Successful Compaction using Vibratory Pneumatic Tire Roller

Hitoshi Fujita[1], Yukinori Tsukimoto[2]

1. *SAKAI HEAVY INDUSTRIES,LTD. Tokyo Japan*
2. *SAKAI AMERICA, Inc. Adairsville GA U.S.A*

ABSTRACT

A vibratory pneumatic tire (VPT) roller has been developed in Japan. The effectiveness of this type of roller has come to light through a comparison test with the conventional static pneumatic tire roller. It was found that that VPT roller could achieve the required level of density in a HMA mix using fewer rolling passes and uniform density distribution throughout the depth of HMA lift. The combination of the kneading action of the pneumatic tires and the vibratory force applied through the pneumatic tires provides "the best compaction of HMA mixture". Recently the VPT roller has been used not only with the thick lift HMA mixture but also the thin layer HMA mixture or surface dressing like the chip seal, especially in Australia . In such cases the VPT roller provides good aggregates bonding and protects crashing of the aggregates and fretting of the aggregates. Finally, the usage of the VPT roller results in good performance of asphalt pavement construction.
Keywords: Compaction, Vibratory pneumatic tire roller, uniform density, chip seal, thick lift

1. INTRODUCTION

It is a pavement researcher's distress that good designed pavement does not always show good pavement performance. There is the construction stage between design and performance. In another words, pavement does not show good performance without good construction them. Most important factor of good construction will be good compaction of asphalt mixture. By decreasing 1% air void, the performance of pavement is improved 10% [1].

The contractor must pay severe attention to get the ideal density of the mix that is evaluated and judged as the best proportion at the mix design stage. They must select the best combination of rollers and use them with the appropriate condition. They must modify the compaction method according to the paving condition such as temperature, wind speed or under-layer condition. Also they must adjust the compaction method like the number of rolling passes or rolling speed according to the type of mixture or thickness of the mixture.

Furthermore reducing the number of rollers needed in the roller "train" behind the paver, reducing the number of roller passes of each roller, as well as achieving the desired degree of density immediately behind the asphalt paver while the mix temperature is high is the desire of an efficient asphalt paving contractor. New compaction devices such as the high frequency vibratory roller and the vibratory pneumatic tire roller (Nose et al 2003) [2] have been developed in order to achieve the required level of density in a more efficient, effective, and economical manner.

In this paper the outline of new developed VPT roller and the effectiveness of VPT roller for various type of asphalt mixture or various thickness of pavement lift are described.

2.OUTLINE OF VPT ROLLER

2.1.Detail of the Development

Until recently, three types of rollers were commonly used to compact asphalt mixtures:

static steel wheel rollers ; pneumatic tire rollers ; and vibratory steel wheel rollers . Vibratory rollers equipped with steel drums on both the front and rear axles and static pneumatic tire (SPT) rollers were commonly used on asphalt mixtures.

Most of the SPT rollers currently in use are in the weight range of 8,000 - 15,000 kg in an un-ballasted and ballasted condition, respectively. There are some larger SPT rollers in the weight range of 12,000 - 25,000 kg in an un-ballasted and ballasted condition, respectively. The development of large steel wheel vibratory rollers has resulted in a decrease in the population of the larger SPT rollers. However, SPT rollers are still beneficial for compacting asphalt mixtures. They achieve their compaction results through a combination of wheel load and tire inflation pressure.

There is an interaction that takes place between pneumatic tires and compacted materials called the "kneading effect", which is generated by the deformation and compression of the pneumatic tires. This kneading action can be simulated in a testing laboratory by a gyratory compactor compressing a cylindrical specimen while applying both shear and vertical compression force simultaneously . This compaction mode is very effective not only in compacting asphalt mixtures, but also in achieving a smooth surface on those materials.

The development of the VPT roller began in the mid - 1990's at Sakai Heavy Industries, Ltd., due to a customer's request for a machine that would successfully compact a newly designed asphalt emulsion cold mix containing Portland cement as an additive to provide a stiffer mix [1]. Many trials were conducted to find the best way to compact the new emulsified cold mix. At first, conventional steel wheel vibratory rollers equipped with different vibratory systems, including radial vibration with a single eccentric shaft and vertical vibration with dual eccentric shafts were tried. However, all of these rollers created hairline cracks on the surface of the material, which were unacceptable to the highway agency. Then, a large SPT roller weighing 25,000 kg (55,000 lb) was used for the breakdown (first) rolling process. A small combination roller weighing 2,500 kg (5,500 lb) with one vibratory steel drum and one set of pneumatic tires was employed for the finish (last) rolling process. Based on this round of testing, it was proposed that Sakai should develop a "hybrid" pneumatic tire roller with both static and vibratory capabilities.

