Research on steel bridge deck pavement mechanical response of Urumqi express way

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Abstract. The cold climate of Urumqi influences the pavement performance of steel bridge. Mechanical response and suitable pavement system of Urumqi express way steel bridge deck pavement were studied in this paper. ABAQUS was utilized to build a model of steel bridge deck pavement. Maximum tension stress, maximum tension strain, maximum vertical displacement and maximum inter-laminar shearing stress of "double EA" pavement structure and "lower EA+upper SMA" pavement structure under different pavement thicknesses and different ambient temperatures were calculated. Results indicate that when both the pavement materials of upper layer and lower layer of pavement structure are same, the maximum tension stress, the maximum tension strain, the maximum vertical displacement and the maximum inter-laminar shearing stress of "lower 3cm+upper 4cm" pavement structure are smaller than both "lower 2.5cm+upper 3.5cm" pavement structure and "lower 3cm+upper 3.5cm" pavement structure; at the range of -45°C ~ 70°C, when the pavement materials of upper layer and lower layer of pavement structure is different, the increase of temperature will lead to the decrease of maximum tension stress and maximum inter-laminar shearing stress and will also lead to the increase of the maximum tension strain and the maximum vertical displacement; the maximum tension stress of "double EA" pavement structure is larger than "lower EA+upper SMA" pavement structure; the maximum tension strain, the maximum vertical displacement and the maximum inter-laminar shearing stress of "double EA" pavement structure are close to "lower EA+upper SMA" pavement structure; the "lower 3cm EA+upper 4cm SMA" pavement structure is recommended for the steel bridge deck pavement of Urumqi expressway.

Keywords: maximum tension stress, maximum tension strain, maximum vertical displacement, maximum inter-laminar shearing stress.

1. Introduction
Vehicle load will lead to fatigue cracking and rutting of steel bridge deck pavement, and the failure of bonding layer. The mechanical response of steel bridge deck pavement under vehicle load also affects the durability and stability of the bridge structure. The mechanical evaluation indexes should be used to design the steel bridge deck pavement.

Existing research mainly focused on the effects of static load response, moving load and ambient temperature on steel bridge deck pavement. The mono-wheel load was usually adopted to study the mechanical response of steel bridge deck pavement and the modulus at room temperature (30°C) was usually adopted. Qian et al. [1] adopted finite element program to analysis the mechanical response of

steel bridge deck pavement, put forward the mechanical evaluation indexes and analyzed the influence of pavement parameters on the mechanical response of steel bridge deck pavement. Cheng [2] built a steel bridge deck pavement model under moving vehicle load and analyzed the mechanical response of pavement under different moving loads. Lu et al. [3] studied the temperature field distribution of steel bridge deck pavement and analyzed the temperature distribution regularity of steel bridge deck pavement. Liu et al. [4] measured the temperature of asphalt pavement of Runyang Bridge when the bridge was paving and the influence of asphalt concrete pavement on the temperature distribution of steel-concrete box girder was obtained. However, there were few studies on the mechanical response on steel bridge deck pavement under different pavement thicknesses, different pavement materials and low temperature.

Urumqi Express Way steel bridge is located in extremely cold areas. The annual average ambient temperature of Urumqi is 6.9°C and the ambient temperature ranges from -45°C to 40°C. Higher performance of steel bridge deck pavement material and structure should be put forward so that to accommodate the extremely cold climate of Urumqi. Relying on the Urumqi Express Way steel bridge project, this paper will build a steel bridge deck pavement system model through numerical simulation. The maximum tensile stress, tensile strain, vertical displacement and inter-laminar shearing stress can be used to evaluate the mechanical performance of steel bridge deck pavement [5-7]. So the maximum tensile stress, tensile strain, vertical displacement and inter-laminar shearing stress of pavement upper surface of "double epoxy asphalt" pavement structure ("double EA" pavement structure) and "lower epoxy asphalt +upper stone matrix asphalt "pavement structure ("lower EA+upper SMA" pavement structure) under different pavement thicknesses and working temperatures were calculated in this paper so that to study the mechanical response of Urumqi Express Way steel bridge deck pavement and put forward a suitable pavement structure of Urumqi Express Way steel bridge.

