New vibratory rollers for longitudinal joint compaction

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ABSTRACT: Insufficient compaction of HMA pavements along the longitudinal joint is a leading cause of premature pavement failure in the United States (US). The challenge in constructing durable longitudinal joints has always been to construct a tight, dense longitudinal joint that matches the existing pavement elevation and is aesthetically pleasing. Low pavement densities and longitudinal cracks resulting from poor joint compaction lead to raveling and subsequent damage to the underlying pavement structure due to moisture penetration along the joint. In the US, some State Departments of Transportation have introduced longitudinal joint density specifications based on different joint geometries and rolling patterns that use conventional rollers. An innovative vibratory three wheel roller was recently developed in Japan. It was specifically developed to improve compaction efficiency and to meet or exceed new joint density specifications. The three-wheel roller has a unique vibratory system that incorporates conventional circular vibration and oscillatory vibration force. This new roller weighs approximately 9 tonnes; much less than conventional static three-wheel rollers that typically weigh 10 to 15 tonnes. First, this paper will present joint density results obtained by the new three-wheel roller on various test sections. Measured pavement density results show that the joint densities achieved are similar to the densities obtained on the mainline road sections. Second, improvement of joint quality compared to the use of conventional rollers for compaction test on a bridge is reported.

KEY WORDS: Longitudinal Joint, compaction, density, three-wheel roller, pneumatic tire roller.

1 INTRODUCTION

Longitudinal joints are the length-wise interface constructed between adjacent pavement lanes paved at different times. If the compaction and bond along the joint are insufficient, it will crack and erode by raveling. Once hot mix asphalt (HMA) mix along joint begins to erode and moisture penetrates into the underlying layer, raveling along the joint is accelerated and the pavement will deteriorate rapidly if effective treatments are not applied. It is reported in Canada that 40 to 50 percent of crack repairs are associated with the longitudinal joint (Marks, et al. 2009). Quality of the joint is one of the most significant factors affecting pavement life and life cycle cost. Various research has been conducted in North America to improve longitudinal joint construction equipment and construction practices. Asphalt pavement associations in North America such as the Asphalt Institute (AI), National Pavement Association (NAPA), and the Canadian Technical Asphalt Association (CTAA) have organized training courses and published construction guideline handbooks to promote quality awareness and teach proper construction methods. The National Center for Asphalt Technology (NCAT) conducted comprehensive research on longitudinal joint construction that included studying the shape of pavement edge for the first lane, joint forming equipment, and studies of various rolling patterns (Kandahl and Mallick, 1996, Kandhal et al. 2002). NCAT’s research resulted in a tapered joint called the notched-wedge joint with 25 mm vertical step at the top and 3:1 taper in the horizontal to vertical direction (3H:1V). The taper was intended to improve traffic safety, especially for motorcycles when the first lane is left open during construction. A couple different pieces of joint-shaping equipment resulted from the NCAT studies such as the Joint Maker and a cutting wheel attachment. The Joint Maker had a tendency to drag HMA mix often leaving high air voids in the HMA at the tapered end of the wedge joint. Cutting wheels mounted alongside the roller drum were not well accepted because it requires highly skilled roller operators to steer straight along the pavement edge and additional cost to recover and recycle the HMA after it is trimmed from the pavement edge. Rubberized joint sealants, tack coat, and asphalt tape placed along vertical portion of the wedge joint was also tested. However, the extra cost for the asphalt tape, placement equipment and labor became a bottleneck in HMA production. A new rolling pattern for the longitudinal joint was proposed that promoted vibratory rolling from the hot side with the drum edge about 150 mm from the joint on the hot side and the second pass would overlap the cold side by about 150 mm. The density achieved using this rolling pattern was 2 % lower than density measured in the main pavement. In Canada, it was reported that the hot joint is the best construction method to build durable longitudinal joints. Joint quality can be further improved by paving in echelon or tandem paving with a material transfer vehicle (Marks et al. 2009, Uzarowski and Henderson, 2009). Improvement of cold joint construction was also discussed and proposed, because it is still a majority of the longitudinal joint construction in North America. Infrared joint heaters have been used on some paving jobs. Heating time needs to be carefully controlled because it may burn the asphalt binder in the HMA, making it brittle. A new rolling pattern proposed compaction from the hot side by positioning the drum to overhang a short distance over the unsupported edge of the joint. Rolling from the hot side was promoted because the time available for compaction of HMA is greatly reduced when compaction starts from cold side of the pavement and the hot side is cooling as the cold side is rolled. In Japan weak longitudinal joints are also a major quality issue. As a result, proper joint construction guidelines are published in pavement construction handbooks.

