Semi-flexible Pavement on Beijing Bus Rapid Transit Line

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ABSTRACT: Bus is still the main means of transportation in Beijing. In order to alleviate traffic jams, in December 2005, the first bus rapid transit (BRT) has been completed and has opened to traffic. But, because of heavy traffic flow, large wheel load and fixed-point parking within stations and other characteristics, there are a number of ruts for several centimeters or even more than a dozen of centimeters in stations and intersections in less than a year since the opening to traffic, bringing a lot of inconveniences for the transportation. In order to solve this problem, we have provided a semi-flexible pavement constructed technology program for Beijing Gonglian Co., Ltd., which is responsible for the road construction, maintenance and management in Beijing, which is initially proposed in Beijing and has been adopted. Upon wheel tracking tests under harsh conditions, after more than 3,000 times of dynamic stability confirmation, a trail pavement has been constructed 480 m^2 at two bus stations in 2006. And then, in 2008, in order to welcome the Olympic Games, the method has been used to pave stations and intersections for more than 40,000m^2 in 3 bus rapid transit lines of Anli Road, Chaoyang Road and South-Center Road. This paper reports on the mix proportion design of Chinese materials and results of physical property confirmatory test and introduces on-site construction cases and the current road conditions.

KEY WORDS: BRT, semi-flexible, pavement, paste, injecting.

1 INTRODUCTION

In order to meet the Beijing 2008 Olympic Games and improve the construction of public transport facilities, a few of subway lines have opened. However, bus is still the main means of transportation. In order to alleviate traffic jams, in December 2005, the first bus rapid transit (BRT) in Beijing has been completed and has opened to traffic. But, because of heavy traffic flow (dispatching a bus in every 2-4 minutes), large wheel load (an individual bus is fully loaded for 28t), fixed-point parking within stations and other characteristics, there are a number of ruts in several centimeters or even more than a dozen of centimeters in stations and intersections in less than a year since the opening to traffic, bringing a lot of inconveniences for the transportation.

Therefore, we have provided a semi-flexible pavement constructed technology program with a good anti-rutting performance and many practical engineering performance for Beijing Gonglian Co., Ltd. and a test pavement has been made at two stations in 2006.

2 THE CONSTRUCTION ROUTE AND REPAIR SECTION

In 2008, we have repaired 13 stations and intersections for 7,500 m^2 on the bus rapid transit of South-Center Road extending to the south with the Tiananmen Square as the center and constructed 48 new stations for 29,000 m^2 totally on the Anli Road extending to the north of the Olympic Stadium and 13 new stations for a total of 5,000 m^2 on the Chaoyang Road extending to the east during the 4 months from April to July.

The repair works include area of 4m wide, 60m ~ 150m long, after 110mm deep was cut, with a method to pave 60mm-thick modified dense graded asphalt concrete (20) in the lower layer and 50mm-thick semi-flexible pavement in the upper. The repair of primary cross-section is shown as Figure 1.

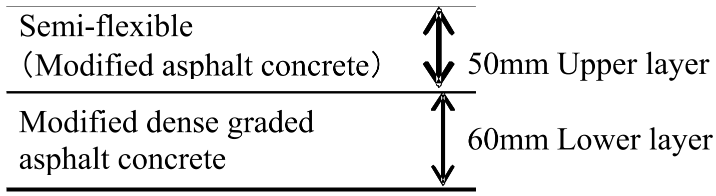

Figure 1: Repair Section

3 DESIGN OF MIX PROPORTION

3.1 Mix Proportion of Open-Graded Asphalt Mixture

3.1.1 Materials

In China, the Grade-1 highway applies basalt, while other road uses limestone in general. The requirements for gravel particle size and titles are divided into 14 categories in accordance with the difference of gravels (75mm ~ 3mm) used in asphalt mixture. According to the provisions, natural sand should be river sand or sea sand. But, due to Beijing is located in the inland areas and high-quality natural sands are not easily available, screening sands are used as the fine aggregate.

In the construction, open-graded asphalt mixture applies basalt as the aggregate and screening sand as the fine aggregate. With a consideration to the traffic situation after the pavement of open-graded asphalt mixture, the SBS modified asphalt is used.

3.1.2 Mix proportion

Firstly, we set the target voids of open-graded asphalt mixture at 22 ~ 23%, and thus to set the gradation in order to carry out design of mix proportion. In the design of mix proportion, we have referred to the Manual for Design and Construction of Asphalt Pavement[1] and the internal specifications for the target gradation and standard values, which are shown in Table 1.