2. Numerical simulation

2.1. Numerical model of steel bridge deck pavement system
Steel bridge deck epoxy asphalt pavement system model has been built by ABAQUS. There are 4 diaphragm plates in longitudinal direction and 7 stiffening rib in transverse direction, as is shown in Figure 1. According to the designed parameters of Urumqi Express Way steel bridge, the detail parameters of steel bridge deck pavement system model is shown in Table 1.
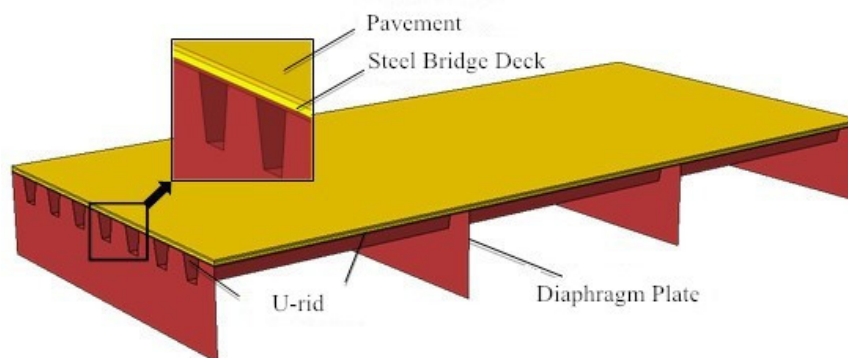
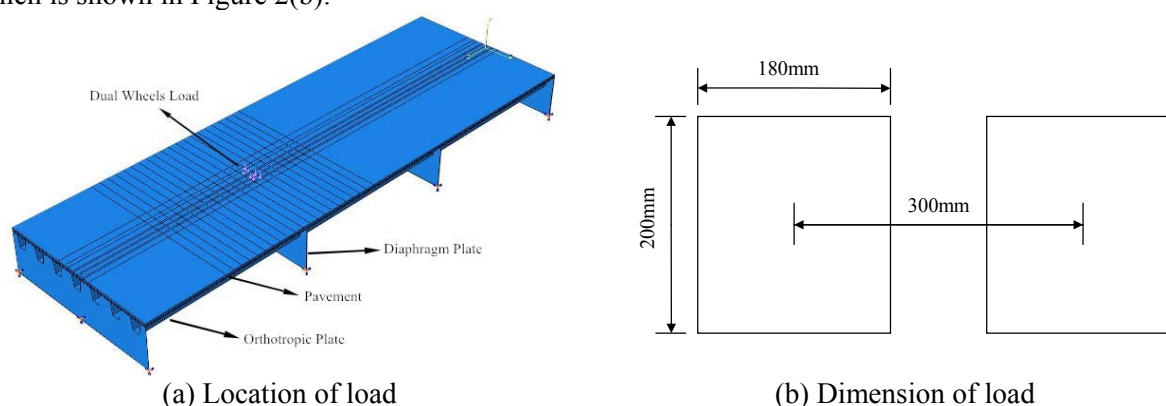**Figure 1.** The model of steel bridge deck pavement system.

Table 1. The detail parameters of steel bridge deck pavement system model.

Geometry Size			
Width of U-rid (mm)	Height of U-rid (mm)	Thickness of U-rid (mm)	Spacing of U-rid (mm)
280	280	8	600
Thickness of Diaphragm Plate	Spacing of Diaphragm Plate	Thickness of pavement (mm)	Thickness of steel deck (mm)

(mm)	(m)		
14	3	60	16

2.2. Load position
According to the investigation of Urumqi Express Way steel bridge engineering, the main damages of bridge deck pavement is longitudinal cracks because of the transverse tensile stress [8, 9]. So the key mechanical control index of bridge deck pavement is maximum transverse tensile stress located on the pavement surface above the stiffening ribs. The second important mechanical control index of bridge deck pavement is maximum longitudinal tensile stress located on the pavement surface above diaphragm plates. The dual wheels load (0.7MPa) is adopted in this paper. And the dual wheels load is exerted on the pavement surface above longitudinal stiffening rib and the pavement surface above diaphragm plate, as is shown in Figure 2(a). The dimension of dual wheels load is 200mm×180mm×2 which is shown in Figure 2(b).

