaction was accomplished using steel vibratory and pneumatic tired rollers.

Sections 1 and 2, and a portion of section 3, were placed the first day. Mix No. 1 was used in each section. Section 1 was constructed using two 5 inch lifts. After it was completed, work began on section 2. This section was placed in one 10 inch lift. Several batches of mix remained after section 2 was completed, so a decision was made to begin construction of section 3. Approximately 50 feet of the first lift was placed and compacted.

Paving was scheduled to continue the following day. However, rain and modifications made on the Pav-Saver screed delayed further paving.

The Pav-Saver screed required adjustment to better fit the Blaw Knox paver. The paver could not supply enough hydraulic power to effectively operate the four tamping bars of the screed. Therefore, the screed was adjusted so that only two tamping bars were used.

Paving resumed the morning of Friday, April 24. A vertical face was cut where paving had ended and the first lift of section 3 was then completed. Before beginning the second lift, a grout was used to bond the previously placed 50 foot section of the first lift to the second lift. Once section 3 was completed, the paver was moved to begin section 4. Mix 4 was constructed in a manner similar to sections 1 and 3. Mix 1 was used and placed in two 5 inch lifts. Once section 4 was completed, the mix used was changed to Mix No. 2 for paving section 5.

It was obvious after the first several loads were placed that Mix No. 2 was inadequate. The mix could not be sufficiently compacted by any of the equipment available. The mix would shove laterally when passed over by a roller. It was evident too much fine material was being used. The larger sized aggregate was spaced too far apart in the mix to develop adequate aggregate interlock. Production of Mix No. 2 was stopped after three loads were produced. Mix No. 1 was again used while a stiffer mix was being developed (Mix No. 3). Mix No. 1 was used the remainder of section 5 and section 6.

By the time section 6 was completed, the new mix design was prepared. The stiffer mix was used to construct section 7 before operations were shut down for the day.

Paving resumed the following Monday, April 27 with Mix No. 3 being used on section 8. The section was placed in two lifts. The first lift was placed 7 inches thick and the second lift three inches. Construction was completed by mid morning.

After each day's work the pavement was sprayed with a white pigmented curing compound. Water was sprayed on the pavement throughout each day to keep the surface moist until the curing compound was applied.

CONSTRUCTION SUMMARY

Construction of the test slab took longer than anticipated because of delays due to rain and necessary equipment adjustments. Overall, the construction process was satisfactory. Mix could be laid and compacted with conventional asphalt paving equipment. However, several problems arose during construction which must be eliminated before RCC paving can be used successfully on the Iowa road system.

One of the more significant problems experienced on this project concerned mix stability. As discussed previously, the maximum particle size used in the mix was 3/8 inch. During compaction the mix tended to shove from beneath the roller as it passed. This was especially true of the mixes containing higher percentages of the fine aggregate (Mixes 1 and 2).

The shoving was especially noticeable when the roller ran over an unconfined edge of pavement. The edge of slab, when not confined by an already compacted slab, would break down under the force of the roller's weight during final compaction. The outside three to six inches of pavement would shove laterally and not get compacted. Several days after construction, this edge of uncompacted material could easily be removed from the rest of the pavement.

Another problem which arose concerned the amount of bonding which was occurring between RCC lifts and along the centerline longitudinal joint of the pavement. The mix was too stiff to penetrate into the underlying lift or longitudinal edge of an existing lane to form a bond of significant strength. Even the 50 foot area of section 3 which had the grout treatment failed to form an adequate bond.

A third problem with the paving process concerned the smoothness of the finished pavement. Profilometer measurements indicated the road profile had a roughness sometimes exceeding 200 inches per mile. Although the profilometer measurements were unusually high, more prudent subgrade preparation, tighter gradeline control, and contractor experience with RCC will dramatically reduce surface roughness.

TESTING

In order to test the early load supporting ability of the RCC, a loaded truck was continually run on a section of freshly placed pavement. Other testing conducted during and after construction was performed by Iowa DOT Materials Office laboratory and District 1 personnel. Tests run during construction included nuclear gauge checks on density, profilometer measurements of pavement smoothness and Road Rater tests of the pavement's structural capacity. Also, compressive strength, flexural strength, and durability specimens were made for future testing.

Early Pavement Loading

Testing the early loading capability of the RCC pavement was accomplished by continually running a loaded haul truck over one section of the pavement. The truck had tandem axles to distribute its fifteen ton load.

