NCAT Report No. 96-3

A STUDY OF LONGITUDINAL JOINT CONSTRUCTION TECHNIQUES IN HMA PAVEMENTS (INTERIM REPORT - COLORADO PROJECT)

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Paper presented at the 75th Annual Meeting of the Transportation Research Board held in Washington, DC (January 7-11, 1996).

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February 1996

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ABSTRACT

There is a need to identify suitable longitudinal joint construction techniques for multilane hot mix asphalt (HMA) pavements, which can minimize or eliminate cracking at the joint and/or ravening adjacent to the joint. It is believed that the longitudinal cracks primarily result from the density gradient which is usually encountered across the joint. This density gradient can be attributed to the low density at the unconfined edge when the first lane is paved, and a relatively high density at the confined edge when the adjacent lane is paved.

Seven different longitudinal joint construction techniques were used on Interstate 25 in Colorado in 1994. The techniques included different rolling procedures to compact the joint, providing a vertical face with a cutting wheel, and using a rubberized asphalt tack coat on the face of the unconfined edge. Two longitudinal joint construction techniques were used on Interstate 79 in Pennsylvania in 1994. These consisted of the conventional technique (control) and New Jersey type wedge joint. The latter technique uses a 3:1 taper at the unconfined edge of the first lane. The face of the taper is heated with an infrared heater just prior to placing the adjacent lane.

Pavement cores were taken on the joint and 305 mm (1 foot) away from the joint for density

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measurements in all experimental test sections. Different joint construction techniques have been ranked based on statistical analysis of all density data. Various joints were also evaluated visually by a team of at least four engineers in June 1995.

The performance or ranking of the joints on both Colorado and Pennsylvania projects after one winter seems to have been influenced by the overall density at the joint. The joints with high densities show better performance than those with relatively low densities. These ranking may change in the future based on the long-term performance (in terms of cracking and ravening).

KEY WORDS: longitudinal joint, joint, asphalt pavement, hot mix asphalt, construction, HMA, joint construction

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INTRODUCTION

Relatively low density and surface irregularity are the two main defects which are commonly encountered in the construction of longitudinal joints in multilane Hot Mix Asphalt (HMA) pavements. The two main distress conditions in longitudinal joints are cracks and ravening. It is believed that the longitudinal cracks primarily result from the density gradient which is usually encountered across the joint (1). This density gradient can be attributed to the low density at the unconfined edge when the first lane (hereinafter called the cold lane) is paved, and a relatively high density at the confined edge, when the adjacent lane (hereinafter called the hot lane) is paved. Low densities at the joint also lead to ravening.

Surface irregularities at longitudinal joints, like difference in height of adjacent lanes, can result in water accumulation adjacent to the joint, and a potential problem during fast lane changing. Such irregularities are caused by improper construction practices.

Usually the density at a longitudinal joint is about one to two percent less than the density in the lanes away from the joint (1, 2, 3). However, significantly lower density values are not uncommon at the j oint. The main problem is to increase the overall density at the joint so that it is consistent with the lane densities thus minimizing the potential for longitudinal cracking and ravening. Although possible, it is rarely practical to use a wide paver or two pavers in echelon formation to pave the two lanes at the same time and thus at the same temperature.

Therefore, different methods of longitudinal joint construction need to be evaluated to identify a method or methods which increase the overall density at the joint and/or minimize the cracking and ravening problems. This study conducted in Colorado and Pennsylvania is a continuation of the study which involved projects in Michigan and Wisconsin (4).

OBJECTIVE

The objective of this study is to evaluate seven different longitudinal joint construction techniques used in one HMA paving project in Colorado and two different techniques used in another paving project in Pennsylvania.

PROJECT DETAILS AND JOINT CONSTRUCTION TECHNIQUES

Colorado

Seven different longitudinal joint construction techniques were used in seven 152-m (500-feet) sections in the Colorado project (constructed in July 1994), located on I-25 just north of Colorado Springs. These test sections are located on the southbound lanes of I-25 beginning at the El Paso/Douglas county line (milepost 163.37) and continuing to milepost 161.78 which is adjacent to the port of entry scales at Monument, Colorado. Due to traffic control, construction time restraints, and HMA production scheduling, it was not possible to construct the test sections sequentially with one test section adjacent to the other. The work consisted of removal of 101.6 mm (4 in.) of HMA in the southbound lane of the existing pavement and replacement with an HMA overlay 101.6 mm (4 in.) thick in two lifts of 50.8 mm (2 in.) each. The different longitudinal joint construction techniques were used in the wearing course.