One such method proposes using wooden forms that are placed and anchored along the unsupported edges of a HMA pavement when the first lane is constructed. This makes the laydown process easier because the edge of the pavement is straight and the forms make it easier to control the depth of mix being placed by the paver screed. To finish longitudinal and transverse joints, plate vibratory compactors are used, although there is no density specification at joints.

In this paper, the compactive effort of a new vibratory roller developed to improve quality of longitudinal joints is reported. This new roller design can be used to improve the quality of both hot and cold longitudinal joints, the authors will discuss the equipment, completed test sections, and applications of this new roller to joint construction.

2 COMPACTION EQUIPMENTS

Sakai Heavy Industries developed two new rollers to improve joint density. One is a vibratory three-wheel (VTW) roller and the other is a vibratory pneumatic tire (VPT) roller. In this paper, both rollers are evaluated.

This VTW roller has vibration mechanisms in all three drums and either one of the front wheels can be selected to vibrate, or any combination of three drums can be selected to vibrate at one time. The operator can easily choose the vibration mode using one switch at the driver's position. The vibration system of the VTW roller can generate circular vibration and oscillatory vibration which generates a back and forth movement rubbing on the pavement surface. The operator can choose one of these two kinds of vibration at any time. This roller can also be used as a static three-wheel (STW) roller without vibration. All combinations of vibration settings can be selected using one switch at the driver's position. The specifications of the VTW roller are shown in Table 1 and the picture in Figure 1. The eccentric weights used for vibration are shown in Figure 2. The oscillatory vibration and circular vibration result from changing the position of the eccentric weight as shown in Table 1. The operating weight of the VTW roller is 8,730kg. The VTW is smaller and lighter than a conventional STW roller. The compaction width is 2,100mm as same as a conventional STW roller. In Japan, a conventional STW roller is used to secure smoothing of surface as break-down roller, however, the VTW can be used as a break-down, intermediate and finish roller for asphalt pavement compaction and aggregate base course compaction. Independent drum vibration control on the VTW roller was designed to allow easy control and compaction of hot and cold joints and edges.

The VPT roller has seven pneumatic tires that can operate in static mode or they can be set to vibrate at a frequency of 40 Hz (2,400 vpm) with a choice of four vibration amplitude settings (Nose, et al. 2006).

Figure 1: VTW roller : MW700.

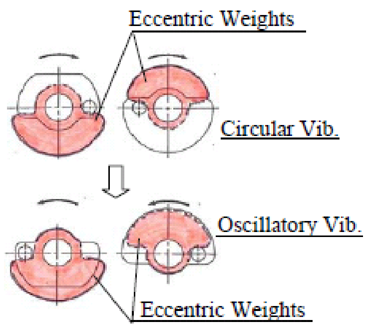


Figure 2: Eccentric weights in the vib-equipment.

Table 1: Specifications of VTW roller.

WEIGHTS	Operating weight	kg (lb)	8,730 (19,246)
DIMENSIONS	Overall length / width / hight	mm (in)	4,700 (185) / 2,100 (83) / 3,065 (121)
	Compaction width	mm (in)	2,100 (83)
	Drum width / Drum diameter for front roll	mm (in)	1,400 (55) / 550 (22) X 2
	Drum width / Drum diameter for rear roll	mm (in)	1,400 (55) / 1,100 (43) X 1
PERFORMANCE	Static linear pressure for front roll	N / cm (lb / in)	392 (224)
	Static linear pressure for Rear roll	N / cm (lb / in)	392 (224)
	Dynamic linear pressure for front roll	N / cm (lb / in)	1,079 (617)
	Dynamic linear pressure for Rear roll	N / cm (lb / in)	1,206 (689)
	Max. centrifugal force for oscillatory vibratio	kN (lb)	145 (32,606)
	Frequency for oscillatory vibration	Hz (vpm)	43 (2,580)
	Max. centrifugal force for circular vibration	kN (lb)	90 (20,238)
	Frequency for circular vibration	Hz (vpm)	43 (2,580)
FLUID CAPACITY	Sprinkler tank	L (gal)	680 (179)