Sections 1 and 2 were chosen for early loading testing. The haul truck began making passes over these sections approximately 4 hours after the sections were compacted. Passes were continually made for 8 hours.

The following morning the pavement was examined. An insignificant amount of rutting was observed. Also, the truck traffic had the effect of sealing the RCC surface in the wheel paths. Prior to traffic the surface contained small shear cracks from steel drum compaction. The traffic removed these cracks in the wheel paths. Thus the overall effect of early loading was actually to improve the pavement.

Nuclear Density Testing

The Pav-Saver Company claimed their screed could compact RCC to 95% of proctor density, thus eliminating the need for rollers. However, because the paver could not supply enough hydraulic power, the screed could not operate at its full capacity. As mentioned previously, the screed had to be adjusted so that only two of the four tamping bars were used. Density tests prior to rolling showed the screed was able to compact the RCC to between 85 and 90 percent proctor density. Further passes by a steel drum roller increased this to above 95 percent. Anywhere from 1 to 4 passes were required to compact the RCC sufficiently. An effective rolling pattern could not be established because of this variation.

Profilometer Measurements

Profilometer readings were exceedingly high, reaching 200 inches per mile in some areas. A listing of the profilometer test results is given in Appendix C. The unusual roughness of the paving surface can be attributed to several things. First, the subgrade was not maintained after haul trucks passed. This led to a number of rough areas in the subgrade. Since roughness in the subgrade will reflect through to the surface of a RCC pavement, this led to numerous areas of roughness in the pavement surface. Second, no elevation markers or stringline were used to guide the paver. The surface elevation was determined from the edge of the adjacent existing slab. Any roughness present in the existing slab would also be present in the RCC pavement. Third, contractor inexperience with RCC paving resulted in some roughness. The paving crew and roller operators had not worked with RCC and did not have the expertise required to deal adequately with the roughness problems encountered. Finally, much of the work was confined to a small area in the corner of the construction yard. The paver had to be maneuvered in this area. Each change of direction made obtaining a smooth surface very difficult.

Road Rater Testing

Road Rater testing of sections 1 and 2 was conducted to gain information on the early age structural capacity of RCC. Tests were run shortly after completion of the test sections, at 1 day after construction, and at 4 days after construction. The test data indicates the pavement gains strength rapidly, with the majority of the total strength gain coming within 24 hours. Structural rating values at the end of 4 days indicated the pavement had obtained a structural capacity comparable to that of 6 inches of hardened portland cement concrete.

The test data also revealed that the pavement placed in one 10 inch lift (section 2) provided more structural capacity than the pavement placed in two 5 inch lifts (section 1). Structural rating values obtained after 4 days were 4.94 and 3.34 for sections 2 and 1 respectively.

Strength Tests

Conventional 6" diameter by 12" cylinder molds and 6"x6"x20" beam boxes were used to prepare compressive and flexural strength test specimens. The methods used to compact the specimens were developed in the Iowa DOT Central Materials Office laboratory. The compressive strength cylinders were compacted in 5 lifts.

Each lift was compacted by dropping a 24 pound steel post driver onto the extension of a 5 7/8" diameter plate covering the material. Twenty-five drops of the post driver were applied per lift. The flexural strength beams were compacted in a similar manner. The beams were compacted in 3 lifts. Each lift was compacted by dropping the post driver onto the extension of a 5 7/8" x 4 5/8" plate. One hundred drops of the post driver were applied per lift.

Two sets of test specimens were made using these methods, ideally cured specimens and field cured specimens. The ideally cured specimens were placed in a moist room until tested. The field cured specimens were sprayed with a white pigmented curing compound and left outside the moist room. Specimens from each of the three mix designs were prepared. Because only three batches of Mix No. 2 were produced, the number of specimens made from this mix was limited.

Of the two mixes used extensively, Mix 3 was clearly a higher strength mix than Mix 1. This is shown graphically in Figures 3 and 4. Mix 2 showed surprisingly good results. However, because it could not be compacted in the field like it could in a confined area (i.e., the beam boxes or cylinder), it is doubtful the in-field strength is comparable to the laboratory strengths. Individual strength test results are given in Appendix B.