The HMA mix composition is given in Table 1. The mix has a substantial amount (17 percent) of material passing 19 mm (3/4 in.) and retained on 12.5 mm (1/2 in.) sieve, which increases the potential for segregation.

The HMA mixture was delivered to the construction site in belly dump trailers and deposited in windrow fashion on the lane to be paved. A Barber Greene pick-up elevator was used to place the HMA into a Blaw Knox paving machine. Equipment used for compaction consisted of an eleven -ton Ingersoll Rand vibratory roller for breakdown. A ten-ton Bros pneumatic-tired roller was used for intermediate compaction. A ten-ton steel-wheeled Hyster roller was used for finish rolling. The temperature of the mix in the windrow was 154- 157°C (310-3 15°F). The temperature of the mix prior to breakdown rolling was about 143°C (290°F). The following different types of longitudinal joint construction techniques (LJCT) were used on this project.

LJCT 1 (3:1 Taper Rolled from Hot Side)

The unconfined edge of the first paved lane was constructed with a 3:1 taper at the proposed joint. Normally, a steel plate is rigidly attached to the screed to give the desired taper. However, on this project a piece of steel plate was dragged by chain behind the screed. The resulting taper was not as smooth as would be obtained with a plate rigidly attached to the screed. The taper was then tacked with a diluted slow-setting emulsified asphalt (50% emulsion + 50’% water), and a conventional overlapping technique was used to place the hot side material on the following day. The end gate of the paver extended about 25 to 38 mm (1 to 1.5 inch) over the top surface of the previously placed material. The height of the uncompacted material above the previously placed material was about 6 mm (1/4 inch) for each 25 mm (1 inch) of compacted material placed. No luting was done. The joint was compacted from the hot side, overlapping the cold side of the joint approximately 152 mm (6 inch). This type of compaction, in which the major portion of the roller weight travels on the hot side, is believed to result into a good bond between the cold and hot sides of the joint@ 6). The compaction technique is shown in Figure 1.

LJCT 2 (3: 1 Taper Rolled from Cold Side)

The only difference between this method and LJCT 1 is that the rolling was done with a major portion of the roller wheel on the cold side with about 152 mm (6 inch) of the roller wheel on the hot side of the joint. This technique is believed to produce a “pinching” effect on the joint. However, timing in this type of rolling is critical. When the roller is operated on the cold side, the hot side undergoes cooling which can make it difficult to achieve the desired compaction level. The method is shown in Figure 1.

LJCT 3 (3: 1 Taper Rolled from Hot Side 152 mm away)

Compaction in this method was started with the edge of the roller about 152 mm (6 inch) from the joint on the hot side (Figure 1). Other than that, this method is similar to LJCT 1. The lateral pushing of the material toward the joint during the first pass of the roller is believed to produce a high density at the joint. This method is particularly recommended by some asphalt paving technologists for tender mix or thick lifts, which have the potential for the mix to be pushed towards the joint.

LJCT 4 (Taper Removed and Tack Coated)

In this method (Figure 2), the cold side unconfined edge was constructed with a 3:1 taper. Then the full width of the taper was removed on the following day with a cutting wheel attached to a motor grader. Since the material had cooled, the cutting was done very carefully, avoiding any disturbance to the lower lifts. The hot side material was then placed after applying a tack coat on the vertical face of the cut. Laydown and compaction were achieved as indicated in LJCT 1, that is, rolling of the joint was accomplished from the hot side. Initially, cutting could not be done in a straight line because the operator of the motor grader did not have experience in this operation. Later, a straight line cut was obtained.

LJCT 5 (Taper Removed but no Tack Coat)

This type of joint was constructed in the same way as LJCT 4 except that no tack coat was applied to the vertical face before placement of the adjacent hot lane.

LJCT 6 (3: 1 Taper with 25 mm Offset)

In this method, the cold side unconfined edge was constructed with a 25.4 mm (1 inch) vertical step (offset) at the top of the joint. The remainder of the joint was constructed with a 3:1 taper (Figure 2). The vertical face was not tacked, but the taper surface was tacked, before placement of adjacent hot material and subsequent rolling according to the method of LJCT 1 (rolling from hot side). The vertical step (offset) was formed by placing a 610 mm (2 feet) long piece of51 mmx51 mm (2 in. x 2 in.) angle iron under the drag device used to form the 3:1 taper. There was some pulling of the larger particles of aggregate, but the overall vertical step face was satisfactory.

LJCT 7 (Rubberized Asphalt Tack Coat)

The unconfined edge of the first paved lane adjacent to the joint was not provided with any taper in this experimental section. On the following day, a rubberized asphalt tack coat (Crafco pavement joint adhesive Part Number 34524) was applied on the face of the unconfined edge before placing the adjacent lane. The thickness of the tack coat was about 3 mm (1/8 in.). Laydown and compaction of the adjacent lane were achieved following the procedures in LJCT 1 (rolling from hot side).