In 1995, Sakai developed the first VPT roller and then improvement of the VPT roller was continued. Finally the fourth VPT roller called the Model GW750 was developed in 2003 [3]. This VPT roller equipped sufficient engine power to drive and vibrate both axles. It was equipped with seven tires: three tires on the front axle and four tires on the rear axle. The GW750 and a conventional SPT roller weighing 25,000 kg are shown side by side in FIGURE.1.

FIGURE.1 Conventional SPT static roller (left); fourth generation VPT roller (right).

2.2 Detail of VPT Roller

The VPT, named as GW750 is illustrated in FIGURE 2. The maximum mass with water capacity of 600 litters is 9,100 kg, and a wheel load per tires is 12.7 kN. Four different kind of centrifugal forces of 10 kN, 29 kN, 44 kN, and 78 kN are available, thus the dynamic load (the sum of static and dynamic load) per wheel are 14.1 kN, 16.8 kN, 19.0 kN, and 23.8 kN.

Tires with rolling width of 1950 mm in the other axle cover the gaps between adjacent tires in one axle. The articulated frame in the front and rear support three and four tires, respectively. Both of the tires on each axle is driven and vibrated by hydraulic motors. Variable vibration system is employed in an internal cylinder fixing the tires, and four different kinds of amplitude are available such as 0.2 mm, 0.5mm, 0.7mm, and 1.3mm. Pneumatic rubber tires are 14/70-20-12PR that is specially designed for improving smoothness and widely applied to the pneumatic rubber tire rollers in Japan. Detail of the specification of VPT roller is shown in TABLE 1

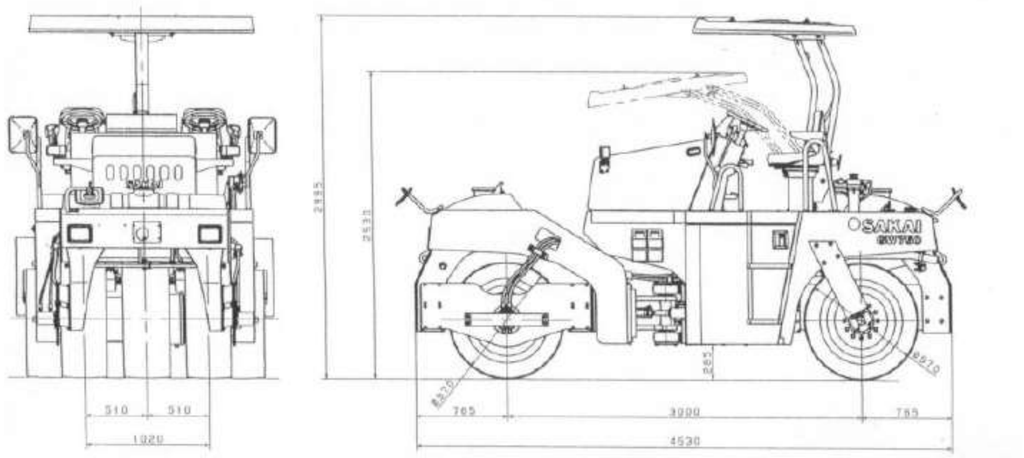


Figure 2. General view of VPT, GW750

TABLE 1 Detail of specification of VPT

WEIGHT with Awning	Gross	kg	9,100			
	Load on front axle	kg	3,900			
	Load on rear axle	kg	5,200			
SPEEDS (F&R) 1-2-3		km/h	0 - 3, 0 -5, 0 - 9			
VIBRATION	Amplitude	mm	0.2	0.38	0..51	0.71
	Centrifugal force	kN	11	22	34	45
	Frequency	vpm	2400			
MINIMUM TURNING RADIUS		Outer, m	5.4			
GRADABILITY		% (˚)	38 (21˚)			
ENGINE	Model		ISUZU "DD-4BG1T"			
	Type		Diesel Engine, Water-cooled, 4-cycle			
	Displacement	l	4329			
	Rated output	kW{PS}(HP)/min^{-1}	77 {105} (104) /2,300			
	Battery	V	24			
TRANSMISSION TYPE			Hydrostatic transmission			
VIBRATING SYSTEM		Transmission Type	Hydrostatic transmission			
		Vibrator	Eccentric shaft type (Variable)			
BRAKE SYSTEM		Service brake	Hydrostatic & mechanical, multi-wet disc type			
		Parking brake	Mechanical, multi-wet disc type (S.AHR)			
STEERING SYSTEM			Hydraulic type (Articulated type)			
TIRES (FRONT & REAR)			14/70-20-12PR			
SPRINKLER SYSTEM			Pressurized type (F&R)			
RELEASE AGENT SYSTEM			Pressurized type (F&R)			
FLUID CAPACITY	Fuel tank	l	130			
	Sprinkler tank	l	300 x 2			
	Release agent tank	l	20			