Table 1: Target gradation and standard value

As.（%）	Size of sieve pit (mm) and percentage passing (5%)									Stability ※	Flow value ※
	26	19	13.2	4.75	2.36	0.6	0.3	0.15	0.075	（kN）	（1/100cm）
3.0～4.0	100	95-100	40-70	15-30	9-18	6-12	5-10	4-8	3-6	3.0 or above	20～40

※ Marshall stability test method is conducted according to Pavement Investigation and Test Manual[2] B001.

3.2 The Mix Ratio of Cement Paste

3.2.1 Materials

In the materials, super-solidifying cement and other domestic materials available in Beijing areas are applied. In order to improve the construction of cement paste and the performance of pavement, rubber latex of SBR series is used. Otherwise, some bus stations have added yellow pigments to get colored pavement.

Due to the used cement starts gel in about 5 minutes, originally, we had considered using cement retarder, but several days later, the strength and other performance indicators still can't meet the requirements. Thus, we decided to use high-performance water reducing agent to ensure the working life. Upon the performance identification on three kinds of high-performance water reducing agents that can be bought in China, we have selected out one that can ensure the performance.

3.2.2 Selection of water reducing agent

The water reducing agent is selected out from three kinds of high-performance water reducing agent of polycarbonate series. Please refer to Table 2 for efficiency of construction and gel tests, Table 3 for test mix proportion.

Table 2: Efficiency of construction and gel tests

Performance	Items	Test methods	Target values	Tested values
Efficiency of Construction	Flow	Flow test of cement paste (P hopper method) (Omitted):JSCE-F 521-1999	Less than 13 seconds	Time of flow (S)
	Working life	P hopper method (can ensure 13 seconds)	Less than 15 minutes	Working life (M)
	Appearance	Visual observation (color, foaming etc.)	-	Photo
Solidification	Strength	Cement physical experimental methods (Curing time 3h.1d.3d): JIS R 5201	5MPa above (open to traffic)	Compression strength (MPa)

Table 3: Testing mix proportion

W/C (%)	Rubber latex (C×%)	Unit volume (kg/m^3)			
		Cement (C)	Water (W)	Rubber latex (R)	Water reducing agent ※
55	5	1049	577	52	C×%
Density (g/cm^3)		2.83	1.0	1.0	1.0

※ Water reducing agent and water are alternatively used.

3.2.3 Types of water reducing agent and determination of additive amount

(1) Selection result of type of water reducing agent

With a consideration to the construction in summer, tests are conducted under the test temperature of 35℃ to determine the type of water reducing agent. Its flow, working life and strength results tested in the test temperature are shown in Table 4.

The testing results show that in the case when there is same additive amount, the water reducing agent which can best ensure the working life (the time of flow value below 13 seconds) is water reducing agent A and its 1.0% of additive amount can ensure 15-minute working life. But, the water reducing agent B and C can only ensure less than 5 minutes working life even 1.0% is added. So water reducing agent A is selected and used.

Table 4: Test results of flow value, working life and strength under 35℃ (indoor mix proportion)

Mix proportion No.	Test temp.	W/C (%)	Rubber latex (C× %)	Types of mixture	Mixture (%)	Initial flow value (s)	Working life (min)	Compression strength σ 3d (MPa)
①	35℃	55	5	A	0.4	9.6	4	—
②					0.6	9.4	8	18.1
③					1.0	9.0	15	21.5
④				B	0.6	10.2	1	—
⑤					1.0	9.7	5	—
⑥				C	0.6	10.2	1	—
⑦					1.0	9.9	4	—

(2) Determination of additive amount of water reducing agent

In order to determine the additive amount of water reducing agent selected out through (1) in non-summer construction, we have studied the relationship between the adding amount of water reducing agent and working life.

The water reducing agent A is selected, and its testing results of flow value, working life and strength under the test temperature of 20℃ and 5℃ are shown as the Table 5. Please refer to the Figure 2 for the compression strength of solidified cement paste at different time at different test temperature.

In the test temperature at 20 ℃, we have obtained the relationship between water reducing agent and additive amount like that, 0.5% of water reducing agent can ensure the working life of 15 minutes.

In the test temperature 5 ℃, we have obtained the relationship between water reducing agent and additive amount like that, 0.8% of water reducing agent can ensure the working life of 15 minutes (deduced).