As mentioned earlier, no luting was done on this entire project. It was observed from the cores taken on the joint that the hot lane overlap was about 3 mm to 5 mm (1/8 in. to 3/16 in.) higher than the cold mat after compaction in most test sections.

Pennsylvania

Two types of longitudinal joint construction techniques were used in the Pennsylvania HMA paving project in September 1994. The project is located on I-79 about three miles north of I-76 (Pennsylvania Turnpike) and I-79 junction. The entire paving was completed with a New Jersey type wedge joint. A 152-mm (500-feet) long control section using the conventional joint construction technique was built on the southbound lanes for comparison.

These two types of joints were constructed in the 38 mm (1-1/2 in.) thick wearing course which was placed on a 51 mm (2 in.) thick binder course. The wearing course mix composition is given in Table 1.

A Caterpillar paver was used on the project. Breakdown rolling was accomplished with a 10-ton Caterpillar dual-drum vibratory roller. Intermediate rolling and finish rolling was done with a 10-ton Gallion pneumatic- tyred roller and a 10-ton Caterpillar dual-drum vibratory roller (in static mode), respectively. The temperature of the HMA mix ranged from 146° to 152° C (295° to 305° F). The ambient air temperature during paving ranged from 9° to 22° C (48° to 72°F).

The two joint types were constructed as follows.

Conventional Joint (C)

The unconfined edge of the first paved lane did not receive any taper and, therefore, had its natural slope. The edge was tacked with an AC-20 asphalt cement. A conventional overlapping technique was used to place the mix in the adjacent lane which was placed after about a week. The end gate of the paver extended about 76 to 102 mm (3 to 4 in.) over the top surface of the previously compacted lane. Luting was done to bump back the coarse aggregate particles of the HMA mix from the cold (first paved) lane onto the edge of the hot lane. The joint was compacted from the cold side, overlapping the hot side of the joint approximately 152 mm (6 in.), using the breakdown roller in static mode.

Wedge Joint (W)

The longitudinal wedge joint consists of two overlapping wedges. A sloping steel plate was attached to the inside corner of the paver screed extension to form a 3:1 taper on the unconfined edge of the first paved lane. The inclined face of the taper was neither compacted nor tack coated. An infrared heater attached to the paver was used to heat the face of the taper when the adjacent mat was placed after about a week. The heater was turned off whenever the paver was stopped. LPG Vapor fired convection type ribbon burners in the infrared heater had a total capacity of 522,000 BTU/hour and heated a surface area381 mm x 1930 mm (15 in. x 76 in.). A surface temperature ranging from 1210 to 138° C (250° to 280° F) was obtained on the taper face.

Overlapping, luting, and compaction techniques for the wedge joint were similar to those used for the conventional joint described earlier.

TEST PLAN

152-mm (6-inch) diameter cores were obtained from the test sections in Colorado and Pennsylvania and tested in the NCAT laboratory for thickness and and bulk specific gravity (ASTM D2726). Air voids were calculated using the maximum specific gravity (Rice) data obtained from the two projects. The cores taken on the joint were sawed into cold (first lane) and hot (second lane) halves and bulk specific gravity (ASTM D2726) was measured for each half of all the cores. No bond strength measurements were made. For each project, mean and standard deviation of the densities were calculated for all test sections. Statistical analyses were done to rank the joint construction techniques based on the joint densities, and comparison of joint densities with cold and hot mat densities. For the Pennsylvania project, only the cold mat and the joint densities were used, since hot mat cores were not obtained. Eighteen cores were obtained from each of the test sections (except LJCT 7 from which no cores were obtained) in Colorado, six at a distance of 305 mm (1 foot) on either side of the joint, and six from directly over the joint. In the Pennsylvania project, twenty cores were obtained from each of the two sections, ten from directly over the joint, and ten at a distance of 305 mm (1 foot) from the joint in the cold mat (first lane).

TEST RESULTS AND ANALYSIS

Colorado

Table 2 shows the summary statistics for density and air voids of cores obtained from six different sections. No cores were obtained from Section LJCT 7 which used a rubberized asphalt tack coat. As expected, densities and air voids on the joint generally show higher standard deviation compared to those 305 mm (1 foot) away on either side of the joint. In all the sections, the joint density is observed to be lower than the cold and hot mat densities. Figure 4 compares the average joint density obtained in all sections.