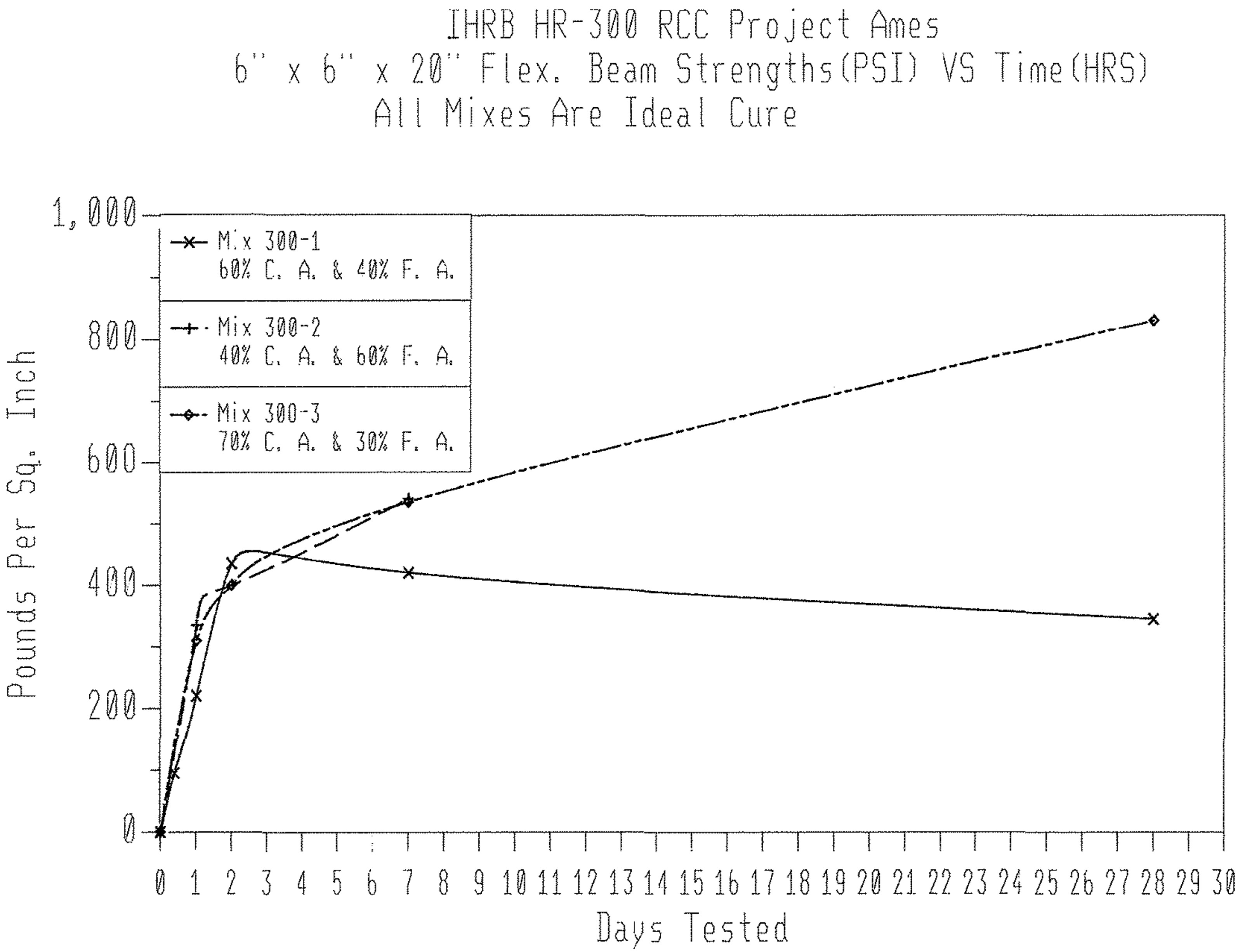

Figure 3
RCC Flexural Strength Results

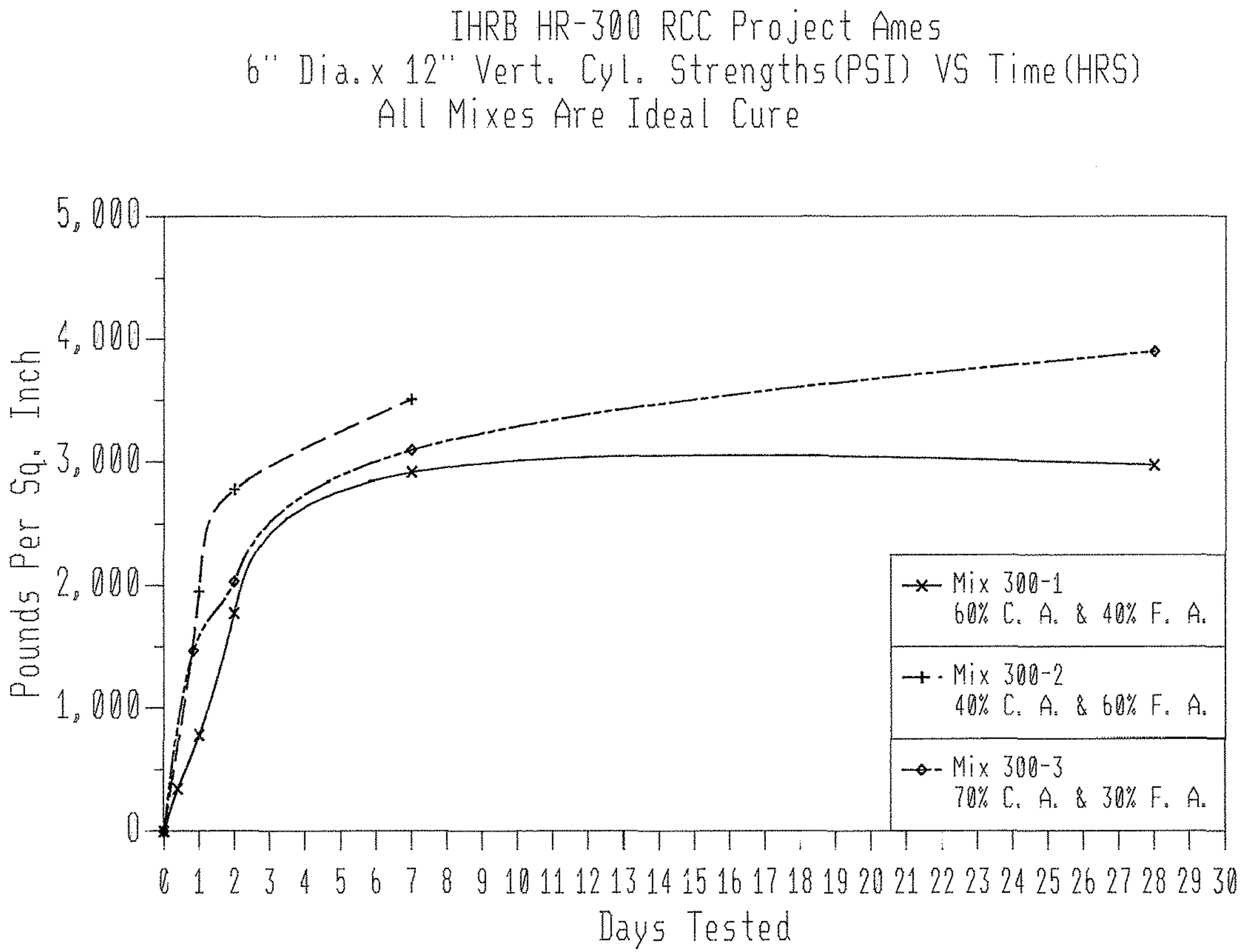

Figure 4
RCC Compressive Strength Results

Durability

Durability testing of specimens made during construction revealed that the RCC pavement would likely be susceptible to freeze-thaw deterioration. All the test specimens from each of the three mixes failed before being subjected to 300 freeze-thaw cycles. Of the three mix designs used, Mix No. 1 exhibited the most resistance to freeze-thaw deterioration. However, the best of the Mix 1 specimens was only able to withstand 213 freeze-thaw cycles before failing.

These results are in contrast to durability results obtained in laboratory specimens made as part of MLR-86-6 report, "Laboratory Evaluation of Roller Compacted Concrete".

A final field evaluation showed the RCC surface and longitudinal joints appeared to be deteriorating after two winter seasons.

CONCLUSION

A considerable amount of knowledge was gained from this research. From this standpoint the research was successful. Roller compacted concrete of adequate strength can be placed using conventional asphalt paving equipment. On future projects, the compaction technique used should be determined on a test slab prior to construction.

The project also uncovered several problems which must be addressed before RCC paving can become a viable construction alternative.

The problem of pavement roughness can likely be solved by adherence to proper construction practice (i.e., maintaining the subgrade and using automated paver-gradeline control). However, problems with compacting an unconfined edge, obtaining a bond between lifts and along longitudinal joints, and with the durability of RCC must be resolved before paving on the Iowa road system can be considered.

