STEEL DECK PAVEMENT DESIGN AND CONSTRUCTION OF PELJEŠAC BRIDGE

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Abstract

Steel bridge orthotropic deck paving has generally been a technical challenge in the field of bridge engineering due to its complexity and uniqueness. This article describes the detailed design and construction technologies of the waterproof bonding system and the asphalt pavement structure of the Pelješac Bridge. The entire pavement area of the carriageway is approximately 38,000 m2. The epoxy resin waterproof bonding system was applied in this bridge, which was approved and certified by the German ZTV-ING series specifications. It is divided into the base layer, adhesion layer made of reactive resins, and sticky layer. The asphalt pavement comprises two layers: protective and wearing. The protective layer is 4cm-thick mastic asphalt MA11 (German: Gussasphalt) with the polymer modified bitumen PMB 25/55-55A, while the wearing layer is 4cm-thick asphalt concrete AC11 with the PMB 45/85-65. The contractor, China Road and Bridge Corporation (CRBC) researched and designed the details of the bridge's waterproof bonding system and pavement structure in two years in advance to ensure that the waterproof bonding system and pavement structure can not only match the steel deck structure properly but also provide long-term stable performance in Mediterranean climate condition of high humidity, high salt content, and changeable weather. The contractor overcame the unfavorable objective conditions such as the difficulties in organizing special engineering equipment for paving, special bitumen materials, and special process operators required for paving. The deck pavement was accomplished within five months while maintaining a high level of quality. The acquired experience and exploration should be considered as a guideline for similar mega sea-crossing bridge steel orthotropic deck pavement projects in the future.

Keywords: steel deck paving, mastic asphalt (MA), asphalt concrete (AC), epoxy resin, polymer-modified bitumen(PMB), waterproof

1 Introduction

The extra-dosed cable-stayed bridge is located in the southern part of Croatia and crosses the Mali Ston Bay in the Adriatic Sea, connecting the Mainland with Pelješac peninsula. The project was mainly funded by the EU (85 %) and construction started in August 2018 and is being undertaken by CRBC. With a length of 2,440m including approach spans, the extra-dosed cable-stayed bridge has six towers with single central cable planes and five main spans of 285m [1]. The whole layout is 84 +108 +108 +189,5 + 5 x 285 +189,5 + 108 + 108 + 84 = 2404 m, and the total length of the bridge including abutments was 2440m [2]. The bridge lies in the region of Mediterranean climate, and this region is typically characterized by dry summers and mild, wet winters. The average annual amount of rainy days is 142 and the av-

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erage volume of annual precipitation is 1530 mm. November is the wettest month with 201.0 mm of precipitation. The coolest month is January with an average air temperature of 8.5 °Cand at night it could reach -4 °C, while the warmest month is August it exceed 40 °C, July is the most sunniest month with 324 hours of sunshine [3]. In addition, the strong wind has a serious impact on the bridge. The maximum 10-minute wind speed was 33.7 m/s, based on the local meteorological data recorded from 2005 to 2014, however, since 2018 the gust wind speed was breaking recorded over 50 m/s. The waterproofing construction would be seriously impacted by high salt content and humid sea wind.

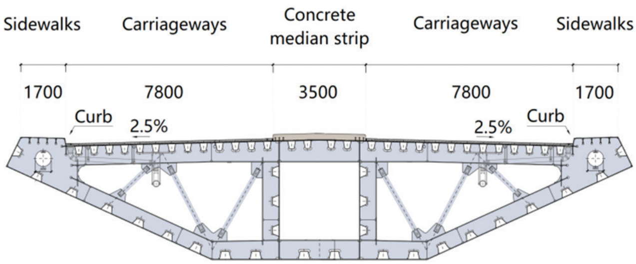

Figure 1 The various pavement regions of steel deck

The Pelješac bridge's carriageway deck is entirely steel box girder with 14mm-thick top plates except for the 6 pylons regions and both abutments, which have concrete surface, totaling 37,000 m² of steel deck and 1,000 m² of concrete surfaces. The same asphalt pavement structure could be applied to different bottom surfaces, however, the corresponding separate waterproofing systems must be constructed ahead of asphalt paving. The steel deck cross-section is divided into various functional areas, as a result, four different waterproof systems were adapted to two 7.8m-wide carriageways, 3.5m-wide concrete median strip, curbs, and sidewalks (Figure 1). In addition, the corresponding concrete bottom surfaces have also four waterproof systems. This article describes mainly the pavement detailed design and construction in the regions of carriageway.