3 TEST SECTION

In Jul 2009, the VTW roller and the VPT roller were used in the construction of a test section at Obayashi Corporation's yard. The purpose of this test was to compare the compactive effort and characteristics of the VTW roller with a combination of a conventional STW roller and static pneumatic tire (SPT) roller. The existing pavement surface was milled to a depth of approximately 80 mm. The total test section consisted of an area 45 m long and 3.7 m wide. The width was divided into two parallel lanes, each 1.85 m wide. An asphalt emulsion tack coat was applied to the milled surface. The HMA was delivered to a VOGEL 1603-1 paving machine (Figure 3). Both the VPT and the SPT rollers were used behind the VTW and STW rollers (Figure 3 and 4).

Figure 3: Paver (right) and VTW roller (left).

Figure 4: VPT roller.

The HMA mixture was a recycled, dense-graded hot mix asphalt (13), and the percent of recycled material in the mix was 60 %. The job mix formula, including aggregate gradation, binder content, and theoretical maximum density (TMD) information is shown in Table 2. The target density level was 93.3 % of TMD.

Table 2: Job Mix Formula.

	Sieve Size (mm)	Percent Passing (%)	Gradation Requirements (%)	Sieve Size (mm)	Percent Passing (%)	Gradation Requirements (%)
Aggregate Gradation	19	100	100	0.6	22.4	18~30
	13.2	98.6	95~100	0.3	16.3	10~21
	4.75	66.8	55~70	0.15	11.1	6~16
	2.36	44.0	35~50	0.075	5.9	4~8

Mix Properties		
Item	Value	Specification
Asphalt Contents (%)	5.5	-
Marshall Density (g/cm3)	2.388	-
Air Voids (%)	3.9	3~6
Voids Filled with Asphalt (%)	76.5	70~85
Marshall Stability (kN)	9.92	Over 4.9
Flow Value (1/100cm)	31	20~40
Maximum Theoretical Density (g/cm3)	2.484	-

The internal temperature of the HMA immediately behind the paver screed was approximately 145 °C. The internal temperature at the time of first pass of the breakdown roller and the finish roller was approximately 140 °C and 110 °C, respectively, as shown in Table 3. All of these temperatures were measured using a thermocouple sensor. The rolling patterns used by the four rollers are shown in Table 3. The breakdown roller for each section was a STW or a VTW roller. In case of the VTW roller section, first 2 passes of this roller were in static mode and the next 4 passes were done in oscillatory vibration mode. The finish roller for each section was a SPT or a VPT roller. In the case of the VPT sections, the first 2 passes were made in static mode and the next 4 passes were completed in vibration mode 2. Each roller's speed was 1.5 km/h. All the rollers compacted from cold side 200 mm (8 in) away from longitudinal joint.

Table 3: Rolling Pattern and Percent of TMD.

Section No.	Rolling Process	Roller Type (Model)	Roller Mass (kg)	Operating Speed (km/h)	Number of Roller Passes	Mat Temp. at the First Pass (℃)	Avg. Percent of TMD (%)	Number of Cores	Fnished thicness (mm)
1	Breakdown	VTW (MW700)	8,730	1.5	2 Static 4 Vibratory Oscillation	146	93.3	8	98
	Finish	SPT (T2)	13,480	1.5	6	121			
2	Breakdown	STW (R2)	8,730	1.5	6	145	93.3	8	82
	Finish	SPT (T2)	13,480	1.5	6	119			
3	Breakdown	VTW (MW700)	8,730	1.5	2 Static 4 Vibratory Oscillation	134	93.9	8	75
	Finish	VPT (GW750)	9,100	1.5	2 Static 4 Vibratory Mode 2	104			

Table 3 shows the average percent of TMD based on eight core densities taken from each section. The minimum required level of TMD was 93.3 % and all sections met or exceeded this requirement.