2.3 Mechanical Feature of VPT Roller

Among the benefits derived from the use of a Vibratory Pneumatic tire roller are the dynamic, instead of static, kneading effect (FIGURE 3). Conventional rubber tire rollers achieve compaction through a combination of wheel load and inflation pressure. As the wheel load increases with the same tire inflation pressure, the compaction effort is extended deeper into the pavement layer. As the inflation pressure increases with the same wheel load, the compaction effort is also extended deeper into the pavement layer.

At the contact points between the rubber tires and the surface of an asphalt concrete mixture, a so-called kneading effect is generated due to the deformation of the rubber tires under load. This kneading action is effective in improving the density of the mix as well as increasing the tightness of the pavement surface.

The use of a vibratory rubber tire roller appears to be the "best of both worlds". The roller allows for the compaction of a tender asphalt concrete mix within the middle temperature zone without shoving or movement of the mix as under a vibratory roller. In addition, the use of the rubber tires decreases the permeability of the pavement surface compared to use of a vibratory roller. Further, the combination of the kneading action of the rubber tires and the vibratory compaction effort permits the reduction in the size of the rubber tire roller for the same relative compaction effort.

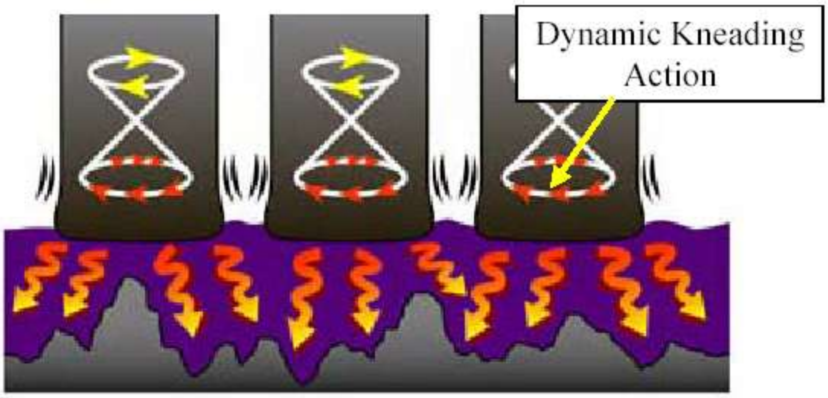


FIGURE 3 Dynamic Kneading Action

Pavement construction is becoming more difficult and complex for highway contractors. For instance, paving contractors are now required to achieve uniform density throughout the entire mat, because it increases the life cycle of pavement systems. Also, performance bonuses and penalties are often linked to test reports from the jobsite. The vibratory pneumatic tire roller is best suited to satisfy today's toughest requirements than any other compaction machine on the market today.

2.3.1 Uniform density

1) Conventional steel drum rollers typically compact the pavement layer from the top down. The density of the top 1/3rd is higher than the bottom 1/3rd (FIGURE 4).
2) Conventional pneumatic tire rollers typically compact the pavement layer from the bottom up. The density of the bottom 1/3rd is higher than the top 1/3rd (FIGURE 5).
3) The VPT roller compacts the pavement layer uniformly from top to bottom (FIGURE 6).