(a) Location of load   (b) Dimension of load

Figure 2. The setting of load.

2.3. Output of mechanical control indexes
Fatigue cracking, rutting and the failure of bonding layer is the general damages of steel bridge deck pavement. The tensile stress and strain on pavement surface will lead to fatigue cracking. The insufficient resistance to permanent deformation will lead to rutting. The insufficient shear strength will lead to the failure of bonding later [10]. So the maximum tensile stress, tensile strain, vertical displacement and inter-laminar shearing stress are selected as the mechanical control indexes to evaluate the mechanical performance of steel bridge deck pavement so that to put forward a suitable pavement project of Urumqi Express Way steel bridge.

3. Results and conclusions

*3.1. Effects of pavement thickness on the mechanical control indexes*
According to the meteorological data of Urumqi, Urumqi is located in extremely cold area and the annual average ambient temperature is 6.9℃. The modulus and Poisson's ratio of epoxy asphalt concrete and SMA at 10℃ is shown in Table 2. The thickness of steel bridge deck asphalt concrete pavement ranges from 50mm to 80mm [11]. The effects of pavement thickness on the mechanical control indexes of steel bridge deck pavement are discussed in this section. Respectively calculate the mechanical control indexes of "double EA" pavement structure and "lower EA+upper SMA" pavement structure. The thickness of pavement layer adopts "lower 3cm+upper 3.5cm", "lower 2.5cm+upper 3.5cm" and "lower 3cm+upper 4cm", respectively. Moreover, according to the results, a suitable pavement thickness project of Urumqi Express Way steel bridge will be put forward. The calculated results are shown in Figure 3.

**Table 2.** Parameters of steel bridge deck system.

| Parameters of Steel Deck		Parameters of Epoxy Asphalt Concrete		Parameters of SMA	
Modulus (MPa)	Poisson's Ratio	Modulus (MPa)	Poisson's Ratio	Modulus (MPa)	Poisson's Ratio
$2.1×10^5$	0.25	10000	0.25	7500	0.25
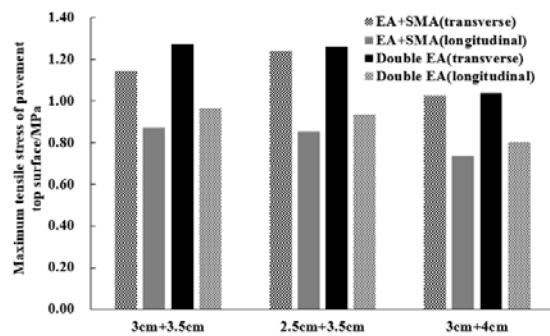
(a) Pavement thickness versus maximum tensile stress of pavement top surface
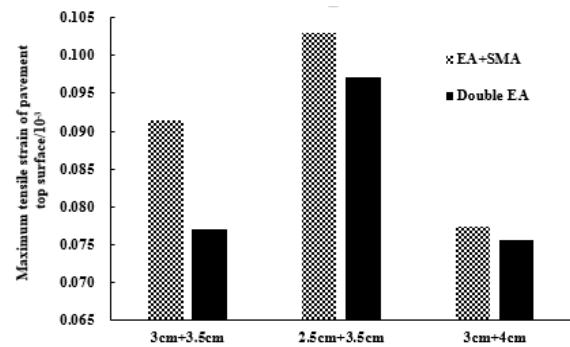
(b) Pavement thickness versus maximum tensile strain of pavement top surface
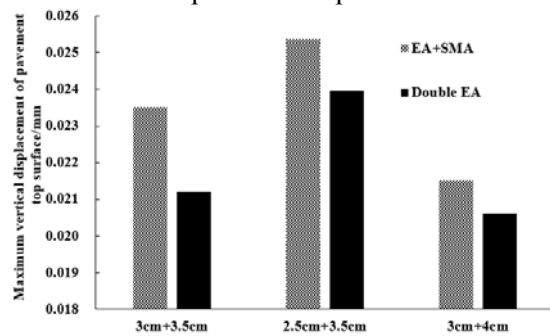
(c) Pavement thickness versus maximum vertical displacement of pavement top surface
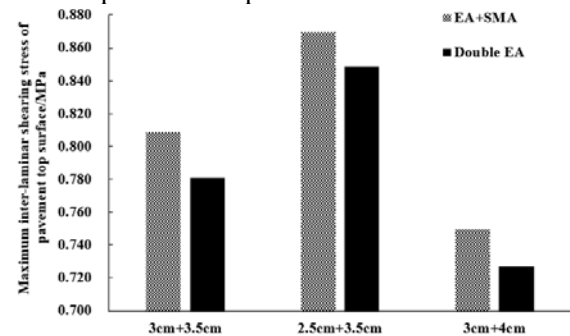
(d) Pavement thickness versus maximum inter-laminar shearing stress of pavement top surface