Duncan’s Multiple Range Test was used to group different techniques. This procedure involves multiple comparison of treatment means and testing for equality of means. The joint construction technique represents the treatment in this case. Table 3 shows the ranking and grouping of different joints, based on Duncan’s Multiple Range Test ($\alpha = 0.05$) on joint densities. LJCT 6 produced the highest density, followed by LJCT 4. The other methods did not produce any significantly different results, except LJCT 1, which produced the lowest joint density.

To normalize the usual variation in the compaction levels from section to section, the joint densities were expressed as percentage of cold mat density, and the construction techniques were grouped accordingly (Table 3). No difference is observed among LJCT 2, 3, 4, and 6. However, the rankings show LJCT 5 and LJCT 1 produced greater difference in density between joint and cold mat than the other methods.

The rankings of the different techniques based on joint density expressed as percentage of hot mat density is also shown in Table 3. Again, this was done to normalize the usual variation in the compaction levels of the second (hot) lane from section to section. The groupings show that LJCT 6 produced the lowest difference between joint and hot mat density, and is ranked higher than the other methods, all of which fall in the same group. Table 3 also shows the groupings based on the density of cold half and hot half of the cores taken on the joint.

It should be noted that except for LJCT 4 and LJCT 5 wherein the 3:1 taper was removed, the core on the joint includes most of the material from the cold side (or the first lane paved) due to the taper.

Overall, it appears that the technique LJCT 6 (which consisted of 25 mm (1 in.) offset and a 3:1 taper) appears to be the best in terms of density (Table 3). This is followed by LJCT 4 in which the 3:1 taper with relatively low density was removed by a cutting wheel. Similar results were also obtained in Michigan and Wisconsin experimental sections involving the use of cutting wheel (4).

Among the three rolling techniques (LJCT 1, LJCT 2, and LJCT 3) attempted with a 3:1 taper on this project, rolling from the hot side (LJCT 1) gave the lowest density at the joint. This is unlike Michigan and Wisconsin projects where this rolling technique gave the highest density at the joint when no taper was provided at the edge of the first lane.

Pennsylvania

Table 4 shows the summary statistics of density and air void data obtained for the joint and cold mat cores. The standard deviation of density and air voids at the joint is higher than that for the cold mat 304 mm (12 in.) away from the joint. The difference is about the same for the two types of techniques: conventional (C) and wedge (W), used on this project.

Table 5 shows the relative ranking of the two joint construction methods based on density. The results obtained from the sampled cores do not show any significant difference between the two techniques based on joint density and joint density expressed as percentage of cold mat density.

VISUAL EVALUATION OF JOINTS

Both Colorado and Pennsylvania projects were constructed during the 1994 paving season. These projects were inspected visually after the first winter to evaluate the relative performance of different joint construction techniques. Both projects were evaluated by a team of at least four engineers in June 1995. The visual evaluation will be continued for about four more years.

Colorado

This project was inspected on June 23, 1995. The visual evaluation of the seven experimental sections is given in Table 6. Sections LJCT 1 and LJCT 2 have longitudinal cracks

152 mm (6 in.) away from the joint in the cold side. None of the joints have developed any cracking (except localized cracks in LJCT 4 and LJCT 5) after the first winter. Some sections are exhibiting slight to moderate ravening on the cold side adj scent to the joint. Sections LJCT 6 and LJCT 4 do not exhibit any ravening at this time. Many sections are showing snow plow damage on the hot side of the j oint. It is probably due to the fact that the hot side overlap on the cold side after compaction was about 3 to 5 mm (1/8 to 3/16 inch) high, and, therefore, was scrapped off by the snow plow.

According to the evaluators, LJCT 6 was considered the best section in appearance followed by LJCT 4. It should be noted that LJCT 6 has the highest density as well followed by LJCT 4. It should be noted that the joints in LJCT6 and LJCT4 were rolled from the hot side.

Among the three rolling techniques (LJCT 1, LJCT 2, and LJCT 3) LJCT 3 (rolling from the hot side 152 mm from the joint) appears to be the best at this time. LJCT 3 also has the highest density of the three techniques (Table 3).

The advantages of applying a tack coat, if any, whether conventional emulsified asphalt as in LJCT 4 or rubberized asphalt as in LJCT 7, are likely to be evident after a few years.

At this time, the performance or ranking of the joints seems to have been influenced by the overall density at the joint. The joints with high densities show better performance than those with relatively low densities. It is quite likely that the rankings may change based on the long-term field performance (in terms of cracking, ravening and surface texture at the joint).

Pennsylvania

This project was inspected on June 14, 1995. After one relatively mild winter, both types of joint (conventional and wedge) were performing equally well. There was no cracking at the joint nor any significant ravening adjacent to the joint at the time of inspection. It is interesting to note that both joint types have comparable densities (Tables 4 and 5).

