Evaluation of Narrow Transverse Contraction Joints in Jointed Plain Concrete Pavements

Masood Rasoulian[1], Hani Titi[2], and Mark Martinez3

Abstract

This paper presents the results of a research project conducted at the Louisiana Transportation Research Center (LTRC) to evaluate the performance of narrow transverse contraction joints in jointed plain concrete pavements. In addition, the paper evaluates the early entry dry saw cutting method in crack control of jointed plain concrete pavements. Two test sections were established during the construction of a new jointed plain concrete pavement on Northline Road in Port Allen, Louisiana. The first test section is 1200-ft long in which standard transverse contraction joints were created using the conventional wet double saw cut method. The second section is also 1200-ft long in which narrow transverse contraction joints were created using the early entry dry cut method. A monitoring program consisted of visual surveys to observe the cracking development, measurements of joint dimensions, pavement and joint distress surveys, and measurements of joint load transfer. Evaluation of the effectiveness of both joint types (standard and narrow) in controlling the cracking in concrete pavements is presented. Research results demonstrated that the sealed narrow joints performance was comparable with the performance of the standard joints

Introduction

Jointed plain concrete pavement (JPCP) is the most commonly constructed type of rigid pavements. In this type of pavements, a transverse contraction joints is established to control the location of cracking, which naturally occurs in plastic concrete as it hardens. The joint is usually created by saw cutting part of the slab thickness. Load transfer devices (dowel bars) are placed at these cut locations to provide loading continuity when the pavement is subjected to traffic. Figure 1 shows the concept of creating a joint in a concrete pavement.

---

1 Senior Pavement Research Engineer, Louisiana Transportation Research Center, Baton Rouge, LA 70808
2 Assistant Professor, Department of Civil Engineering and Mechanics, University of Wisconsin-Milwaukee, Milwaukee, WI 53201
3 Pavement Research E.I., Louisiana Transportation Research Center, Baton Rouge, LA 70808

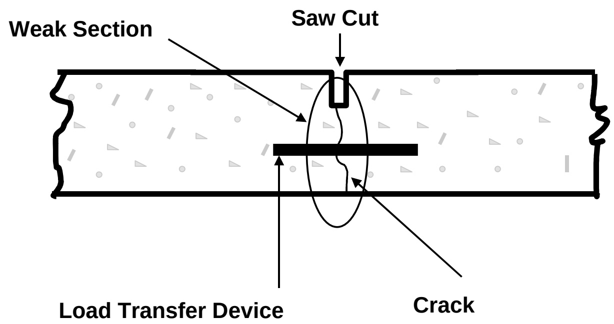


Figure 1. The concept of transverse contraction joints in jointed plain concrete pavements

The conventional wet cut method consists of creating an initial deep thin saw cut within a limited time after concrete placement. The sawing time depends on many factors such as weather conditions and concrete materials characteristics. The Louisiana Department of Transportation and Development (LA DOTD) requires the creation of transverse contraction joints in JPCP. The LA DOTD specifications include wet initial saw cutting to achieve a joint width of $\frac{1}{8}$ in. and joint depth of 3.5 in. for concrete pavements that are 10 in. thick. The first cut is then widened to a shallower depth a few days later for placement of the backer rod and sealant material (usually Silicone). The second cut is usually $\frac{3}{8}$ in. wide and 1.5 in. deep. Typical transverse contraction joint dimensions are shown in Figure 2.

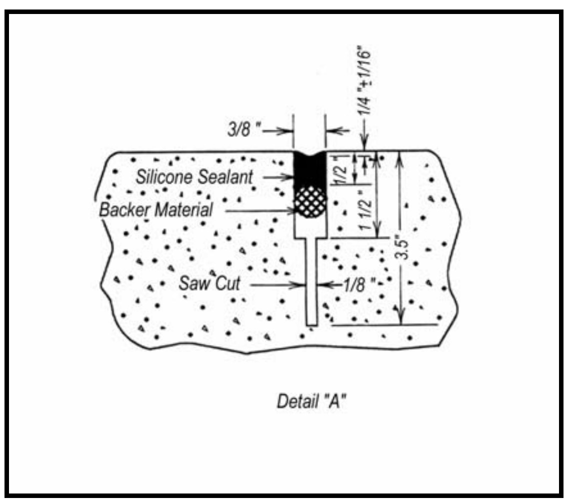


Figure 2. Transverse contraction joint used in LA DOTD jointed plain concrete pavement projects.