Appendix A

Aggregate Gradation Analyses

Gradation Analysis for
3/8 Inch Minus Crushed Limestone
From the Martin Marietta Ames Mine

Sieve No.	Percent Passing
3/8	100
No. 4	69
No. 8	45
No. 16	36
No. 30	31
No. 50	23
No. 100	17
No. 200	13

Gradation Analysis for
Concrete Sand From Hallett's Ames Pit

Sieve No.	Percent Passing
3/8	100
No. 4	98
No. 8	80
No. 16	55
No. 30	32
No. 50	11
No. 100	1.0
No. 200	0.3

Appendix B

Flexural and Compressive Strength Test Results

TABLE B1
RCC Strength Results
Flexural Strength

Mix No.	Cure Type	Flexural Strengths, PSI 8-12 hr.	1 day	2 day	7 day	28 day
1	IDEAL	95	180	450	450	350
		95	260	420	390	340
		(95)	(220)	(435)	(420)	(345)
	FIELD	135	270	490	250	240
		170	270	445	265	350
		(153)	(270)	(468)	(258)	(295)
2	IDEAL	---	340	400	525	---
		---	325	400	550	---
		---	(333)	(400)	(538)	---
	No Field Cured Specimens From Mix 2					
3	IDEAL	---	290	330	525	850
		---	200	315	540	810
		---	360	460	(533)	(830)
		---	385	500	---	---
		---	(309)	(401)	---	---
	No Field Cured Specimens From Mix 3					

Values in parentheses represent the average of strength tests run.

TABLE B2
RCC Strength Results
Compressive Strength

Mix No.	Cure Type	Compressive Strengths, PSI 8-12 hr.	1 day	2 day	7 day	28 day
1	IDEAL	345	820	2145	2990	3120
		345	740	1400	2850	2830
		(345)	(780)	(1773)	(2920)	(2975)
	FIELD	760	1330	2530	2760	2900
		730	1555	1520	3040	2690
		(745)	(1443)	(2025)	(2900)	(2795)
2	IDEAL	---	1910	2765	3325	---
		---	1985	2800	3700	---
		---	(1948)	(2783)	(3513)	---

No Field Cured Specimens from Mix 2

Mix No.	Cure Type	8-12 hr.	1 day	2 day	7 day	28 day
3	IDEAL	---	1325	1995	3275	4160
		---	1530	2095	2920	3820
		---	1520	2040	---	---
		---	1460	2010	---	---
		---	(1459)	(2035)	(3098)	(3990)

No Field Cured Specimens from Mix 3

Appendix C

Profilometer Test Results

Date	Section	Location	Length Miles	Roughness Inches	Profile Index Inches/Mile
4-16-87	1	1/4 pt	0.032	2.10	65.6
4-22-87	1	1/4 pt	0.032	2.20	68.8
4-16-87	1	Left Wheel Track	0.032	2.90	90.6
4-16-87	1	Right Wheel Track	0.032	2.55	79.7
4-22-87	1	Left Wheel Track	0.032	3.25	101.6
4-22-87	1	Right Wheel Track	0.032	2.95	92.2
4-16-87	2	1/4 pt	0.016	2.95	184.4
4-22-87	2	1/4 pt	0.016	2.90	181.3
4-16-87	2	Left Wheel Track	0.016	3.05	190.6
4-16-87	2	Right Wheel Track	0.016	4.05	253.1
4-22-87	2	Left Wheel Track	0.016	3.75	234.4
4-22-87	2	Right Wheel Track	0.016	3.45	215.7
4-24-87	4,5,6(partial)	First Lift	0.072	7.15	99.3
4-24-87	4,5,6(partial)	Left Wheel Track	0.072	8.35	116.0
4-24-87	4,5,6(partial)	Right Wheel Track	0.072	6.50	90.3
4-24-87	4,5,6	1/4 pt	0.101	12.10	119.8
4-24-87	4,5,6	Left Wheel Track	0.101	11.95	118.3
4-24-87	4,5,6	Right Wheel Track	0.101	12.20	120.8
4-24-87	3 & 7	1/4 pt	0.059	8.10	137.3
4-24-87	3 & 7	Left Wheel Track	0.059	7.25	122.9
4-24-87	3 & 7	Right Wheel Track	0.059	5.20	88.1
4-24-87	8	South Lane	0.038	5.40	142.1
4-24-87	8	North Lane	0.038	4.00	105.3
4-27-87	8	South Lane, Left Wheel Track	0.041	4.55	111.0
4-27-87	8	South Lane, Right Wheel Track	0.038	7.85	206.6
4-27-87	8	North Lane, Left Wheel Track	0.039	4.85	124.4
4-27-87	8	North Lane, Right Wheel Track	0.039	4.25	109.0