The density distribution in the three sections is shown in Figure 5. The horizontal axis represents distance of the core from the longitudinal joint. The vertical axis indicates the percent of TMD. In Figure 5, the 5 cm point on the horizontal axis is the vicinity of the longitudinal joint and the 100 cm point is the center of the lane. The center of the lane satisfied the required level of 93.3 % TMD in all sections. At the vicinity of longitudinal joint, the percent of TMD in section 3 (a combination of VTW and VPT) was the highest, and was the roller combination that satisfied the required density of 93.3 % TMD. Section 1 (a combination of VTW and SPT) was the second highest average density at 92.9 %. Section 2 (a combination of conventional STW and SPT) was 92.5 % TMD. In addition, Section 3 had a small difference in density between the center and the joint by + 0.4 % (joint is high). Section 1 had the second by - 0.7 % (center is high). Section 2 had the largest difference in density between the center of the lane and the joint with a 1.4 % difference (center is high).

The depth of texture is shown in Figure 6. The depth of texture means texture of pavement surface. Sand volumetric technique was used at center of the lane for measuring the openness or surface texture of pavement. The tighter the pavement surface (fewer air voids at the surface), the more impermeable the surface of the pavement is to water. Test section 3 showed the tightest, most impermeable surface as measured using the sand volumetric technique.

As a result, considering the density of the longitudinal joint, average density, uniformity and surface texture, the combination of the VTW and VPT rollers was more effective than the conventional STW and SPT rollers (Kimura, et al. 2009).

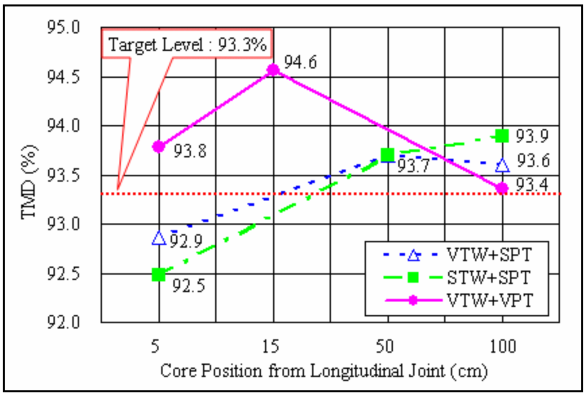


Figure 5: Distribution of density.

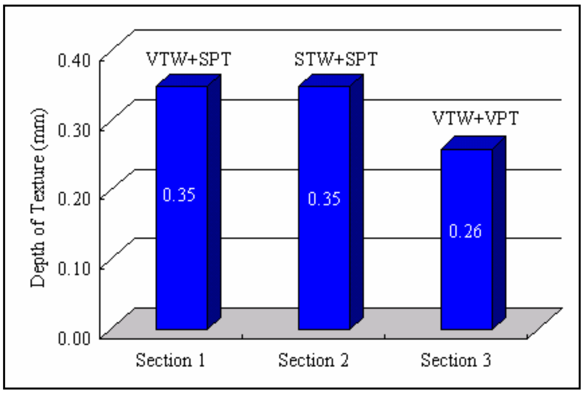


Figure 6: Depth of texture.

4 APPLICATIONS FOR STONE MASTIC ASPHALT PAVEMENT ON STEEL BRIGDE

Stone mastic asphalt (SMA) pavement mixes have a large percentage of inter-granular void space that is filled with asphalt cement, fiber, mineral fillers and air. After compaction, the SMA mix must be impermeable to water to prevent the steel bridge from rusting. SMA pavement was used as the base layer, binder course on the steel bridge. Compaction is very important for the performance of SMA.

In Sep 2009, the VTW roller and the VPT roller were used for compacting SMA on a bridge on the national highway at Miyagi prefecture. The purpose of this field test was to compare the effect of compaction between the VTW roller and a combination of a conventional STW roller and SPT roller.

The compacted layer thickness was 40 mm. There were three sections and each area was 20 m long and 5 m wide. The SMA was delivered to a paver VOGEL super 2100 (Figure 7). The VTW roller (Figure 8) was used the Break Down, The VPT roller (Figure 9) was used the intermediate position behind the VTW and STW rollers.

Figure 7: Paver.

Figure 8: VTW roller.

Figure 9: VPT roller.

The job mix formula including aggregate gradation, binder content and theoretical maximum density (TMD) is shown in Table 4. The target density level was 93.3 % of TMD.

Table 4: Job Mix Formula.