A new saw cut methodology (Concrete Construction, 1998) was introduced in 1988 called the early entry dry cut method. In this method, the transverse contraction joints are dry cut earlier at a shallower depth than the conventional wet cut method. This is also known as Soff-Cut method. It is believed that this methodology will effectively reduce random thermal cracks in concrete pavements (Zollinger 2001, Zollinger et al. 1994). The early entry dry cut at shallower depths raised a concern about the risk of having random cracks. To avoid this risk, some specifications allow the use of the early entry dry cut method, but require that the joints be chased later using the conventional diamond saw, to increase the depth to one-fourth or one-third the slab (Portland Cement Association, 1994).

This paper presents the construction and the three-year evaluation results of a research project conducted by the Louisiana Transportation Research Center (LTRC) to evaluate the performance of narrow transverse contraction joints in jointed plain concrete pavements in Louisiana. The project also investigated the performance of the early entry dry saw cutting method in cracking control of jointed plain concrete pavements. Test sections were established during the construction of a newly jointed plain concrete pavement (Northline Road) in Port Allen, Louisiana.

Research Methodology

The research was conducted during the new construction of concrete pavement on Northline Road in Port Allen, Louisiana. The road begins from the Route LA-1 service road and ends at the LA DOTD Pavement Research Facility. The Northline Road project consisted of a 1.97-mile new construction of JPCP with dowel bars for the purpose of load transfer.

Concrete Properties

The concrete mix was designed according to LA DOTD specifications (Type D concrete paving mix) in which 5.8 bags/yard^3 cement factor used with a water cementitious materials ratio of 0.48, fine aggregate content of 1,300 lb/yard^3 and coarse aggregate content of 1,800 lb/yard^3. The concrete mix consisted of type IS cement with 50% by weight Portland blast-furnace slag, fine aggregate, coarse aggregate with 2.5 in. maximum size, water reducer, and air entrainment agents. A computer-controlled mix plant was assembled near the site. During construction, laboratory-testing program was carried out to evaluate the concrete mix properties. Test specimens were made at the construction site. The tests were conducted according to the ASTM standard procedures. These tests are: compressive strength (ASTM C39), splitting tensile strength (ASTM C496), and flexural strength (ASTM C78). The setting time of the concrete mix was conducted, under conditions similar to those in the field, according the ASTM C 403 procedures in "Time of Setting of Concrete Mixtures by Penetration Resistance."

Pavement and Transverse Contraction Joints Construction

The roadbed was scarified and compacted. A 10 in. thick crushed limestone base course layer was placed. The slip form paving method was then used to place a 10 in. thick Portland cement concrete surface layer. Figure 3 depicts a typical section of the constructed pavement. The transverse contraction joints were created using the saw cut method. For most of the project, the joints were created using the conventional wet cut method. Five test sections with total length of 5400 ft on the pavement were identified to investigate the performance of narrow transverse contraction joints and the early entry dry cut method of the narrow transverse contraction joints.

Figures 4 shows the construction of JPCP at Northline Road, which does not indicate any difference compared to conventional concrete paving operation due to implementation of narrow joint concept. Figure 4 also depicts the early entry dry saw being used during the cutting process of the narrow joints in test section S2.

In this paper, only the narrow transverse contraction joints using the early entry dry cut method are investigated. As shown in Figure 5, two sections are used to investigate this type, which are:

(a) Section S1 (Control Section): the total length of this section is 1200 ft. The transverse joint was saw cut using the conventional wet double cut method. The joints of this section are standard type joints. Backer rod was installed and the transverse joint was sealed with silicone.

(b) Section S2: the total length of this section is 1200 ft. The transverse joint saw cut was conducted using the early entry dry cut method. Transverse joint was left unsealed. The cut width and depth are $\frac{1}{8}$ in. and 1.5 in., respectively. Ten days after the concrete placement, the early entry dry cut joints were deepened to 2.5 in. The joints of this section are narrow type joints.