2 Design and preparation work

The steel deck pavement structure design should comprehensively take into account the requirements of rust prevention, waterproofing, bonding, structural bearing capacity, durability, drainage, and final appearance. The detailed pavement structure of the carriageway is confirmed based on the German ZTV-ING series specifications as shown in Table 1 and Table 2.

Table 1 Steel deck pavement structure detailed design

	Structure layer	Detailed design	Technical requirements
Asphalt layer	Wearing layer	Asphalt concrete AC 11S with PMB 45/85-65	4 cm thick, compaction degrees ≥ 98 %
	Adhesive layer	Emulsified bitumen	0.5 kg/m²
	Protective layer	Mastic asphalt MA 11S with PMB 25/55-55A	4 cm thick, spreading 2 to 5 mm aggregate
Waterproof bonding layer	Sticky layer	Hot melt particles (MA special)	800 g/m², grain size 2 mm
	The adhesion layer	Epoxy resin material	1700 g/m², 1000 μm
	Base layer	Epoxy resin coating	215 g/m², 80 μm
	Steel deck plate	Shot blasting	Cleanliness Sa2.5

Table 2 Concrete deck pavement structure detailed design

	Structure layer	Detail design	Technical requirements
Asphalt layer	Wearing layer	Asphalt concrete AC 11S with PMB 45/85-65	4 cm thick, compaction degrees ≥ 98 %
	Adhesive layer	Emulsified bitumen	0.5 kg/m²
	Protective layer	Mastic asphalt MA 11S with PMB 25/55-55A	3.7 cm thick, spreading 2 to 5 mm aggregate
Waterproof bonding layer	Waterproof layer	Bituminous membrane	4 mm thick
	Base layer	Epoxy resin coating and 0.3-0.8 mm sand	500 g/m² / 0.5-0.8 kg/m²
	concrete deck	Shot blasting	Surface clean

The mature epoxy resin technology was used for the waterproof bonding system in this project. After curing, the resin materials have high tensile and bonding strength, the epoxy resin materials become more resistant to rutting and delamination than asphalt waterproof materials. The material HM Primer and HM Mastic were applied as epoxy resin primer and resin bonding layer in the waterproofing system respectively, which were tested and certified by the German specification ZTV-ING Part 7, Section 4, design type 1 [4]. Besides, waterproofing is the most significant phase of steel deck pavement, therefore, the overlapping of the various waterproof systems must be paid more attention to. The bituminous membranes on concrete zone extended 20 cm toward the steel deck's sticky layer. Besides, for the overlapping position between the deck and the curb, the bottom 12cm-tall curbs were applied in the same waterproofing system as the steel deck. Finally, asphalt rubber waterproof tapes were widely applied to the lap joints, such as the steel deck and concrete median strip, the wearing layer and curbs. These mentioned lap joints are typically the weakest places of waterproofing, improving the pavement durability by strengthening its quality. As mentioned the deck pavement design was based on the German ZTV-ING series specifications, however, the climate in the Mediterranean region is quite different from in Germany. As a result, the contractor started to collect and record the meteorological data on-site in 2018, the recorded highest air temperature in August is up to 44 °C and the road surface temperature exceeded 60 °C. Therefore, the asphalt stability at high temperature on-site must be paid more attention to than that in high latitudes in Germany. The initially proposed polymer modified bitumen PMB 45/80-50 with the softening point of 50 degrees centigrade was applied to the asphalt concrete mixture of the wearing layer, which could not resist the high temperature during the hot summer season in Croatia obviously. Finally, the required softening point of the bitumen is increased up to 65 degrees centigrade, which is modified according to the client Croatian roads technical guideline TUAK 2015 [5]. The new modified bitumen possesses less temperature sensitivity than PMB 45/80-50 while maintaining its workability at high temperatures. As a consequence, it could meet the anti-rutting technical requirement during the summer.

3 Construction and quality control

3.1 Shot blasting

At the present, the advanced vehicle-mounted 1.2-meter-wide shot blasting equipment is widely adopted for steel deck bridge construction. The operator can handle approximately 2000 m² each day. However, there is no such equipment in surrounding European countries, and the expense of dispatching such specialized equipment from China is quite expensive.

As a consequence, the contractor utilized 3 sets of 80 cm and 50 cm-wide dust-free shot blasting machines respectively. The moving speed was around 0.5 m/min, the 80cm-wide machine could shoot blast the steel surface approx. 25 m^2/hour, based on the air temperature and humidity of that day, approximately a total of 1300 m^2 of deck surface were cleaned every day (Figure 2).