CONCLUSIONS

The following conclusions can be made based on the statistical analysis of test results obtained from the cores and the visual evaluation of different j oint types after one winter.

1. Of the seven different types of longitudinal joint construction techniques evaluated in the Colorado project, the method LJCT 6 (consisting of 3:1 taper with a 25-mm (1-inch) offset and tack coat on the taper) appears to be the best, followed by the method LJCT 4 (consisting of 3:1 taper which was removed by a cutting wheel and tack coated).
2. Of the three rolling techniques tried in the Colorado project, the method LJCT 3 (rolling from the hot side 152 mm or 6 in. from the joint) seems to be the best at this time.
3. The advantages, if any, of applying light or heavy tack coat (such as rubberized asphalt in LJCT 7) on the unconfined edge of the first lane will most likely be evident after a few years.
4. There is no significant difference in the performance of conventional joint and New Jersey type wedge joint in the Pennsylvania project after one relatively mild winter.
5. The performance or ranking of the joints on both Colorado and Pennsylvania projects after one winter seems to have been influenced by the overall density at the joint. The joints with

high densities show better performance than those with relatively low densities. These rankings are likely to change in the future based on the long-term performance (in terms of cracking and ravening).

ACKNOWLEDGEMENT

This project was sponsored by the NAPA Education Foundation. The cooperation of personnel from the Colorado Department of Transportation, and IA Construction Corporation is greatly appreciated. Thanks are due to Bob Johnson, Steve Horton, Donna Harmelink, Tim Aschenbrener, Charles MacKean, Scott Shuler, Carl Lubold, Earl Neiderhaiser, Red Brubaker, and Frank Piedimonte for assistance in monitoring and evaluating the two projects.

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LIST OF TABLES

Table 1. Composition of Mixtures used in Colorado and Pennsylvania

Test	Colorado	Pennsylvania
A. Mix Gradation:		
Percent Passing		
19 mm (3/4 in.)	100	
12.5 mm (1/2 in.)	83	100
9.5 mm (3/8 in.)	74	97
4.75 mm (No. 4)	60	67
2.36 mm (No. 8)	44	45
1.18 mm (No. 16)		30
0.6 mm (No. 30)	20	18
0.3 mm (No. 50)		13
0.15 mm (No. 100)		7
0.075 mm (No. 200)	4.0	4.0
B. Asphalt Content	5.0	6.3
C. Asphalt Cement Grade	AC-20	AC-20

Table 2. Summary Statistics for Density and Air Voids of Cores from Different Joints (Colorado Project)

Joint No./ Location	Density kg/m^3		Theoretical Maximum Density kg/m^3	Air Voids	
	Mean	Std.Dev.		Mean	Std.Dev.
LJCT1					
Joint	2142	29	2462	13.01	1.20
Cold Mat	2244	16	2469	9.10	0.64
Hot Mat	2274	12	2456	7.40	0.49
Cold Half	2097	29	2469	15.1	1.17
Hot Half	2183	32	2456	11.1	1.28
LJCT 2					
Joint	2153	6	2462	12.54	0.25
Cold Mat	2220	12	2469	10.09	0.50
Hot Mat	2290	25	2456	6.77	1.02
Cold Half	2095	36	2469	15.2	1.46
Hot Half	2197	19	2456	10.6	0.76
LJCT 3					
Joint	2165	20	2462	12.08	0.82
Cold Mat	2227	15	2469	9.82	0.61
Hot Mat	2301	14	2456	6.32	0.59
Cold Half	2126	37	2469	13.9	1.49
Hot Half	2203	6	2456	10.3	0.24
LJCT 4					
Joint	2183	28	2456	11.12	1.16
Cold Mat	2235	8	2456	8.99	0.31
Hot Mat	2280	15	2456	7.19	0.59
Cold Half	2141	28	2456	12.8	1.15
Hot Half	2222	12	2456	9.5	0.51
LJCT 5					
Joint	2167	24	2456	11.77	0.96
Cold Mat	2247	9	2456	8.53	0.39
Hot Mat	2281	14	2456	7.15	0.58
Cold Half	2132	42	2456	13.2	1.69
Hot Half	2200	16	2456	10.4	0.64
LJCT 6					
Joint	2230	29	2456	9.22	1.20
Cold Mat	2296	17	2456	6.50	0.69
Hot Mat	2273	10	2456	7.45	0.41
Cold Half	2193	23	2456	10.7	0.92
Hot Half	2260	27	2456	8.0	1.09