Table 5: Test results of flow value, working life and strength under 20℃ and 5℃ (Indoor mix proportion)

Mix proportion No.	Test temp.	W/C (%)	Rubber latex (C× %)	Type	Mixture (%)	Initial flow value (s)	Working life (min)	Compression strength σ 3d (MPa)
⑧	20℃	55	5	A	0.4	9.8	10	—
⑨					0.5	9.9	16	19.5
⑩					0.6	9.7	25	22.9
⑪	5℃	55	5	A	0.4	10.6	3	5.1
⑫					0.6	10.6	9	7.3

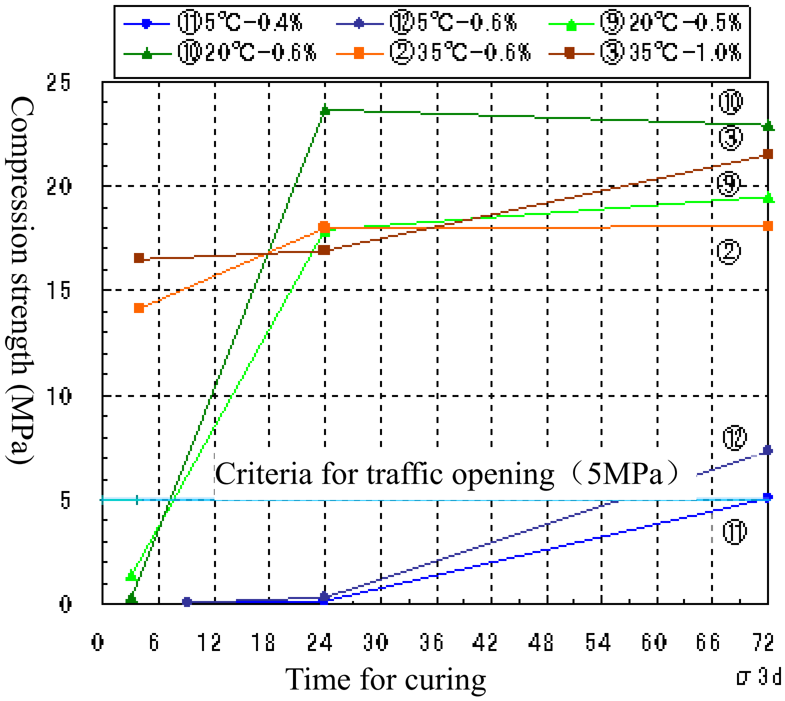

Figure 2: Compression strength of cement paste at different time

In Figure 2, if the strength for traffic opening is required at 5MPa above, the curing time that the pavement needs is shown as follows since adding cement paste with water reducing agent at a rate to ensure 15-minute working life. As inferred, it may require 3 hours at the temperature of 35℃ (1.0% of water reducing agent), about 7 hours at 20℃ (0.5% of water reducing agent) and about 3 days or so at 5℃ (0.8% of water reducing agent).

3.2.4 The physical property test of semi-flexible pavement (wheel tracking test under the harsh conditions)

(1) Test methods
In order to evaluate the fluidity resistance performance of semi-flexible pavement, we have carried out unconventional wheel tracking tests under harsh conditions. Under the condition of 70℃, we have had solid tires with load of 0.7MPa, 1.0MPa and 1.3MPa run on a semi-flexible test piece again and again for 60 minutes and taken the driving times when the amount of deformation reached 1mm as the dynamic stability (times/ mm) for evaluation. If there is greater dynamic stability, there is better fluidity resistance performance. The test equipment is shown as the Photo 1.