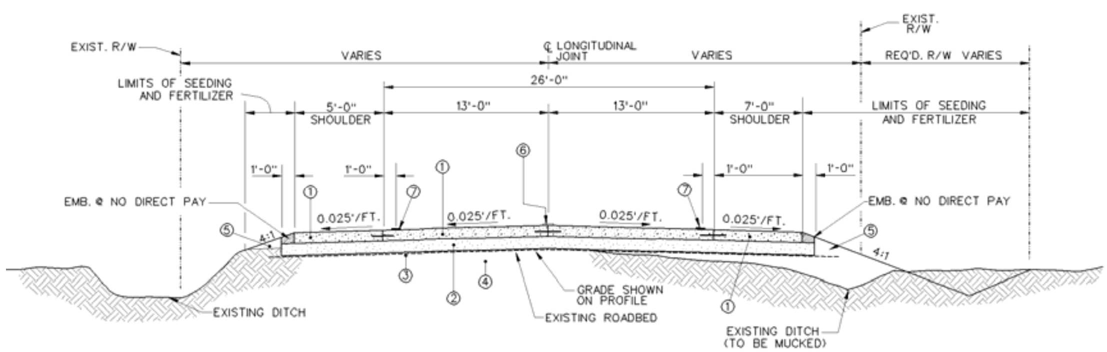


Figure 3. Typical section of the constructed JPCP

Placement of dowel bars

Slip form paver during pavement construction

Placement of tie bars to the finished concrete pavement

Creating pavement surface texture

The early entry dry cutting of the narrow joints at test section S2

The new jointed plain concrete pavement

Figure 4. Construction of JPCP at Northline Road, Port Allen, LA

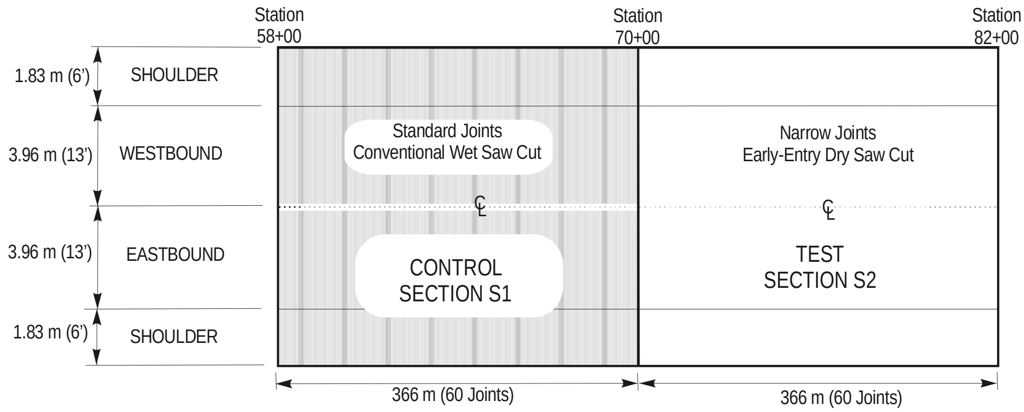


Figure 5. Test sections at Nothline Road.

Field Testing Program

A field-testing program was conducted on the pavement test sections to evaluate the short term and long-term performance of the narrow transverse contraction joints. The short-term performance evaluation consisted of: (1) conducting visual monitoring program to observe the development of controlled cracking and the time required for the cracks to develop along the investigated types of the transverse contraction joints, and (2) measuring the dimensions of the joints after construction and during extreme hot and cold temperatures for the first year.

The long-term performance evaluation consisted of: (1) conducting joint evaluation twice a year during the winter and summer periods to measure joint width, joint faulting, and load transfer across each joint type, and (2) conducting a pavement distress survey to record cracking, joint spalling, faulting, pumping, corner breaks, twice a year.

After transverse contraction joints were cut, a cracking survey plan was executed to monitor the development of the controlled cracks across these joints and the development of any random cracks that might develop within the pavement slabs. Cracking surveys were conducted on a daily basis during the first week after concrete placement and every 3 days thereafter for a period of one month. Development of controlled and random cracks was observed by visual inspection. In order to categorize the cracks, a code number was given for each controlled crack, depending on its size. The cracking code is 1 if no crack is developed across the joint, the cracking code is 2 if hairline crack is developed, and the cracking code is 3 for a large size crack.

Measurements of joint dimensions (depth and width) were recorded after pavement construction and during cold weather. Monitoring the movement of these joints during the coldest temperatures will provide information about the maximum width of the investigated narrow joints.