Table 3. Ranking Order of Joints based on Duncan Grouping of Joint Densities (Colorado Project)

Basis of Ranking	Joint No./LJCT	Mean Value	Grouping
Density at Joint	6	2227	A
	4	2177	B
	5	2162	B C
	3	2158	B C
	2	2148	B C
	1	2135	c
Joint Density as a Percentage of Cold Mat	4	97.62	A
	3	97.17	A
	6	97.07	A
	2	96.97	A
	5	96.40	A B
	1	95.38	B
Joint Density as a Percentage of Hot Mat	6	98.05	A
	4	95.72	B
	5	94.97	B
	1	94.15	B
	3	94.05	B
	2	94.00	B
Density of Cold Half of Joint	6	2193	A
	4	2141	B
	5	2132	BC
	3	2126	BC
	1	2097	c
	2	2095	C
Density of Hot Half of Joint	6	2260	A
	4	2222	B
	3	2203	BC
	5	2200	BC
	2	2197	BC
		2183	r-

Note: Means within the same group do not differ at significance level (α) of 0.05

Table 4. Summary Statistics for Density and Air Voids of Cores from Different Joints (Pennsylvania Project)

Joint No./ Location	Density kg/m^3		Theoretical Maximum Density kg/m^3	Air Voids	
	Mean	Std.Dev.		Mean	Std.Dev.
c					
Joint	2112	30	2400	12.0	1.20
Cold Mat	2213	20	2400	7.8	0.63
Cold Half	2063	62	2400	14.1	1.76
Hot Half	2122	44	2400	11.6	1.83
W					
Joint	2107	30	2400	12.2	1.35
Cold Mat	2187	20	2400	8.9	0.93
Cold Half	2057	44	2400	14.3	1.83
Hot Half	2136			11.0	2.09

Table 5. Ranking Order of Joints Based on Duncan Grouping of Densities (Pennsylvania Project)

Basis of Ranking	Joint Type	Density kg/m^3 Mean Value	Grouping
Density at Joint	C	2112	A
	w	2107	A
Joint Density as a Percentage of Cold Mat	w	96.36	A
	c	95.48	A
Density of Cold Half of Joint	c	2063	A
	w	2057	A
Density of Hot Half of Joint	c	2122	A
	w	2136	A

Note: Means within the same group do not differ at significance level (α) of 0.05

Table 6. Visual Evaluation of Longitudinal Joints (Colorado Project)

Section	Technique Used	Cracking at the Joint	Ravening of Adjacent Mat	Comments
LJCT 1	3:1 taper; rolling from hot side	None	Slight to moderate (cold side) - 100%	Cold Side has longitudinal crack 152 mm (6 in.) away from the joint; ravening between this crack and joint; snow plow damage on the hot side of the joint.
LJCT 2	3:1 taper; rolling from cold side	None	Slight to moderate (cold side) - 100%	Same as above, general condition slightly worse than LJCT 1.
LJCT 3	3:1 taper; rolling from hot side 152 mm (6 in.) away	None	None to slight (cold side) - 20%	Snow plow damage on the hot side; general condition appears better than LJCT 1 and LJCT 2.
LJCT 4	3:1 taper removed; vertical face not tacked	One localized crack 3 m long	None	Snow plow damage on the hot side; cutting wheel was not operated straight; general condition next to LJCT 6 which is the best in June 1995.
LJCT 5	3:1 taper removed; vertical face not tacked	Two localized cracks, each about 3 m long	None to slight (cold side)	Appears slightly worse than LJCT 4.
LJCT 6	3:1 taper with 25 mm (1 in.) offset	None	None	Some snow plow damage on the hot side; very smooth joint; best so far.
LJCT 7	Rubberized asphalt tack coat	None	None to slight (cold side)	General condition similar to LJCT 3 at this time.