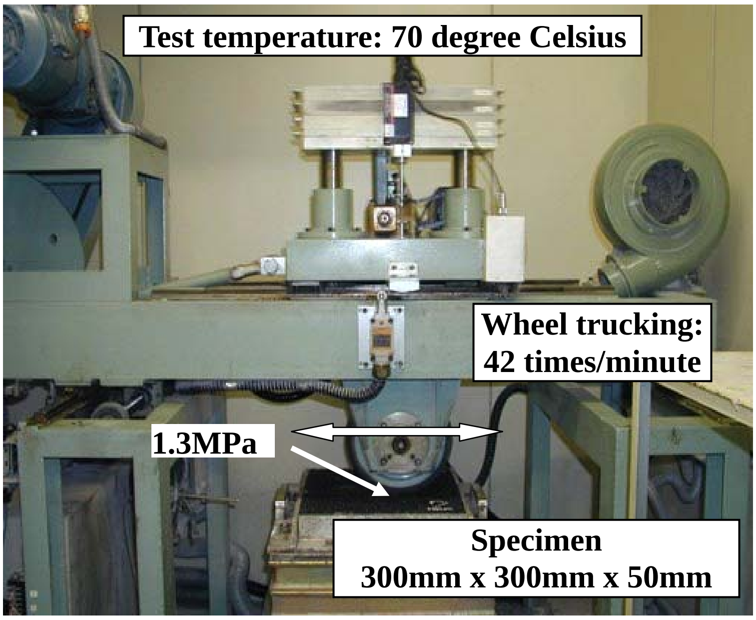

Photo 1: Test of Wheel tracki

(2) Preparation of sampling block
Inject the cement paste mixed as the mix proportion specified in Table 4 ⑨, which can ensure the 15-minute working life under the temperature of 20℃ into the standard mix proportion open-graded mixture (see Table 1, size: 300mm × 300mm, thickness: 50mm) and cure it in dry within 7 days (at a room temperature of 20℃ and a humidity of 60%).

(3) Test procedure
After 7 days cure, place the semi-flexible pavement test piece in a room at a temperature of 70 ℃ for 5 hours for cure and conduct 60-minute wheel tracking test with a tire loaded at 1.3MPa to get the dynamic stability.

The calculation formula of dynamic stability is shown as the Formula 1.

$$\text{Dynamic stability (times/mm)} = 42 \times \frac{t_2 - t_1}{d_2 - d_1}$$

t_1 45(min) d_1 : Amount of deformation at 45th minute(mm)
t_2 : **60(min)** d_2 : Amount of deformation at 60th minute(mm)

Formula 1: The calculation formula of dynamic stability

(4) The confirmed results of physical properties
The results of wheel tracking test are shown in Table 6.

Table 6: Results of wheel tracking test

Test temperature	Wheel load	Unit	Dynamic stability
70℃	0.7MPa	Times/mm	36,248
	1.1MPa	Times/mm	22,878
	1.3MPa	Times/mm	15,511

The results showed that even under the harsh conditions of 70℃ and 1.3MPa, its dynamic stability also keeps at more than 15,000 times/mm, which proves that semi-flexible pavement is a good pavement method with excellent resistance to flow.

4 CONSTRUCTION IN SITE

4.1 Construction Procedure

The construction procedure for repair works of bus station is shown as below:

(The 1st day)

a. To cut the existing pavement, which is 4m wide, 110mm deep and 60 ~ 150m long.

b. To pave 60mm-thick modified dense-graded asphalt concrete (20) on the lower layer and open to traffic after curing.

(The 2nd day)

a. To pave 50mm-thick modified open-graded asphalt mixture on the upper layer

b. To inject cement paste after the road surface is cooled to 50℃ below and open to traffic after 8-hour curing.

4.2 The Pavement of Open-Graded Asphalt Mixture on the Surface Layer

The open-graded asphalt mixture at a void of 22 ~ 23% is mixed at asphalt mixing plant in the Beijing city and transported to the construction site in accordance with the targeted gradation shown in Table 1.

The large-scale VOGEL asphalt finisher is used to pave the asphalt mixture and 15t-grade steel-wheel vibratory rollers without vibration are applied to compact the road.

4.3 Injecting of Cement Paste

4.3.1 The on-site mixing of cement paste

Using the material in site, the flow values are firstly tested to confirm the flow and working life of cement paste (within 13 seconds) and determine the actual ratio of cement paste. The actual mixing ratio is shown in Table 7. Please refer to Figure 3 for flow values at different time.

Table 7: the test results of flow value and working life (actual mix proportion)

Mix proportion No.	Test temperature	W/C (%)	Rubber latex (C×%)	Water reducing agent (%)	Initial flow value (s)	Flow value at 15th minute (s)	Working life (min)
⑬	25℃	55	5	0.3	10.9	Can't be measured	5
⑭				0.35	10.9	13.5	12
⑮				0.4	10.7	12.5	20
⑯				0.5	10.7	11.3	30～