	Sieve Size (mm)	Percent Passing (%)	Sieve Size (mm)	Percent Passing (%)
Aggregate Gradation	19	100	0.6	24.1
	13.2	99.8	0.3	16.8
	4.75	47.5	0.15	12.7
	2.36	32.8	0.075	10.6

Mix Properties		
Item	Value	Specification
Asphalt Contents (%)	6.4	-
Marshall Density (g/cm3)	2.410	-
Air Voids (%)	2.5	2~3
Voids Filled with Asphalt (%)	85.7	-
Marshall Stability (kN)	8.15	Over 6.0
Flow Value (1/100cm)	41	-
Maximum Theoretical Density (g/cm3)	2.473	-

The surface temperature of the SMA pavement immediately behind the paver screed was approximately 157 °C. The surface temperature at the time of first pass of the breakdown roller and the second roller was approximately 152 °C and 111 °C, respectively, as shown in Table 5. All of these temperatures were measured using an infrared thermometer.

The rolling patterns used by the four rollers are shown in Table 5. The breakdown roller for each section was a STW or a VTW roller. In the case of VTW roller sections, all passes of the VTW were made in oscillatory vibration mode. The second roller for each section was a VPT roller. Amplitude setting number one was used in section 1, amplitude setting 2 in section 2 and amplitude setting 4 in section 3. The finish roller for each section was VT roller. All passes of this roller were static mode. Each roller traveled at 3 km/h and all the rollers compacted from cold side 200 mm (8 in) away from longitudinal joint.

Table 5: Rolling Patterns and Percent of TMD.

Section No.	Rolling Process	Roller Type (Model)	Roller Mass (kg)	Operating Speed (km/h)	Number of Roller Passes (pass)	Vib. Mode	Mat Temp. at the First Pass (℃)	Avg. Percent of TMD (%)	PQI Point	Fnished thicness (mm)
1	Breakdown	STW (MW700)	8,730	3	8	Static	152	93.9	20	40
	Second	VPT (GW750)	9,100	3	8	Vib.1st Amp.	111			
	Finish	VT (SW650)	7,100	3	8	Static	77			
2	Breakdown	VTW (MW700)	8,730	3	8	Oscillation	152	94.7	20	40
	Second	VPT (GW750)	9,100	3	8	Vib.2sd Amp.	111			
	Finish	VT (SW650)	7,100	3	8	Static	77			
3	Breakdown	VTW (MW700)	8,730	3	8	Oscillation	152	95.3	20	40
	Second	VPT (GW750)	9,100	3	8	Vib.4th Amp.	111			
	Finish	VT (SW650)	7,100	3	8	Static	77			

Table 5 also shows the average percent of TMD based on 20 densities measured in each section by an electromagnetic density gauge (Transtec's Pavement Quality Indicator – PQI gauge). The required density in these test sections was 93.3 % of TMD.

The density distribution in the three sections is shown in Figure 10. The horizontal axis indicates the density measurement location relative to the center of the pavement. The vertical axis indicates the percent of TMD. The average of density of all sections met or exceeded the required level, however, the measured density values are different. In section 3 using a combination of VTW and VPT on amplitude setting 4, the percent of TMD at the longitudinal joint was the highest of all test sections and was the only longitudinal joint that exceeded the minimum requirement of 93.3 %. At the vicinity of longitudinal joint, the percent of TMD in Section 3 was the highest of all test sections and at the center of lane, the percent of TMD in Section 3 was the highest of all test sections. In test Section 2 at the edge of the bridge, using a combination of a VTW and a VPT roller on amplitude setting 2, the percent of TMD was the highest, and exceeded the required level of 93.3 % TMD.

Section 1 had the smallest difference in density between the center of the lane and the joint by at 2.3 % (center is high). Section 2 had a difference of 3.6 % (center is high) and Section 3 had a difference of 3.7 % (center is high).

As mentioned above, the SMA pavement requires high density and Section 3 resulted in the highest density results and the most favorable visual inspection of the pavement surface. The surface of the center of the lane is shown in Figure 11. An excellent surface was obtained in the Section 3. The surface condition around the longitudinal joint is shown in Figure 12-A. The vertical line indicated by the pen in Figure 12-A is aligned with the longitudinal joint. The cold side is on the left, and the hot side is on the right. The longitudinal joint is seamless. The photo of the same longitudinal joint taken in the horizontal direction is shown in Figure 12-B. The pen points along the longitudinal joint. The cold side is on the left, and the hot side is to the right. The longitudinal joint is smooth.