Discussion of Results

The concrete mix consisted of type IS cement with 50% by weight Portland blast-furnace slag, fine aggregate, coarse aggregate with 2.5 in. maximum size, water reducer, and air entraining agents. Results of the laboratory-testing program carried out to evaluate the concrete mix properties are shown in Table 1 and Figure 6. Strength test results showed that the concrete used in the pavement construction gained an average compressive strength of 4,728 psi, 28 days after placement. Compressive, tensile, and flexural strength test results of the concrete showed the expected strength gain during the curing process.

Test results showed that the initial setting time of the concrete is 4.4 hours under the concrete temperature of 91 ^{o}F, and the final setting time is 6.62 hours under the concrete temperature of 99 ^{o}F. These temperatures are higher than the range specified by the ASTM C403 laboratory procedure (from 68 to 77 ^{o}F). This indicates that the initial and final set times for the concrete with 50% slag were retarded, which is expected when pozzolanic materials are used.

Table 1. Results of the laboratory tests on the pavement concrete mix

Concrete Property	Specimen Age (day)	Strength (psi)	
		Average	Range
Compressive Strength (Compressive Strength of Cylindrical Concrete Specimens – ASTM C39)	3	3,017	2,119-3,968
	7	3,758	2,889-5,120
	28	4,728	3,948-6,158
Tensile Strength (Splitting Tensile Strength of Cylindrical Concrete Specimens – ASTM C496)	3	245	229-260
	7	368	357-379
	28	362	348-375
Flexural Strength (Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) – ASTM C78)	3	383	382-384
	7	500	485-515
	28	616	568-664

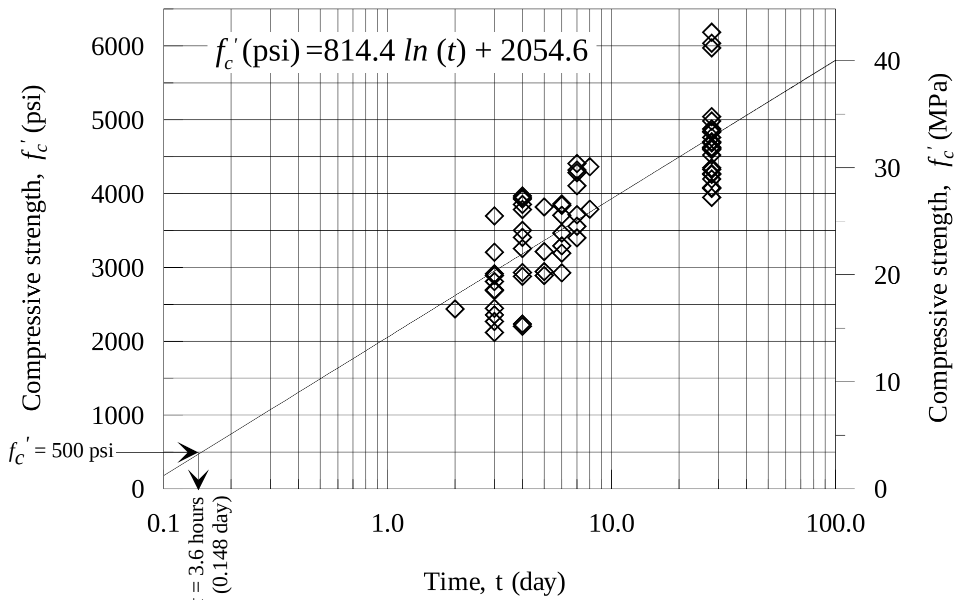


Figure 6. Compressive strength of the cement-slag concrete mix used for the pavement construction.

Development of Controlled Cracks

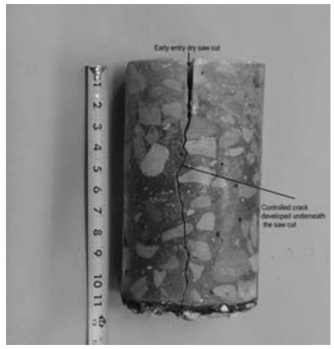
The visual survey conducted 24 hours after concrete placement showed that in Sections S1 and S2 the controlled cracks propagated along the transverse contraction joints in both. Figure 7 depicts picture of a controlled crack developed underneath the early entry dry cut narrow joint (test section S2). Considering the conventional wet cut standard joints 11 days after construction, 53% of the joints did not show cracks compared to 87% in the case of the early entry dry cut narrow joints. It is evident in both test sections that the rate of propagation of controlled cracking along the joints was slow. The use of cement-slag with 50% slag in the concrete mix resulted in a delay of the setting time for concrete after construction. Although the delay in the set time may be beneficial for eliminating random cracking during pours in hot weather, such a long delay in controlled crack formation, when high amounts of slag admixtures are used, needs further investigation for the early entry dry cut method. This reasoning was used to justify deepening the joints at the test section S2 to 2.5 in. 10 days after concrete pouring. The results of the cracking surveys for sections S1 and S2 showed that about one month after concrete construction, all of the joints monitored at the test sections developed cracks. The joints were exposed as seen in Figure 8 for visual verification of cracks.