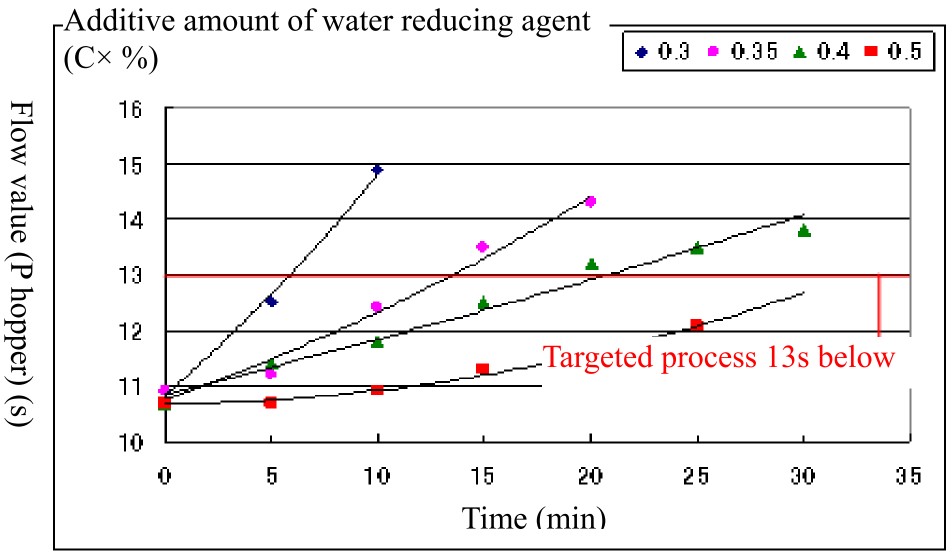

Figure 3: Changes of flow values at different time (site test)

The mix proportion ⑭ (adding 0.4% of water reducing agent) and ⑮ (adding 0.5% of water reducing agent) can ensure the working life (flow value in 13 seconds or less) of more than 15 minutes, and additive amount of 0.4% of water reducing agent is applied.

4.3.2 Mixing of cement paste

The cement paste is mixed at the construction site by used of large mixer which can hold a bag of cement (50kg) with a diameter of 700mm, depth of 300mm and volume of 115 liters. This mixer is reversible and can directly inject cement paste on the road (see Photo 2). Materials should be added in the following order: water → (pigment) → rubber latex → water reducing agent → cement.

Photo 2: Injecting of cement paste

4.3.3 Injecting of cement paste

(1) Preparation before injecting
Before injecting, the road should be cleaned with broom and other tools firstly. And then, in

order to prevent cement from splashing and attaching to the curbs and adjacent lanes, vinyl sheet and gum tape should be used for protection. As moving the mixer, injecting cement paste directly to the targeted location. In addition, put one bag cement in each distance advanced by every mixing should be well calculated and marks should be painted on the road, so as to achieve adequate injecting and avoid the loss of mixing time.

(2) Injecting
The basic injecting volume of cement paste is 12 ℓ / m^2 (1m × 1m × 0.05m × void of 23% = 11.5). The mixed cement paste injected from the mixer, as shown in Photo 3, is leveled by use of rubber rake and injected into the void of open-graded asphalt mixture through vibration of plate compactor.

Move the cement paste near the plate compacter by using rubber rake and fully inject it into void through vibration of plate compactor. Finally, scrape the remaining cement paste by using rubber rake until surface aggregate uncovering.

Photo 3: Injecting of cement paste

4.4 Traffic Opening

Upon the completion of construction, remove all vinyl sheet and gum tape used for curing and clean the surface upon completely drying. Since more than 8-hour curing after injecting, the cement paste at initial stage can meet the intensity requirements to open to traffic (50kgf/cm^2). Please refer to Photo 4 for the situations after completion.

Photo 4: About the completion

5 USAGE

Since the construction of BRT line used semi-flexible pavement in 2006, up to date, there are no rutting on the roads and all roads keep a good performance. The usage is shown as Photo 5.

Photo 5: About the usage

6 CONCLUSIONS

In Japan and many foreign countries, semi-flexible pavement has been widely applied as a general construction method. But, it is the first try in Beijing.

All the materials and machinery are local and the mixer is designed and manufactured by ourselves. Through repeated tests and summaries, we have succeeded finally. In the future, we have to make more efforts in materials and equipment in order to improve construction efficiency.

So far, there are serious rutting in bus stations and intersections, which have to be repaired every year, but the problem still can’t be solved fundamentally. However, the application of semi-flexible pavement can greatly reduce the repair frequency and lower the construction cost.

Now, semi-flexible pavement has been widely used in stations and intersections of bus rapid transits, which is expected to be widely used in other cities and other lines in the future.

If this paper can provide a reference for other countries and regions that would like to use semi-flexible pavement technology, we would be honored.

REFERENCES

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