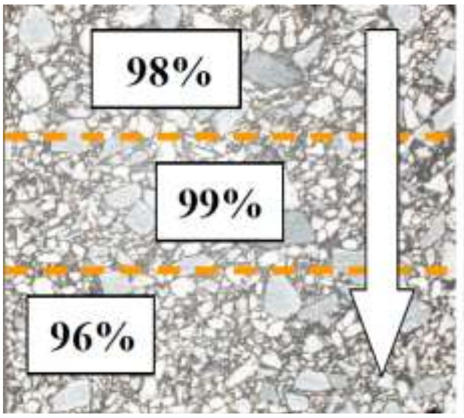


FIGURE 4. Top down using steel drum rollers

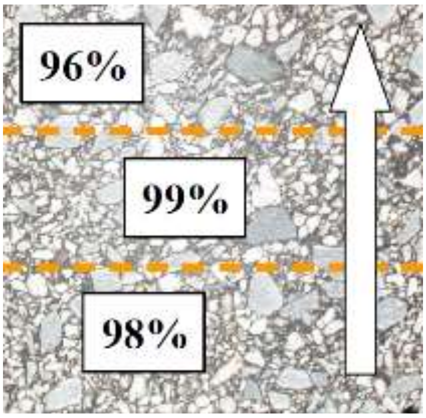


FIGURE 5. Bottom up using static pneumatic tire rollers

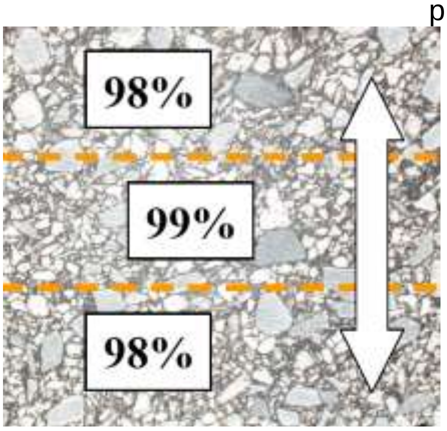


FIGURE 6. Uniform density using VPT roller

2.3.2 Good bonging

Over the last 10 years, more and more pavement surfaces have been prepared with cold milling machines that produce a very rough surface. In order to meet today's specifications, paving contractors must ensure that the bond between old milled pavements and new HMA overlays is complete. The "Dynamic Kneading Action" of the VPT roler eliminates the "bridging effect" that normally occurs with steel drum rollers as they pass over the high and low spots on a rough milled subbase (FIGURE 7). "Dynamic Kneading Action" of the VPT roller improves the bonding between the old milled surface and the new overlay pavement

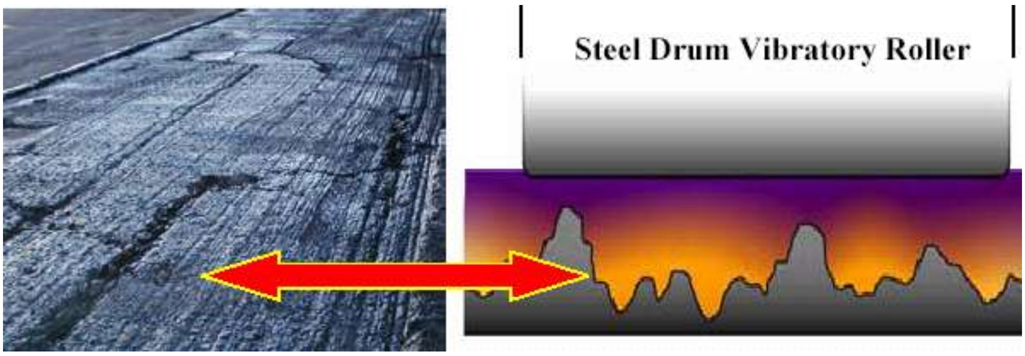


FIGURE 7 "Bridging" problem caused by a steel drum roller

2.3.3 Tight longitudinal Joint

"Dynamic Kneading Action" of the VPT roller also achieves tight longitudinal joints without crushing the aggregate, which makes unwanted changes to the gradation of the mix. This is a big plus for contractors who must meet joint density requirements recently introduced by highway and airport agencies (FIGURE 8).

FIGURE 8. Tight longitudinal joints with no aggregate crushing

2.3.3 Smoothness of finished surface

The developed super-flat tires (FIGURE 9) of the VPT roller provide uniform contact pressure. They achieve smoother finished pavement surfaces compared to conventional rounded pneumatic tires. The comparison of finished surface of the VPT roller and the conventional double drum roller is shown in FIGURE 10.