Figure 2 Shot blasting construction (September. 2021) Credit: CRBC

Through numerous on-site testing, the optimal ratio of steel shot and steel grit was finally confirmed at 5:1, resulting in the best Sa 3.0 cleanliness of steel plates. The humidity on-site became so high since the beginning of autumn, the shot blasting operation was carried out when the humidity dropped below 85 %. The cleanliness and salt content of the steel plate surface affects the quality of shot blasting and primer coating directly so the contractor used sweepers to clean the greasy dirt on the steel deck in advance and ensure the salt content should be less than 70 µS/cm as well. The circumferential seam regions of adjacent steel box girders should be sufficiently smooth that the flatness was controlled less than 1.5 mm.

3.2 Primer and waterproofing

To avoid the re-oxidation and corrosion of the steel surface, the primer coating was painted with the rollers by operators within 3 hours after shot blasting, and the surface dust was blown away by the vacuum before the deck was painted. The waterproof system's test results of the tear strength, shear strength and thermal stability behavior exceeded the requested values in the standards. This waterproof system had been tested by the contractor in the laboratory for at least 24 hours underwater pressure of 0.3 MPa, and the results indicated good permeability due to no water leakage. The wet film thickness of waterproof materials on-site was measured no less than 1100 microns. The modified hot-melt adhesive particles were manually spread evenly on the bonding layer, with a grain size of around 2 mm. The adhesive performance with steel deck was inspected by pull-off testing, the adhesive force was up to 8 MPa, which was more than the requested 2 MPa in the specification. The adhesion testing was performed on the separate samples instead of on the bridge waterproof layer, which was constructed to the same structure and kept under the same environment. In this way, the waterproof bonding system was avoided the destructive damage. The whole waterproofing layer was constructed within seven days after the primer was painted. The bonding effect with the steel deck plates is directly affected by the curing performance of the waterproof layer. As a result, entering into the waterproof layer before fully curing is prohibited. The operators working on the waterproof layer must wear nailed shoe with covers (Figure 3), besides, the mastic asphalt cooker truck's tires were washed with clean fresh water, avoiding damage by soil and crushed stone the waterproof bonding system.

Figure 3 The epoxy resin waterproofing system construction (October. 2021) Credit: CRBC

3.3 Protective layer construction

Mastic asphalt (MA) mixture is mixed and produced under quite a high temperature between 200 °C and 230 °C, it has great fluidity when it is cast on-site, it could fluid and spread by itself without rolling. It is a special asphalt mixture with a high bitumen and mineral powder content and a porosity of less than 1 %. As a result, MA production in the asphalt plant and transportation are huge challenges for the contractor. The total quantity of MA and AC is just approximately 7400 tons, which is not economic to set up a new asphalt plant for asphalt mixture supply. Therefore, the contractor purchased commercial MA from the asphalt plant 35 km away, which has a production capacity of 35 tons per hour. Although the distance is not so far, the route passed through Bosnia and Herzegovina's customs, as a result, the transport period took around 1 to 1.5 hours on the way. The contractor applied a total of 8 mastic cooker trucks with a capacity of 20 tons to ensure the continuity of asphalt cast on-site. The mastic cooker trucks traveled circularly between the bridge site and the asphalt plant. The travel speed of the finisher on the deck was controlled at around 1.0 m/ min. The overall width of the carriageway is 7.8 meters, the mastic asphalt special paving equipment Finisher was adopted to pave the central 5.95m-wide carriageway fully (Figure 4), the rest of both sides regions connecting to the concrete median strip (0.85-meter-wide) and connecting to steel curbs (1-meter-wide) were completed by the Finisher subsequently. The premixed bitumen (1 %) crushed aggregates with a grain size of 2 to 5 mm were spread evenly on the MA surface and embedded into mastic asphalt by the rollers.

Figure 4 Mastic asphalt MA11S pavement construction (November 2021) Credit: CRBC

The contractor paid more attention to the details of the construction to improve overall quality. Firstly, fluidity is the dominant factor of mastic asphalt, the temperature of the mixture must be controlled ranging from 200 to 230 °C during the paving. Then, the bitumen PMB 25/55-50A and MA mixture tested results were all significantly higher than the requested values in German specifications TL Bitumen-StB 07/13 and TL Asphalt-StB 07, as shown in Table 3 and Table 4. After that, the 4cm-thick fusible bituminous joint tapes were stuck on the side surfaces of the concrete median strip and steel curbs, to enhance the joints quality. Besides, the Finisher traveled along the 4cm-thick steel track seriously, the mold dope was painted on the steel tracks inside. In the end, the joint regions were treated carefully, the hardening edges were all preheated with a flame gun to ensure the fused quality of the joint region.

