Asphalt Deck Pavement Design for Concrete Bridge under Frost Climate in the North Sea Region

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Abstract. A preferred waterproofing system and bearing course mixtures for asphalt pavement deck were designed to determine a suitable waterproofing system and material/structure combination optimize proposal for Qingdao Bay Bridge, which was built under the frost climate of Shandong province, through a general analysis on the disease type and the damage mechanism of asphalt deck pavement. Based on the laboratory test results, the test section construction and long-term pavement performance observation, a comprehensive comparison and analysis about five types of waterproofing system(Synchronous Seal coat+ Asphalt Sand, Polymer Modified Bituminous Waterproofing Sheets, Priming Coat+Asphalt Rubber Membrane+Protection Board, Polymer Modified Emulsified Asphalt Waterproof coating, Gussasphalt) were made in terms of waterproof effect, workability, quality reliability and long-term performance. Furthermore, the asphalt deck pavement were proposed to be designed on the basis of the layer performance-related concept, and regarded as the system engineering. The construction effect indicates that both the multi-purpose layer (waterproofing high modulus asphalt sand) and the deck pavement structure are adapted to the evidence temperature difference and windy characteristics during the construction. It also shows the excellent workability and quality reliability.

Key words: Concrete Bridge, Asphalt Deck Pavement, Frost Climate, Waterproofing System, Multi-purpose Layer

1. Introduction
Qingdao Bay Bridge is located in Jiaozhou Bay, north sea region of China with a frost climate. The climate here changes apparently with seasons. Winter months (October to March of the following year) are characterized by a continental climate with dry air and low temperature. And summer months (April to September) are affected by the southeast monsoon, which brings moist air, abundant rainfall and small diurnal temperature range, showing marine climatic characteristics.

The bridge project is a 28057-metre-long complicated clustering one which includes both cement concrete bridge and steel bridge. Therefore, systematic and scientific bridge deck design is urgently needed, including the specific geographical location and characteristic of transportation strategy.
2. Brief Conditions

2.1. Historical Meteorological Data
Meteorological data collected from 1965 to 2004 indicate that the extremely maximum and minimum temperature is 38.9°C and -14.3°C, respectively. Meanwhile, the longest continuous time with temperature above 32°C can reach 12 days per year. The average height of annual rainfall is 662.1 mm, and the maximum snow depth is 20cm, with annually average relative humidity of 70.9%. Usually, 13% days of the year are foggy weather days, meanwhile, salt is rich in fog.

2.2. Temperature Detection in Section
The bridge deck is usually affected by the climatic conditions, most important of which are the temperature and precipitation. In order to detect different layer temperature of the bridge deck pavement, the research group installed EPS-I (Environment Parameter Detection System) in the section of Nv Gukou Bridge deck. Monitoring data (Fig.1) show that the bridge deck pavement temperature decreased a little with the increase of pavement depth. Meanwhile, the annual maximum temperature is 52.3°C, and the minimum temperature is -11.8°C. Compared to semi-rigid asphalt pavement temperature field, the bridge deck temperature gradient appears more slow because the bridge system is totally exposed to the air. In summer, the time with a daily continuous temperature ≥35°C lasts more than 10 hours, the minimum temperature lasting time in winter is relatively short. During the monitoring period, there are 31 days with high temperature above 45°C, mainly concentrating in the late August. There are no more than 5 days during which the low temperature is below -10°C.

![Fig. 1 Daily Temperature Change during the Monitoring Period](image-url)
3. Design for the Cement Concrete Bridge Deck

3.1. Thinking about the Design of Bridge Deck

In recent years, researchers concern not only the location, type and structure of bridges but also the bridge deck design, because the bridge deck quantity greatly affects the bridge deck comfort and useful life. Except for the temperature and humidity, the common distresses (especially earlier failure and leakage) are also caused by big volume of traffic, heavy loads, soil corrosion to the cement concrete, quality control and maintenance measures, which should be considered seriously.

Based on the factors above, we suggest a function-related design concept for each layer of bridge deck pavement, namely, a perfect bridge deck should be a comprehensive waterproofing system. Each layer within the bridge deck has a function complement with each another to increase waterproof insurance efficiency, meet the waterproof design term and ensure long-term performance.