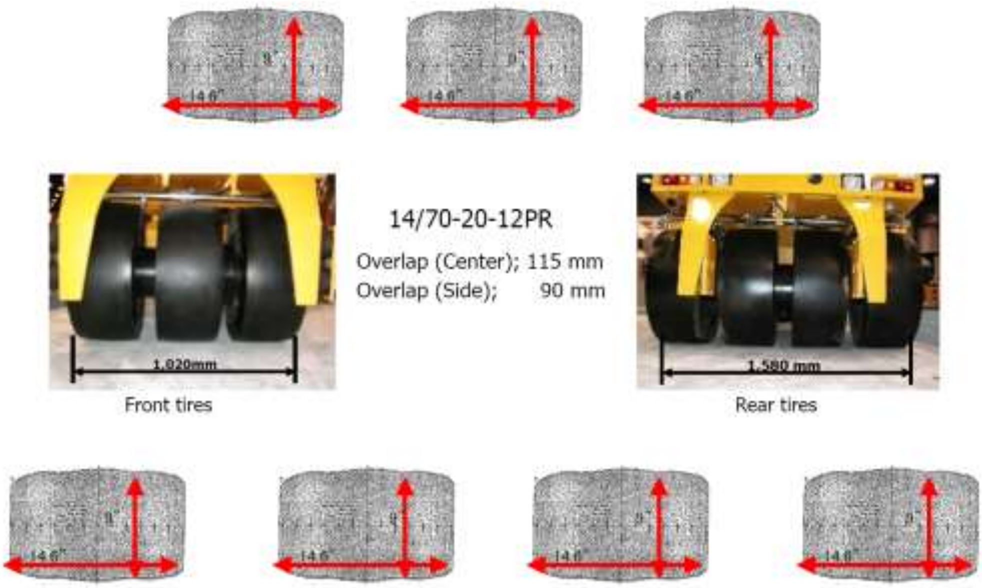


FIGURE 9. “Super-Flat” pneumatic tires for smooth finished surface

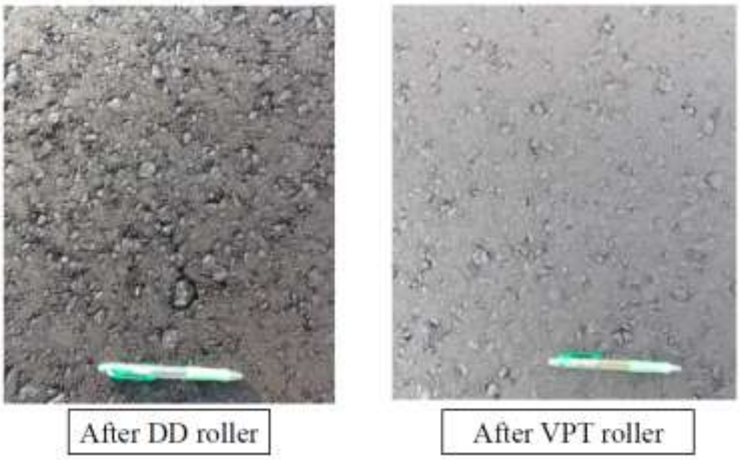


FIGURE 10 Comparison of finished surface

3 . APPLICATION EXAMPLES OF VPT ROLLER

The VPT roller is used all over the world. FIGURE 11 shows the district ratio of VPT roller sales. The Total amount of Japan, North America (U.S.A. and Canada) and Australia comes to more than 90 % of sales. But the application of each district is somewhat different. In North America, the VPT roller is used to obtain higher uniform density of asphalt mixture in the case of incentive/disincentive payment. Another unique application in North America is for the compaction of thick lift asphalt mixture or compaction of dense asphalt mixture to reduce the roller train. In Japan the VPT roller is used for the compaction of special asphalt mixture like stone mastic asphalt (SMA), porous asphalt or epoxy asphalt that are difficult to obtain high compaction ratio. In Australia where asphalt sealing pavements are widely applied, the VPT roller is used for the compaction of thin layer like the chip seal to avoid the cracking of aggregate and increase the bonding between asphalt and aggregate to protect fretting of aggregates.

Of course these are the typical application, there are the example of chip seal in Canada and thick lift in Australia also.

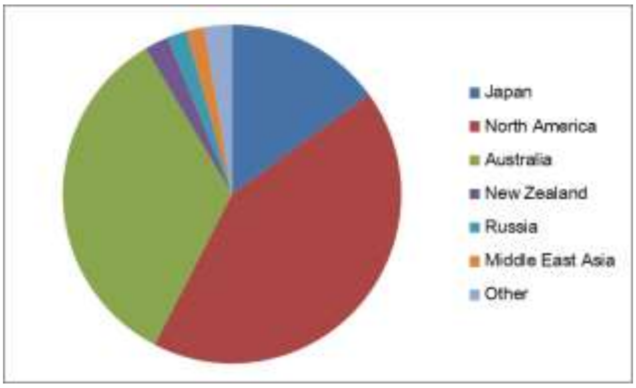


FIGURE11 District of VPT roller sales

3.1. Unique application of VPT roller in North America.

3.1.1. Application for compaction of thick lift mixture

In U.S.A the application for asphalt treated base with laydown thickness of 280mm (FIGURE12).The nominal maximum size of Base Course mixture was 37.5mm. The detail of the mixture is shown in Table.2. The VPT roller was used in the breakdown position and followed by the double drum vibration (DDV) roller. Both rollers made six (6) passes over each point of pavement with the max amplitude The pavement surface after 1 pass and 6 passes of VPT roller are shown in FIGURE13