Figure 7. Controlled crack developed underneath the narrow transverse contraction joint at test section S2 established using the early entry dry saw cut method.

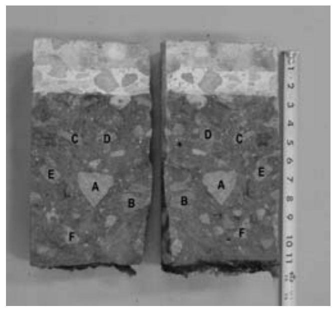
Figure 8. Verification of the development of the controlled crack across the narrow transverse contraction joints

Early Entry Dry Cut

There was concern that the early entry dry cut might cause concrete raveling during the saw cutting process. In this study, no raveling or damage to the concrete on the early entry dry cut joints was observed. Raveling of the concrete due to saw cutting can be avoided by creating joints on concrete that has a compressive strength of 500 psi (Zollinger 2001). Laboratory test results indicated that the concrete mix used to construct the pavement gained strength of 500 psi in 3.6 hours after placement. Another issue that was raised regarding the early entry dry cut method is that placing a saw on fresh concrete may cause particle segregation of the concrete mix as a result of the saw vibrations. In order to check this point, several core samples were taken on the narrow joints section. These joints developed a controlled crack 2 days after the 1.5 in. deep early entry dry saw cut was made. Cores were taken from the investigated pavement at the joint location. As shown in Figure 9, the controlled crack propagated underneath the contraction joint to the bottom of the slab. The crack did not go around the aggregate particles but rather through them as shown in Figure 9b (aggregate particles A, B, etc.). Moreover, the aggregate particles having a maximum size of 2.5 in. were found to be uniformly distributed within the concrete mass. This is evidence that the concrete was hardened enough to resist any particle segregation during the early entry saw cutting process which started after approximately four hours after placement



(a) Crack propagation underneath the early entry dry saw cut.



(b) Uniformly distributed aggregates within the concrete mass and the split of the aggregate particles as a result of the crack propagation.

Figure 9. Core sample taken at the early entry dry cut narrow transverse contraction joint of the test section S2.

Pavement Distress Survey

Cracking surveys showed that random cracks have developed within the concrete slabs using both types of transverse contraction joints. Within the 1.97-mile pavement project, a total of four random transverse cracks developed about 3 to 4 ft from the transverse joint cuts. Two of these cracks were observed within the early entry dry cut narrow joints test section (S2) and the other two within the conventional wet cut standard joints pavement (S1).

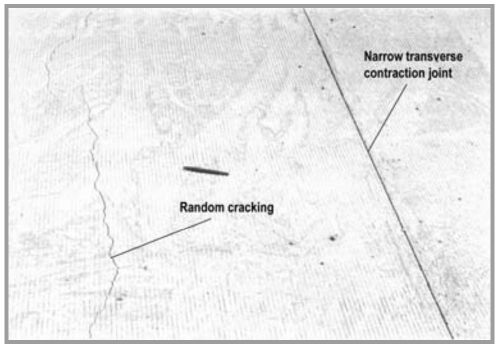
It should be noted that the presence of these cracks within the narrow joint section is irrelevant to the joint type by being narrow or standard. This is simply because the standard joint is cut initially as a narrow joint then the second cut is performed later on for the purpose of creating a reservoir for the sealant. Generally, the presence of the 4 random cracks is considered a reasonable amount of random cracking within 1.97-mile project. Inspection of the crack, during repair in the early entry dry cut section, showed the existence of large voids within the concrete slab where the random crack propagated. Therefore, the random cracks developed due to poor workmanship during concrete placement. Pictures of the random crack and the voids that caused this crack are depicted in Figure 10.