3.2. Technical Composition for Bridge Deck

A complete bridge deck composition is clearly indicated in Fig 2. Each waterproof layer is separately listed in the dotted line box, which is called waterproofing system for short. Waterproofing system is crucial to the whole bridge deck for linking, waterproofing and bonding roles. Meanwhile, it can affect the compound stress between the flexible asphalt concrete and cement concrete. Related researches indicate that an ideal waterproof layer should retain impermeable during construction and design term on the premise of economic. That requires that the waterproofing system should not be destroyed during the construction.

Multi-purpose layer takes into consideration both structure function requirements and mechanical characteristics as below. (1) The waterproofing should be protected from piercing by course aggregate during the construction. (2) Moisture resistance is enhanced by smaller void. (3) Excellent anti-stretching and anti-shearing characteristic. (4) Good deformation compatibility property and anti-rutting ability. (5) Good anti-fatigue properties and cracking resistance at a low temperature should also be considered.

Mixture excellent at high temperature stability and anti-water property is designed as bearing layer in order to lower shearing stress distribution within the pavement and reduce shearing burden at the bottom.
Wearing layer should have uniformly rough texture for good surface service characteristics. Moreover, the replacement layer facilitate the maintenance during the operation. Both the bearing course and the wearing course mixture should have favorable construction operability and less segregation for easier compaction.

3.3. Design Scheme for Pavement Structures of Section

In 2008, the researchers designed five different kinds of bridge deck pavement structures and put them into construction separately. Five typical waterproofing systems which are commonly used in different countries (Fig. 3) was applied in order to study the influence on long-term performance of bridge deck. Four of them were settled in Nv Gukou Bridge Section (2008), and the last one was settled in Qingdao Bay Bridge section (2010).

(a) Section 1, Shangdong Province in China
(b) Section 2, Canada and USA
(c) Section 3, China
(d) Section 4, Germany and Japan
(e) Section 5, France

Fig. 3 Design Scheme for Pavement Structures of Section
Table 1. Technical Index for Bridge Layer

| Order number | Binding layer materials                | Spread quantities (Kg/m²) | Construction form | Cohesive force at 25°C (Mpa) | Capacity shear resistance at 25°C (Mpa) |
|--------------|---------------------------------------|---------------------------|-------------------|-----------------------------|----------------------------------------|
| Section 1    | SBS Polymer Modified Bituminous        | 1.2 to 1.5                | Mechanical        |                             |                                        |
|              | SBS Polymer Modified Asphalt Sand      | 2.0cm (Depth)             |                   |                             |                                        |
| Section 2    | Asphalt Rubber Membrane                | 3.0 to 6.0                | Manpower          | ≥0.4                        | ≥2.5                                   |
|              | Liquid Bitumen                         | 0.1 to 0.5                |                   |                             |                                        |
| Section 3    | Polymer Modified Emulsified Asphalt(with glass fibre) | 2.0 to 2.5 | Manpower |                             |                                        |
| Section 4    | Gussasphalt(SBS+TLA as binder)         | 3.0cm (Depth)             | Mechanical        |                             |                                        |
| Section 5    | Waterproofing Sheet                   | -                         | Mechanical        |                             |                                        |
|              | Liquid Bitumen                         | 0.3-0.8                   | Manpower          |                             |                                        |

The technical index requirements are not always the same with different bonding layer position, bonding object and bearing load conditions among them. The cohesive force and shearing force are critical mechanical factors for bridge deck. The results of most tests indicate that the data are usually far greater than the Specification Standard, which means stricter standards and higher temperature condition for bridge deck according to the actually mechanical response.

4. Construction and Evaluation of Waterproofing System for Concrete Bridge Deck

4.1. Construction for Waterproofing System Materials

Fig.4 shows that construction efficiency and schedule are more easily assured with the mechanic, which also effect a lot on the construction quality and cost. Except for experimental results, more attention should be paid to the field variability.
4.2. Performance Synthetic Comparation

4.2.1. Evenness after Construction. Table 2 shows the obvious distinction between Waterproofing System with multi-purpose layer and with bonding layer only. The evenness of the section is greatly improved by the asphalt sand (2.0cm) and gussasphalt (3.0cm).
Table 2. Evenness after Construction (2008.12)

| Order Number | Maximum Value (m/km) | Minimum Value (m/km) | Average (m/km) | σ (mm) |
|--------------|----------------------|----------------------|----------------|--------|
| Section 1    | 5.19                 | 0.48                 | 2.5            | 1.1    |
| Section 2    | 7.92                 | 0.66                 | 2.7            | 1.4    |
| Section 3    | 12.16                | 0.81                 | 2.8            | 1.7    |
| Section 4    | 11.6                 | 0.28                 | 2.3            | 1.4    |