Figure 3. Effects of pavement thickness on the mechanical control indexes.

As is shown in Figure 3, the maximum tensile stress, tensile strain, vertical displacement and inter-laminar shearing stress of the 3 kinds of pavement thickness projects are compared and the regularity is "lower 2.5cm+upper 3.5cm" pavement structure > "lower 3cm+upper 3.5cm" pavement structure > "lower 3cm+upper 4cm" pavement structure. The "lower 3cm+upper 4cm" pavement structure is recommended to apply to Urumqi Express Way steel bridge.

Then the maximum tensile stress (σ), tensile strain (ε), vertical displacement (U) and inter-laminar shearing stress (τ) of the 3 kinds of pavement material projects of "lower 3cm+upper 4cm" pavement structure are compared and the regularity is $\sigma_{double\ EA} > \sigma_{EA+SMA}$, $\varepsilon_{double\ EA} < \varepsilon_{EA+SMA}$, $U_{double\ EA} < U_{EA+SMA}$ and $\tau_{double\ EA} < \tau_{EA+SMA}$.

The mechanical control indexes of "double EA" pavement structure and "lower EA+upper SMA" pavement structure at 10℃ are calculated in this section. However, temperature is the main factor influencing the material properties of asphalt mixture, so the suitable pavement material project of Urumqi Express Way steel bridge cannot be put forward in this section.

3.2. Effects of temperature on mechanical control indexes of steel bridge deck pavement
Temperature is the key factor influencing the material properties of asphalt mixture [12, 13]. According to the meteorological data of Urumqi, the environment temperature of Urumqi ranges from -45°C to 40°C which belongs to the extremely cold area. The temperature of steel bridge deck is

usually 10°C higher than traditional truss bridge, because the steel box girder is not ventilated and the thermal dissipation of steel box girder is slow in summer [14].

This paper mainly studies the pavement design of Urumqi Express Way steel bridge at the working temperature ranging from -45°C to 70°C, the mechanical control indexes of "double EA" pavement structure and "lower EA+upper SMA" pavement structure at different temperatures are calculated and according to the calculated results, the suitable pavement material project of Urumqi Express Way steel bridge can be put forward. The moduli of asphalt mixture at different temperatures are shown in Table 3 and the calculated results is shown in Figure 4.

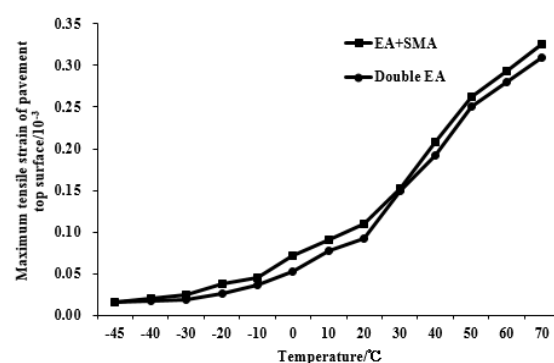**Table 3.** The moduli of asphalt mixture at different temperature(mpa).