LIST OF FIGURES

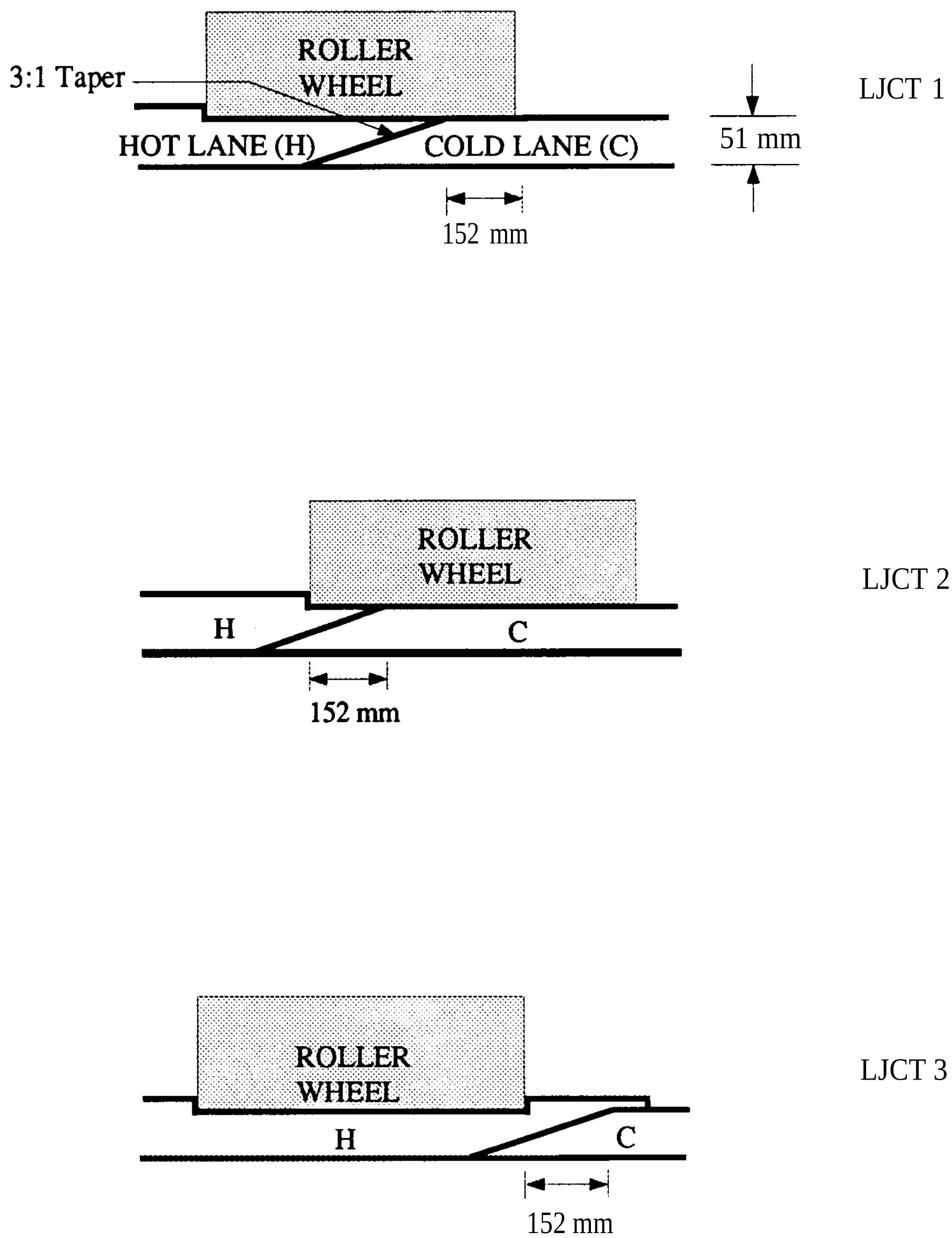
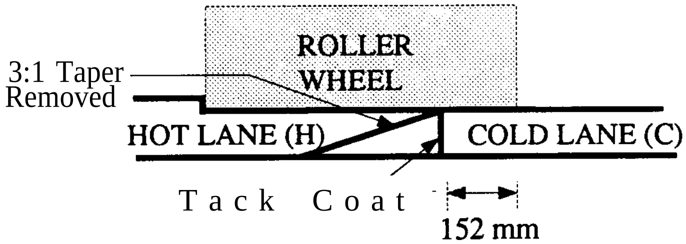


Figure 1. Joint Construction and Rolling Techniques LJCT 1 through LJCT 3 (Colorado Project)