4.2.2. Rutting Index For Section

![Fig. 5 Rutting Depth (2010.10)](image)

Table 3. Rutting Depth for Each Section (2010.10)

| Order Number | Maximum Value (mm) | Average(mm) | σ(mm) | RDI, Average (mm) |
|--------------|--------------------|-------------|-------|-------------------|
| Section 1    | 17                 | 6.3         | 2.6   | 87                |
| Section 2    | 28                 | 9.5         | 5.5   | 79                |
| Section 3    | 30                 | 10.4        | 4.15  | 79                |
| Section 4    | 16                 | 7.7         | 2.8   | 85                |

The results of rutting depth are shown in Fig.5 and Table 3. To some extent, the individual measure point fluctuation for Section 2 may relate to the stability of the mechanic. However, by analyzing the whole data in Table 3, it can be found that the quality varies more fluctuant with greater percentage of manpower during construction, meaning a greater decline of the quality.

4.2.3. Synthetic Comparation for Performance of Waterproofing System. In Table 4, order number 5 means the adaptability to the surface treatment of cement concrete bridge deck and to the linetype. The former includes roughness, evenness and uniformity, the latter includes cure, gradient and superelevation.
Table 4. Synthetic Compare for Performance of Waterproofing System

| Order number | Content                                | Section1 | Section2 | Section3 | Section4 | Section5 |
|--------------|----------------------------------------|----------|----------|----------|----------|----------|
| 1            | Waterproofing system cost               | ★★★★★   | ★★★     | ★★★★★★  | ★★★     | ★★★     |
| 2            | Equivalent thickness cost               | ★★★★★★  | ★★★     | ★★★★★   | ★★★     | ★★★     |
| 3            | Waterproofing effect                    | ★★★★★   | ★★★★★★  | ★★★     | ★★★★★★  | ★★★★★★  |
| 4            | Bonding Strength                        | ★★★★★   | ★★★     | ★★★     | ★★★     | ★★★     |
| 5            | Adaptability to cement concrete deck condition | ★★★★★★  | ★★★     | ★★★★☆   | ★★★★★   | ★★★     |
| 6            | Difficulty of construction              | ★★★★★★  | ★★★     | ★★★     | ★★★     | ★★★     |
| 7            | Reliability of construction quality     | ★★★★★★  | ★★★     | ★★★     | ★★★     | ★★★     |

4.3. Determined Bridge Deck Structure for Qingdao Bay Bridge

Based on the above analysis of test results, the final plan was determined for a large-scale application in Qingdao Bay Bridge (Fig.6).

Fig. 6 Scheme for Qingdao Bay Bridge

The scheme put forward the standard for surface treatment of cement concrete bridge deck and design of mixture volume. The binder type and gradation of the multi-purpose layer are systemically optimized. Multi-modified asphalt was used to improve the stability of asphalt at high temperature and anti-fatigue performance of asphalt sand. With the thickness increased (from 2.0 cm to 3.0 cm) and the void decreased (≤2.5%), the reliability of construction quality and waterproofing characteristic becomes better than the traditional multi-purpose layer (Fig.7).

Fig. 7 Waterproof Characteristic of Multi-purpose Layer in Qingdao Bay Bridge
5. Conclusion

Focusing on the Qing Dao Bay Bridge project, we mainly analyzed the related disease type, damage mechanism, material design, structure design, performance evaluation and construction control of overseas and domestic aspalt deck pavement. Meanwhile, based on the iciness and frost characteristics of the north sea area, the asphalt deck pavement is optimally designed according to the layer performance-related concept and regarding the design as systems engineering, the structure System, waterproofing system and the mixture gradation. Finally, a designing index of the typical asphalt deck pavement and a technical criterion system are put forward, which may be adapted to the frost climate and the load characteristics in north sea region of China.

A good construction quality and a scientific construction control system are needed to meet the design requirement. The scientific, dynamic and quick mathematical statistics method and the detection approach should be adapted to the combined factors inluding the effect of bridge deck treatment, the degree and segregation of mixture paving the gradation deformation, the degree of compaction control, and the watering effect for a rapid reaction/adjustment.

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