FIGURE12 Laydown Mix(280mm)

After 1 pass

After 6 passes

FIGURE13 Compacted Surface

Table2 Detail of the Base Course Mixture

Sieve Size(mm)	%
50	100
37.5	99
25	88
19	74
12.5	55
9.5	42
4.75	29
2.36	19
1.18	13
0.6	9
0.3	7
0.15	5
0.075	3.5
Asphalt Content(%)	3.5
RAP Content(%)	25
Design ESALS	3 to ＜３０

In another section, only the DDV roller was used for both break down rolling and finish rolling.

FIGURE14 shows the cutting core of 2 sections. The left core was cut from the section where the VPT roller was used in the breakdown rolling. The right core was cut from the section where only the DDV roller was used. The right core seemed have more air voids and the left core was compacted uniformly in depth. From the result of density test, around 1% bigger density was obtained in the case of using the VPT roller.

FIGURE14 Comparison of cutting core

3.1.2. Attempt to reduce the roller train

A lot of trial constructions have been done in U.S.A. to reduce the roller train using VPT roller. FIGURE15 shows the typical result of the test.

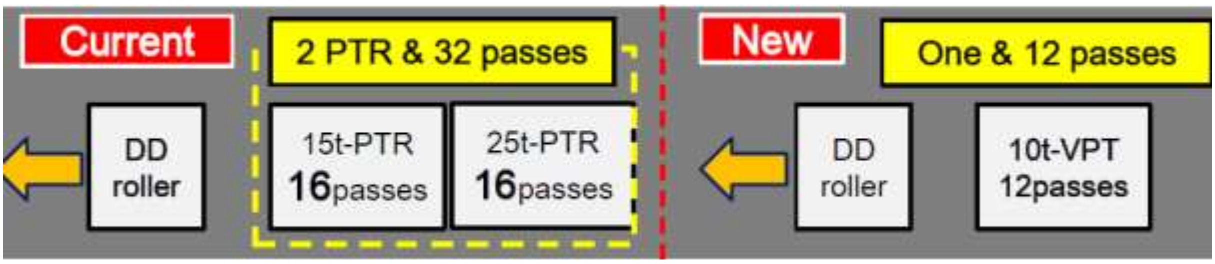


FIGURE15 Typical result of reducing roller train

Usually two static pneumatic tire rollers (PTR) are used. Intermediate(15t) and finish(25t) positions are used, and each of the PTR makes 16 passes. Total of two static PTR passes are 32 with inconsistent roller passes over each point of pavement.

The VPT roller increased the total working efficiency by reducing a number of rollers and its passes. In this case density of 96~97% achieved by the VPT roller is greater than that of 95% by two static PTRs.

3.2 Application for compaction of SMA in Japan

3.2.1 Outline of Japanese SMA

SMA is known as the mixture that is hard to compact in Japan. Japanese SMA is used for both the impermeable binder course especially used in bridge deck pavement and surface course that has high texture like porous asphalt. FIGURE16 shows the concept of both types of SMA. In the case of surface course, the underpart of mixture must be impermeable and top part must be drainage. In some cases, the binder of SMA is straight asphalt and containing cellulose fiber. And in another case the binder of SMA mixture is polymer modified binder and contains no cellulose fiber.

FIGURE16. Concept of Japanese SMA

The laboratory test results using Marshall compaction and Gyratory compaction is shown in FIGURE17. In the case of dense asphalt concrete mixture (DAC13), the number of 25 gyratory is necessary to obtain 96 % of designed Marshall density, while SMA 13 needs the number of 50 gyratory. It means twice the compaction energy is necessary for the SMA compaction compared to ordinary dense asphalt mixture.