The combination of a VTW and a VPT roller proved most effective to compact the longitudinal joint considering density and surface texture of the final HMA mat.

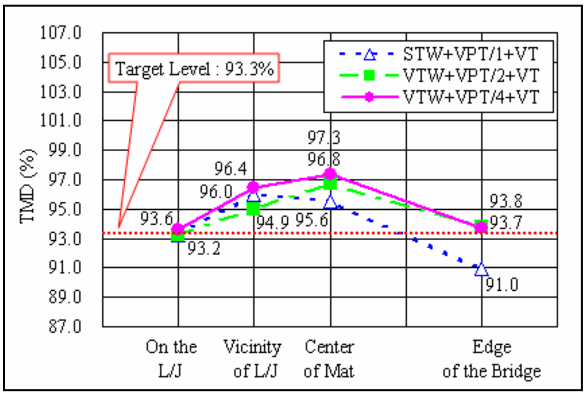


Figure 10: Distribution of density.

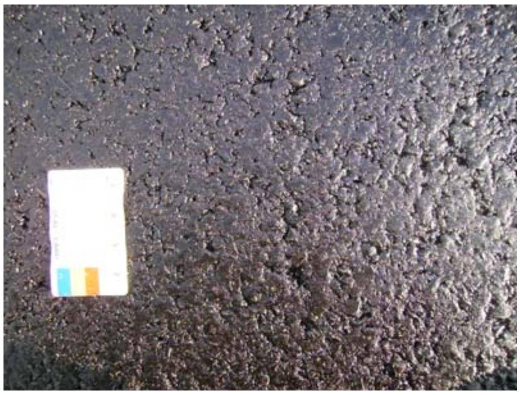
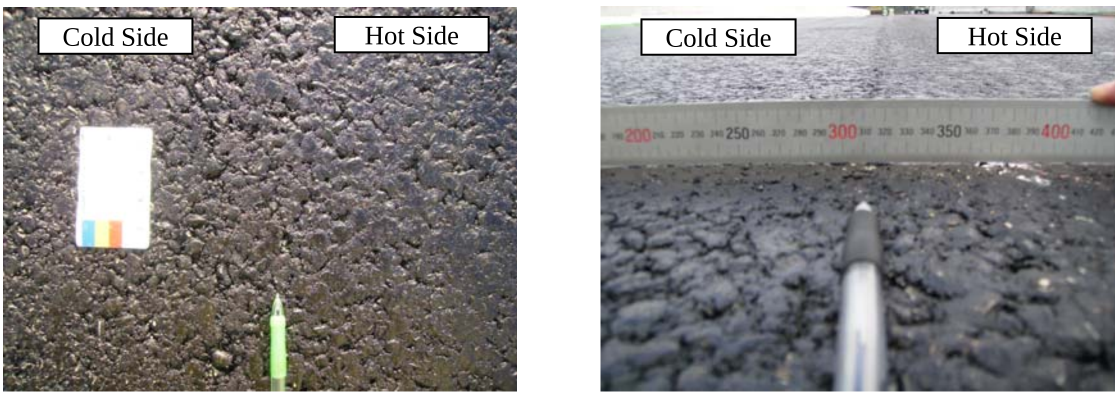


Figure 11: Surface condition of center of lane.



A: Top View

B: Side View

Figure 12: Surface condition of longitudinal joint.

5 CONCLUSIONS

Based on the field tests with the vibratory three-wheel (VTW) roller at Obayashi Corporation's yard and the national highway test sections at Miyagi prefecture, the following conclusions can be made.

5.1 Improvement of density

The VTW roller with oscillatory vibration mode,
1) improved density of the longitudinal joint.
2) produced uniform density between the longitudinal joint and center of lane.
3) can contribute to uniform of construction quality.
4) is more effective in combination with the VPT roller.

5.2 Improvement of surface texture

The VTW roller with oscillatory vibration mode,
1) improved a joint performance of the longitudinal joint..
2) improved a surface texture of the center of lane.
3) can contribute to improve of surface quality.
4) is more effective in combination with the VPT roller.

5.3 Total evaluations

The combination of The VTW roller and the VPT roller,
1) is effective for constructing a durable longitudinal joint.
2) can contribute to increase of life of the pavement and reduce maintenance costs.

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