In August of 2002 and February 2003, surveys were conducted on the test sections. Pavement distress survey after 1.5 year from construction showed that the pavement test sections are in good condition. This is expected since the pavement is newly constructed. For this survey the performance of the sealed and unsealed joints were compared regardless of the construction methods. The unsealed narrow transverse contraction joints at section S2 showed a low severity amount of spalling at few joints as shown in Figure 11. In addition, these joints were filled with small aggregate particles, which may affect the performance in the hot temperature periods when these joints tend to close up. Joints with such distresses were identified in all sections. The numbers of joints with damage greater than 5″ in length were identified as shown in Table 2. It appears that the narrow sealed joints show the least amount of damage.

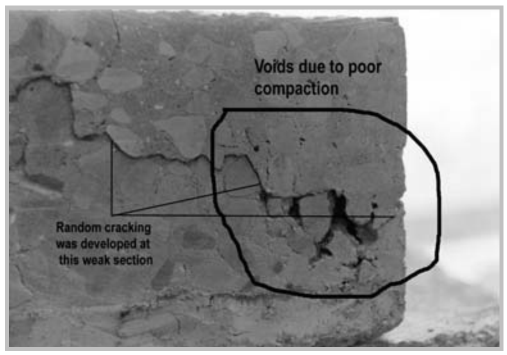
Table 2. Joint damage assessment

Survey Period	**Control Section Section S1**	**Narrow Unsealed Section S2**
August 2002	7%	29%
February 2003	22%	48%

It should be noted however, that there are many unpaved roadways in the area feeding into test sections from the industrial sites. A substantial amount of mud and debris are tracked onto the pavement by the heavy trucks using such facilities. This is not normal for a typical pavement, and may be accelerating the damage on the unsealed joints. The researchers believe that unsealed narrow joints need further investigation in a less critical environment.



(a) Random crack propagated in the concrete slab about 3 ft from the early entry dry cut contraction joint



(b) Improper placement resulted in development of random cracking within the concrete pavement slab

Figure 10. Picture of the random cracking developed within the concrete pavement slab of the test section S2

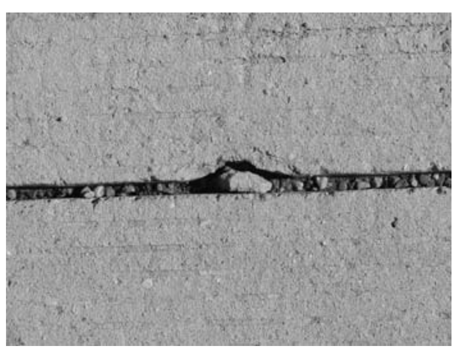


Figure 11. Low severity spalling of unsealed narrow contraction joints at test section S2

Efficiency of Joint Load Transfer

The load transfer efficiency ratings of the joints in the test sections were evaluated from the FWD data. Load transfer was evaluated at low ambient temperatures (53 ºF) to obtain the minimum values for load transfer efficiency and during the hot temperatures in the summer (97º F). Table 4 shows the load transfer efficiency ratings taken at cold and hot temperatures. All joints showed good load transfer efficiency based on the FHWA categorization, even in the coldest period (greater than 70%). There is a 27% loss in load transfer observed going from a hot season to a cold season.

Table 4. Average load transfer efficiency during winter and summer seasons

LOAD TRANSFER EFFICIENCY					
SECT NO.	**Jan-01**	**Jul-01**	**Aug-02**	**Jan-03**	**Aug-03**
1 - EAST	72%	101%	70%	65%	92%
1 - WEST	73%	101%	101%	74%	100%
2 - EAST	89%	99%	96%	77%	98%
2 - WEST	74%	100%	99%	75%	99%

Effect of Temperature on Joints

Figure 12 depicts the results of joint measurements after construction and during a period of cold weather (38 ºF, January 2001) observed at the test site. The joints width measurements, during cold temperatures, showed that the narrow joints opened to less than twice the original saw cut width. The maximum average joint opening was about 0.23 in., which indicates that larger size foreign material will not be able to invade the joints when left unsealed The average width for the narrow joints was about 0.13 in. The average width for the standard joints is about 0.33 in., which is less than 0.38 in. as required by the Louisiana DOTD specifications.