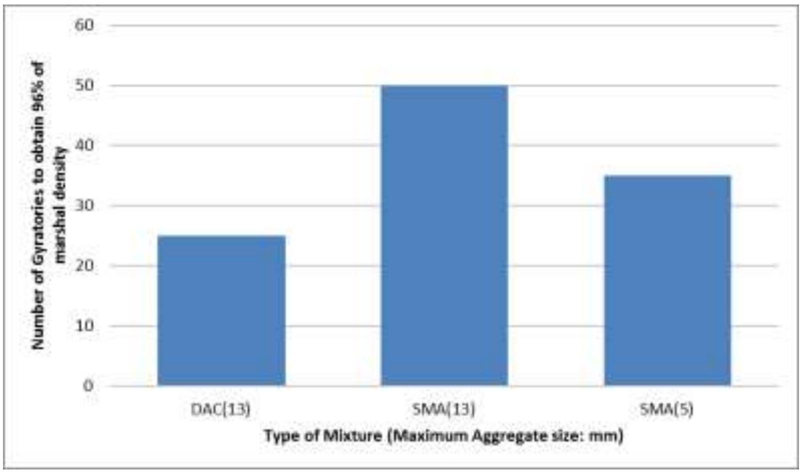


FIGURE17. Laboratory test result using Marshall and Gyratory compaction

3.2.2 Field test results of compaction of Japanese SMA

A field test had been done using the Vibratory Three-Wheel (VTW: MW700) roller and the VPT roller for the compaction of SMA on a national highway bridge. The purpose of this field test was to compare the effect of the combination of the VTW roller and the VPT roller.

The compacted layer thickness was 40 mm. There were three sections and each area was 20m long and 5 m wide. The SMA was delivered to a paver VOGEL super 2100 (FIGURE18). The VTW roller (FIGURE19) was used in the Break Down, The VPT roller (FIGURE20) was used in the intermediate position behind the VTW. The Vibratory tandem (VT) roller was used for finishing compaction as static roller (no vibration).

FIGURE 18. Paver.

FIGURE19. VTW roller.

FIGURE20. VPT roller

The mix design data of the SMA mixture is shown in TABLE.3

TABLE3 Mix design data of the SMA mixture.

Sieve Size (mm)	%
19 mm	100
13.2 mm	99.8
4.75 mm	47.5
2.36 mm	32.8
600 um	24.1
300 um	16.8
150 um	12.7
75 um	10.6
Binder content (%)	6.4
Asphalt binder type（penetration）	60/80

The other information for the SMA mixture, including the bulk and theoretical density, air void, stability are given in TABLE4.

TABLE4 Property of the mixture.

	Density kg/cm^3		Air void	Stability
	Bulk	Theoretical	%	kN
Mix design	2.410	2.473	2.5	8.15
Criteria	None	None	2 - 3	>6

The rolling patterns used are shown in TABLE5. The breakdown roller for each section was a VTW roller but used static roller in section 1. 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 1 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 the 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.

TABLE5 Rolling Patterns and Percent of TMD

Section No.	Rolling Process	Roller Type (Model)	Roller Mass (kg)	Operating Speed (km/h)	Number of Rolling Passes(pass)	Vibration Mode	Average Percent of TMD(%)
1	Breakdown	STW (MW700)	8730	3	8	Static	93.9
	Second	VPT (GE750)	9100	3	8	Vib.1st Amp.	
	Finsh	VT (SW650)	7100	3	8	Static	
2	Breakdown	VTW (MW700)	8730	3	8	Oscillation	94.7
	Second	VPT (GE750)	9100	3	8	Vib.2nd Amp.	
	Finsh	VT (SW650)	7100	3	8	Static	
3	Breakdown	VTW (MW700)	8730	3	8	Oscillation	95.3
	Second	VPT (GE750)	9100	3	8	Vib.4th Amp.	
	Finsh	VT (SW650)	7100	3	8	Static	

TABLE5 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 FIGURE21. 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 (93.3), 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).