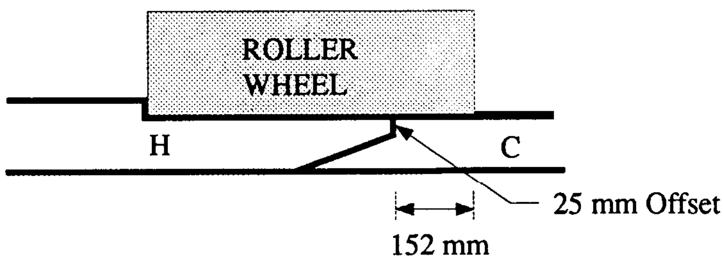
LJCT 4



LJCT 5

SAME AS ABOVE EXCEPT NO TACK COAT ON VERTICAL CUT FACE

LJCT 6



LJCT 7

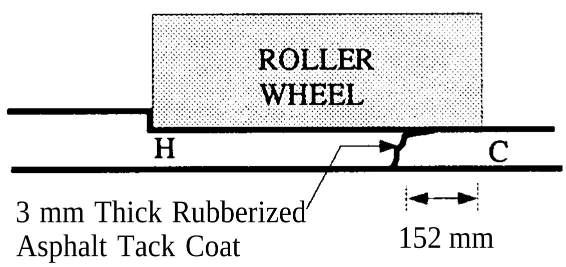
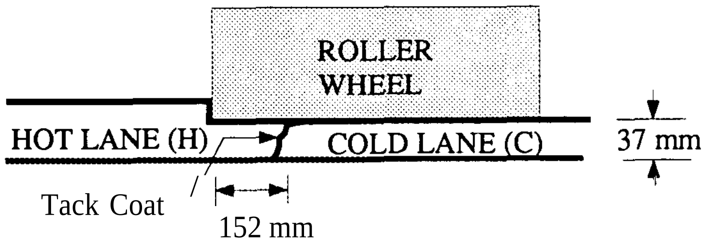
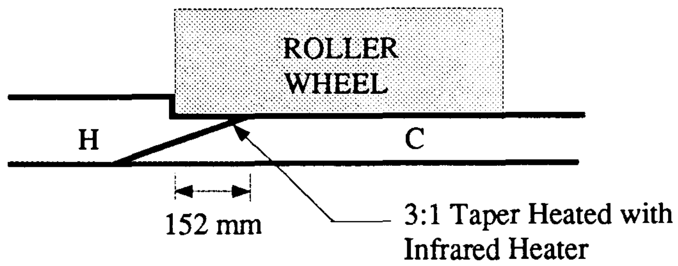


Figure 2. Joint Construction and Rolling Techniques LJCT 4 through LJCT 7 (Colorado Project)



CONVENTIONAL JOINT (C)



WEDGE JOINT (W)

Figure 3. Joint Construction and Rolling Techniques (Pennsylvania Project)

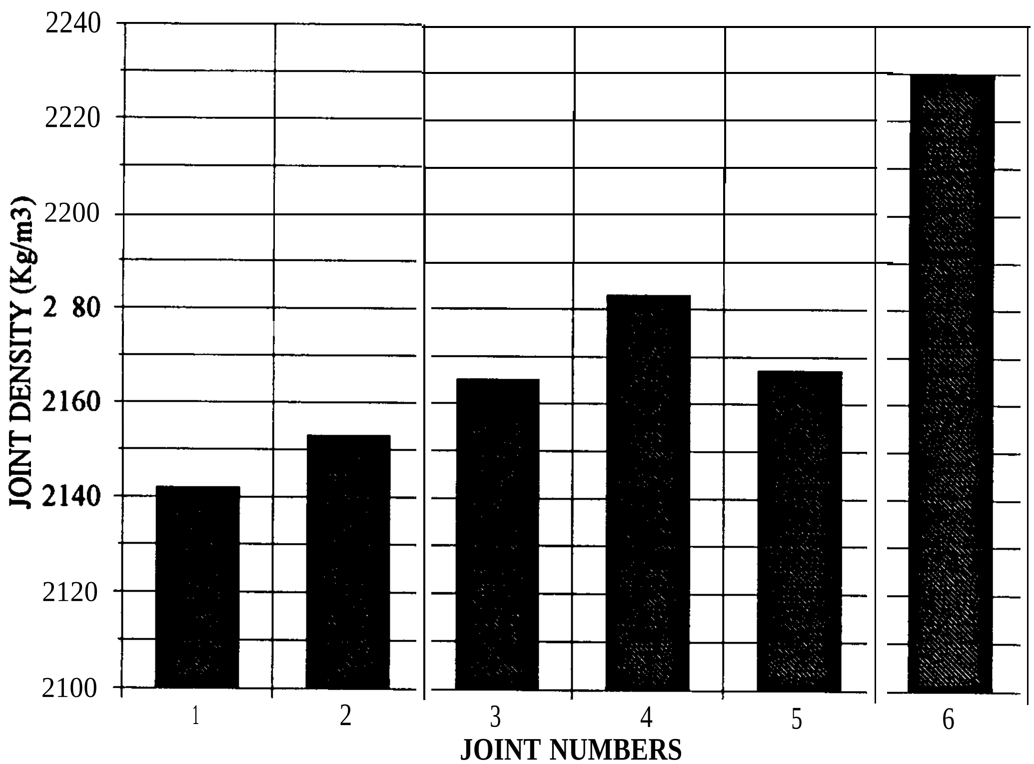


Figure 4. Comparison of Joint Densities (Colorado Project)