The depth of the joint cut is about 1.5 in. according to the original plan. The second widening cut depth for the standard joint is about 1.8 in., which is larger than the 1.5 in. required by the Louisiana DOTD specifications.

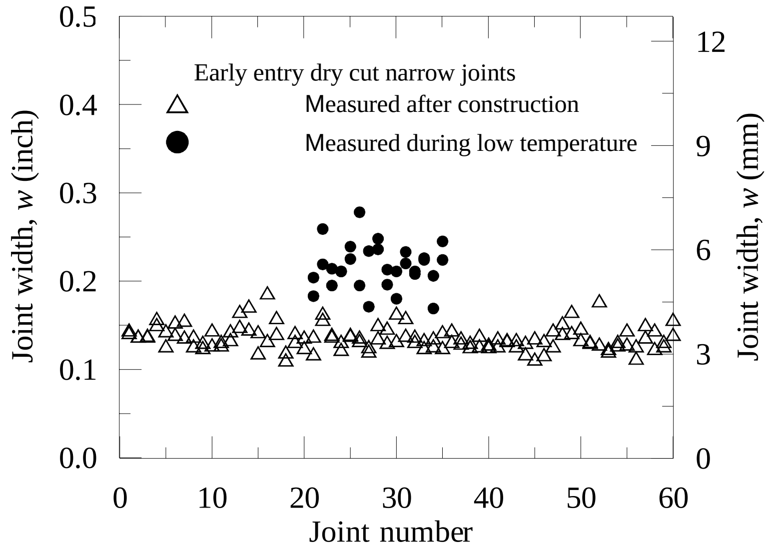


Figure 12. Results of the measurements of joints dimensions after construction and during the extreme low temperature season

Cost Issues

Due to the experimental nature of this research a benefit analysis could not be conducted. However it is estimated that by reducing the requirements of a double saw cut, 50% saving in cost of the labor and blade cost will be obtained. Additionally, since the narrow joint will result in about 1/3 of the volume sawed joint to be sealed, a 67% saving in the cost of the sealing materials will be obtained.

Conclusions

Comparison of the two joint cutting methods showed that both methods were able to successfully cause cracks underneath the established transverse contraction joints. The rate of propagation of the controlled cracks was generally retarded in joints created by both methods but was even slower in the case of the early entry dry cut method. This is due to the use of cement-slag in the concrete mix which affects the set times of concrete. The effect of high slag concrete on the formation of controlled cracking underneath the transverse joints needs further investigation.

The early entry dry cut method neither induced vibrations that caused the concrete to segregate nor caused concrete raveling during the joint cut. The concrete core samples taken at these joints showed that the concrete mass remained intact during cutting.

The early entry dry cut method used to create narrow transverse contraction joints performed similarly to the standard transverse contraction joints in controlling random cracking in concrete pavements. Both joint types created a weakened section within the pavement to facilitate the formation of cracks.

The narrow transverse contraction joints are more cost-effective than the standard joint configuration. This is due to the fact that narrow joints require a single saw cut and, therefore, less labor time and less sealant material. Narrow transverse contraction joints have less opening width during low temperatures, which will prevent the intrusion of larger sized foreign material into the joint.

The load transfer efficiency varied by as much as 27% decrease going from the summer to winter months, however all joints had good load transfer efficiency even in the cold season.

Acknowledgments

The authors would like to thank the pavement research group, Mitchell Terrell, Shawn Elisar, Gary Keel, and Glen Gore, and the concrete research group, Randy Young, and Al Mix, for their effort in different phases of the project. The cooperation of Tom Landry and Walid Shahla, Project Engineers during the construction of the pavement is also appreciated.

References

1. Portland Cement Association, "Controlling Early Cracking of Flatwork," Concrete Technology Today, PL951, March 1995, pages 5-7.

2. Portland Cement Association, "Early Sawing to Control Cracking," Concrete Technology Today, Number 3, Volume 16, November 1995, pp 1-2.

3. "Saw Cuts Concrete Immediately After Finishing," Concrete Construction, March 1998, pages 336-338.

4. Zollinger, D. "The Case for Early - Entry Saws," Concrete Construction, Volume 46, Number 2, February 2001, pp 48-53.

5. Zollinger, D., Tang, T., and Xin, D. "Sawcut Depth Considerations for Jointed Concrete Pavement Based on Fracture Mechanics Analysis," Transportation Research Record 1449, 1994, pages 91-100.