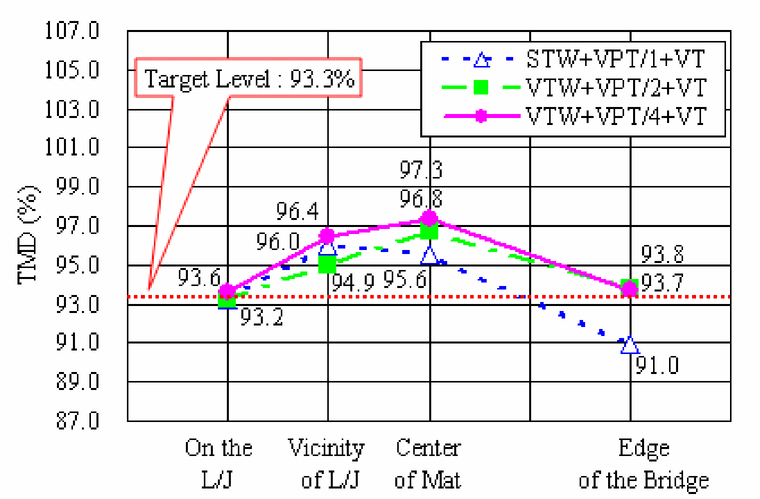
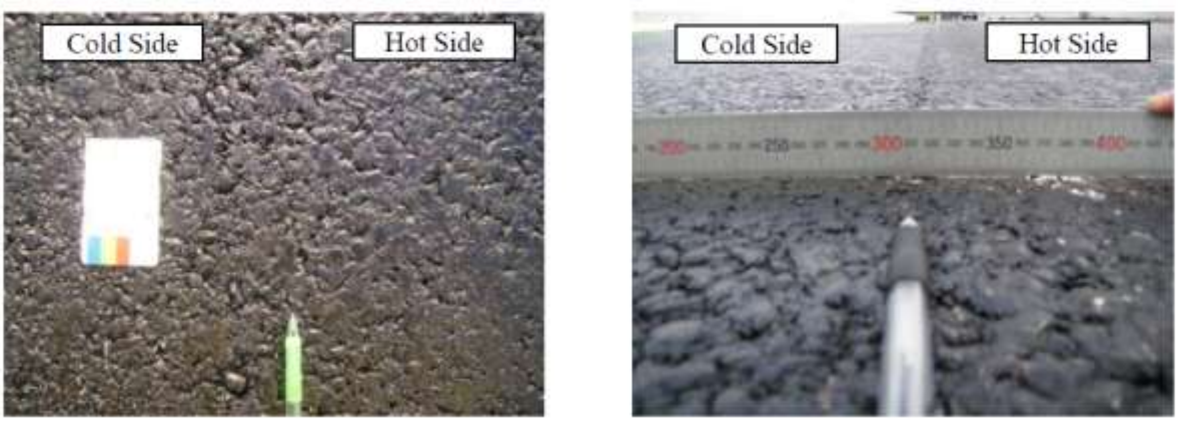


FIGURE21. Distribution of density

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 FIGURE22. An excellent surface was obtained in the Section 3. The surface condition around the longitudinal joint is shown in FIGURE23-A. The vertical line indicated by the pen in FIGURE23-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 FIGURE23-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.

FIGURE22. Surface condition of the pavement (section 3)



A: Top View B: Side View

FIGURE23. Surface condition of longitudinal joint.

3.3. Application for the construction of chip seal in Australia

In Australia sprayed seal is widely used (approximately 90% of the surfaced length) [4].

The medium sized multi-wheel rubber tired roller of loading about 1 ton per wheel is used for aggregate rolling and recently combination roller fitted with a rubber covered vibrating drum at the front and 4 large rubber tired wheels at the rear is introduced [4].

The example of application of VPT roller for Australian chip seal is shown in FIGURE24,25 and 26.

FIGURE24. Chip seal application

FIGURE25. VPT roller(1)

Figure26.VPT roller(2)

The finished surface is shown in FIGURE27. There was no crashing aggregate and kept good bonding between aggregate and asphalt. After opening to traffic the fretting of aggregate was small.

FIGURE27. Finished surface after compaction of VPT roller

4. CONCLUSIONS

The mechanical features of the VPT roller is described in this paper, and based on the worldwide construction examples using the VPT roller, following conclusions can be made.

1) The VPT roller is used for not only thick lift, but also thin lift successfully. Furthermore it is effective to compact various types of asphalt mixture like stone mastic or so.
2) The combination of vibratory roller in oscillatory mode in the breakdown and the VPT roller in the finish is the best option to achieve the required density and tighter surface. It will assure durable and long lasting asphalt pavements.
3) A new roller train using only two rollers, a DDV roller and a VPT roller, easily achieved the required level of density of the asphalt mixture. This results means that the contractor can construct in lower operating costs using two rollers instead of three.
4) The strong point using the VPT roller is the possibility of covering various applications from middle size to large size Pneumatic Tire Roller. The VPT roller is equivalent to 10t, 14t, 18t, 23t, and 28t not using or using vibration. Another strong point is making smoother surface because of the wide-flat tires and avoiding the cracking of the aggregates.

At this moment the VPT roller (GW750) was improved to satisfy EPA Tier 4 Interim (iT4) as the new model GW751 with some mechanical improvement.

5. ACKNOWLEDGEMENTS

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