Table 3 Polymer modified bitumen PMB 25/55-50A real tested values

Tested items	**Penetration Index, 25 °C** [mm/10]	**Softening point** [°C]	**Fraass breaking point** [°C]	**Elastic recovery, 25 °C** [%]
TL Bitumen-StB 07/13	25 - 55	≥55	-10	≥50
Tested average value	34.3	80	-10.8	73

Table 4 MA11S asphalt mixture real tested values

Tested items	**Bitumen** [%]	**Mineral powder** [%]	**Penetration, 40 °C** [mm]	**Penetration increment** [mm]	**Pouring temperature** [°C]
TL Asphalt-StB 07	≥6.8	/	1 - 3	<0.4	200 - 230
Tested average value	7.2	28	2	0.2	219

3.4 Asphalt concrete layer construction

The polymer-modified bitumen PMB 45/80-65 replaced the initial design of PMB 45/80-50A for asphalt concrete (AC) mixture of AC11, and the raised softening point is helpful to the pavement stability at high temperatures. The real-tested average value of softening point was 79 °C. The total quantity of wearing layer is approximately 3700 tons asphalt concrete, the contractor applied the wide asphalt paver to pave the 7,8 m-wide carriageway on one side entirely one-off, avoiding longitudinal joints occurred. In order to ensure the adhesion performance between the mastic asphalt layer and wearing layer, the emulsified bitumen was sprayed on the surface of the mastic asphalt layer one day in advance. The travel speed of the paver was around 2.5 m/min, it was quite faster than that of mastic asphalt paving. As a result, 20 sets of 20-tonne dump trucks were utilized to provide a steady supply of asphalt concrete on-site. Meanwhile, 6 sets of 9-ton steel double drum road rollers cooperated with the paver to compact the wearing layer repeatedly, besides, the regions of expansion joints and the overlapping joints were compacted by a 2-ton road roller, all these road rollers are also equipped with a specialized vibrating component so that the surface was flattened and compacted quickly and efficiently (Figure 5). The AC11S wearing layer's compaction degree was tested by the advanced non-nuclear asphalt density meter instead of the traditional core samplings. This gauge is quite efficient to check the compaction degree and the surface temperature in several seconds on-site and avoided damage to the wearing layer. The initial compacting temperature was controlled not less than 150 °C, and the detailed test items and results as shown in Table 5. The flatness was evaluated by International Roughness Index (IRI_{100}). Its tested IRI_{100} values within the traffic lane on both directions was ranging from 0.60 m/km to 1.42 m/km, as well as the average value was 0.87 m/km, which were less than the requested 1.5 m/km at an operating speed of 60 km/h in the TUAK 2015 [5]. The whole wearing layer was continuously constructed and accomplished within four working days in January 2022.

Table 5 Wearing layer AC11 test results

Tested items	**Degree of compaction** [%]	**Flatness IRI$_{100}$** [m/km]	**Texture depths** [mm]	**Resistance to slipperiness** [SRT units]
Limited values	≥ 98	≤ 1.5	≥ 0.35	≥ 55
Tested values	98.6	0.87	0.39	57

Figure 5 Wearing layer AC11S construction (Jan.2022) Credit: CRBC

Conclusion

The contractor thoroughly researched the epoxy resin waterproofing bonding system in advance, performing numerous testings and collecting current climate data to assess the work performance. German industrial specifications are made depending on their domestic nature, climate, and industry level, which cannot be directly copied and used in other countries. The epoxy resin waterproofing system indicated excellent work performance. Meanwhile, the polymer-modified bitumen PMB 45/80-65 applied to wearing layer construction, which matches the Mediterranean climate conditions in Croatia. Although the Covid-19 pandemic as force majeure had a serious impact on raised prices of raw material and logistics and the heavy rainfall in winter delayed the whole paving progress, the contractor accomplished such a huge quantity of steel deck pavement with high quality and on schedule. The acquired engineering experience could be treated as good reference for mega sea-crossing steel orthotropic deck pavement in the future.

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