Temperature/°C Mixture	-45	-40	-30	-20	-10	0	10
EA	21300	21200	21000	20000	18000	13000	10000
SMA	13100	13100	13200	13000	12000	9000	7500

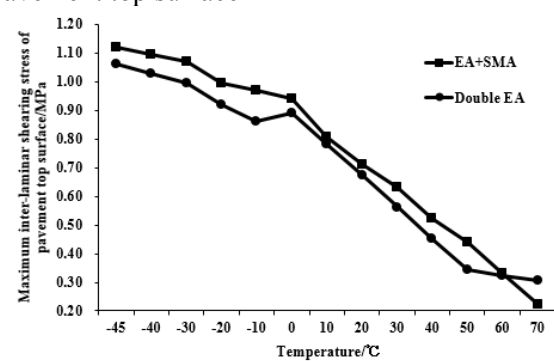| Temperature/°C Mixture	20	30	40	50	60	70	
EA	8000	3200	1800	1200	800	600	
SMA	5500	2500	1100	800	600	550	
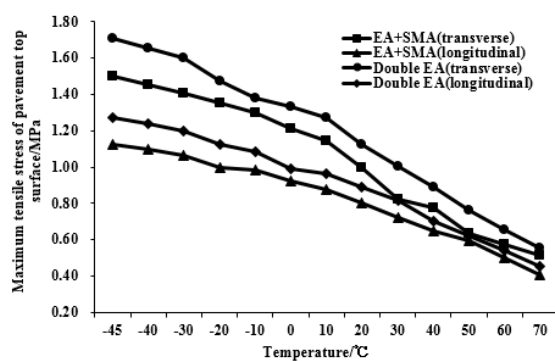
(a) Temperature versus maximum tensile stress of pavement top surface

(b) Temperature versus maximum tensile strain of pavement top surface
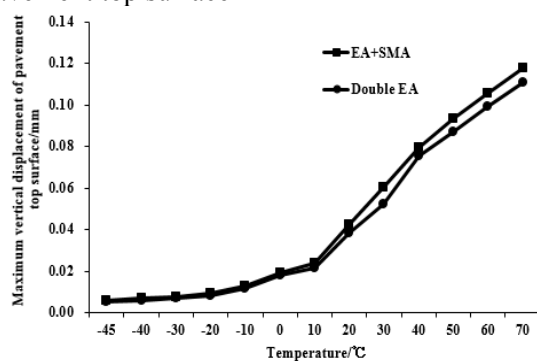
(c) Temperature versus maximum vertical displacement of pavement top surface

(d) Temperature versus maximum inter-laminar shearing stress of pavement top surface

Figure 4. Effects of temperature on mechanical control indexes.

As is shown in Figure 4, the maximum tensile stress and inter-laminar shearing stress of "double EA" pavement structure and "lower EA+upper SMA" pavement structure increase with the decrease of temperature. The maximum tensile strain and vertical displacement decrease with the decrease of

temperature. The maximum tensile stress of "lower EA+upper SMA" pavement structure's top surface is smaller than "double EA" pavement structure at the same temperature. The maximum tensile strain, vertical displacement and inter-laminar shearing stress of "double EA" pavement structure's top surface are similar to "lower EA+upper SMA" pavement structure. The "lower 3cm EA+upper 4cm SMA" pavement structure is recommended to apply to Urumqi Express Way.

4. Conclusions

(1) The maximum tensile stress, tensile strain, vertical displacement and inter-laminar shearing stress of the 3 kinds of pavement thickness projects are compared and the regularity is "lower 2.5cm+upper 3.5cm" structure > "lower 3cm+upper 3.5cm" structure > "lower 3cm+upper 4cm" structure.

(2) The maximum tensile stress and inter-laminar shearing stress of "double EA" structure and "lower EA+upper SMA" structure increase with the decrease of temperature. The maximum tensile strain and vertical displacement decrease with the decrease of temperature. The maximum tensile stress of "lower EA+upper SMA" structure's top surface is smaller than the maximum tensile stress of "double EA" structure's top surface at the same temperature. The maximum tensile strain, vertical displacement and inter-laminar shearing stress of "double EA" structure's top surface is similar to "lower EA+upper SMA" structure's top surface's.

(3) "Lower 3cm EA+upper 4cm SMA" structure is recommended to apply to Urumqi Expressway. This paper has studied the static load response of steel bridge deck pavement, however, the main type of loads on steel bridge deck pavement is dynamic load which is not similar to the load exerted in the model of this paper.

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