NUMERICAL STUDY ON STRESS REDUCTION EFFECT OF STEEL FIBER REINFORCED CONCRETE (SFRC) OVERLAY IN ORTHOTROPIC STEEL DECK (OSD)

Tokyo Metropolitan University Student Member ○Mark Joel Bañares Uaje
Tokyo Metropolitan University Regular Member Jun Murakoshi

1. INTRODUCTION

The orthotropic steel deck (OSD) is commonly used in long-span bridges because of its lightweight and high capacity-to-weight ratio properties. However, it is prone to fatigue cracking. Cracks that initiate from the root of the weld and penetrate the deck or the so-called root-deck cracks have been found in bridges in Japan, as well as China, Netherlands, and Belgium. The Japanese highway bridge specifications addressed this issue by increasing the requirement of the thickness of the steel deck from 12 mm to 16 mm. Meanwhile, bridges that were constructed before this revision and suffered fatigue damage under heavy traffic condition are being reinforced by overlays such as steel fiber reinforced concrete (SFRC) to suppress the stress and crack growth. While a previous study by Murakoshi et al. (2019) clarified the reinforcing effect of SFRC on 12-mm steel decks, it is still important to accumulate data on the fatigue behavior with respect to the deck thickness. Furthermore, the previous study utilized the local stress approach, which might produce arbitrary or infinite values at stress concentration, hence limiting its comparison within its model. The current study aims to clarify the stress-reduction effect of using either SFRC or asphalt in both 12-mm and 16-mm steel decks. Moreover, the current study utilized the effective notch stress approach which handled the stress concentration at the root.

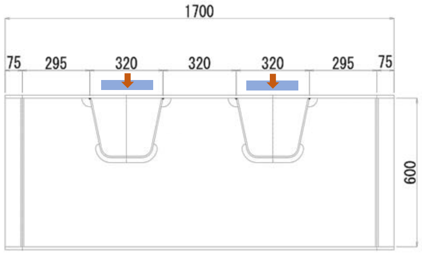

Fig. 1. Configuration of the OSD specimen.

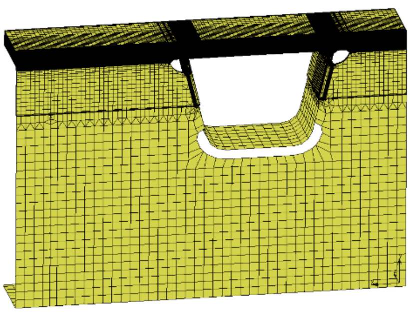

Fig. 2. Finite element model of the OSD specimen.

2. FINITE ELEMENT MODEL

The configuration and the corresponding finite element model used in this study are shown in Fig. 1 and 2 respectively. This configuration was based on the specimens of the previous study by Murakoshi et al. (2019). The deck is welded to the 6-mm trough rib by partial penetration of 75%. For efficiency, symmetry was utilized by modeling only half the span and half of the section, or essentially one-fourth of the configuration shown in Fig. 1. The appropriate boundary conditions were provided to account for the symmetry, as well as the simply supported condition of the whole OSD. The upper portion including the deck and the deck-to-rib weld was modeled as 8-node solid elements, while the lower portion was modeled as 4-node shell elements. It is subjected to a 25 kN wheel load applied over a contact area of 200 mm by 100 mm. This is equivalent to subjecting the whole configuration to a 50 kN wheel load over an area of 200 mm by 200 mm per U-rib.

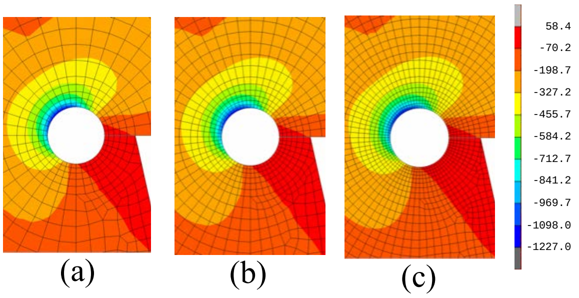

Fig. 3. Minimum principal stress (MPa) contour at the root with the minimum mesh size: a) 0.08 mm b) 0.06 mm c) 0.04 mm.

A fictitious notch is introduced at the root, effectively averaging the stress. The radius of the notch was set to be 0.5 mm to accommodate the weld penetration. As per the recommendation of the International Institute of Welding (Fricke, 2012), the minimum linear element mesh size was taken to be one-sixth of the radius, i.e., 0.08 mm. Away from the notch, the mesh size was then gradually increased. A gap of 0.01 mm was provided between the deck and the trough rib.

To confirm the suitability of the mesh size, a sensitivity analysis using an unpaved, 12-mm steel deck model was conducted by varying the minimum mesh size around the notch. Since the minimum recommended mesh is 0.08 mm, finer minimum meshes of 0.06 mm and 0.04 mm were tested. The mesh size of the rest of the elements around the notch is then adjusted as shown in Fig 3. It should be noted that the contour shape of the minimum principal stress among the three models is set to be the same. Based on the stress contour, it can be argued that the three models have no meaningful difference. This is supported further by the insignificant percent difference of the critical minimum principal stress which is 0.53% for the 0.06 mesh and 1.5% for the 0.04 mesh. The point with the critical minimum principal stress is located 54 degrees clockwise from the horizontal, with the crack direction likely to initiate at about 42 degrees for the three models. Therefore, it can be concluded that the use of a minimum mesh of 0.08 mm is sufficient.

Keywords: Root-deck crack, Effective notch stress, SFRC, Fatigue
Contact address: Tokyo Metropolitan University 1-1, Minami-Osawa, Hachioji-shi, Tokyo, 192-0397, Japan
Email: uaje-mark-joel-banares@ed.tmu.ac.jp

The unpaved, 12-mm steel deck model was also validated by comparing the experimental testing strain data from the study of Murakoshi et al. (2019). The location of the 3-mm strain gauges is shown in Fig. 4. Gauges at the top were placed at the centerline projection of the trough rib. Gauges No. 5, 8, 9, and 12 were placed 5 mm from the weld toe. Gauges No. 6, 7, 10, and 11 were placed 5 mm from the trough rib inside surface. All the gauges are in the centerline of the crossbeam. To obtain the strain range, Murakoshi et al. (2019) obtained the difference in strain when the specimen is subjected to 10 kN and 110 kN axle loads. This is then compared to the transverse strain from the current analysis. It can be seen from Fig. 5 that the analysis strain follows the testing closely. Hence, from the point of view of experimental data, the current analysis model is valid.

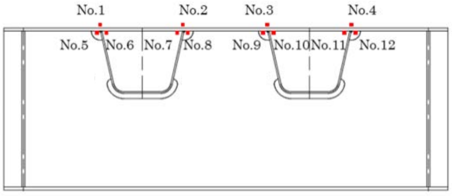

Fig. 4. Strain gauge location Murakoshi et al. (2019).

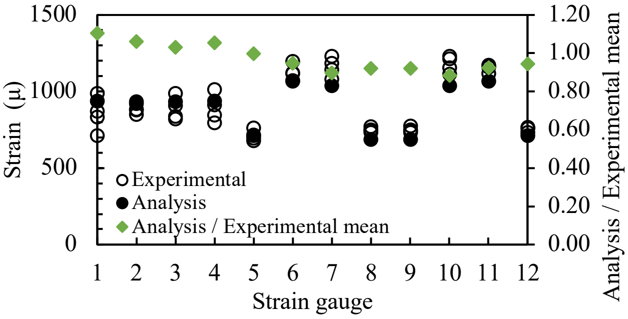

Fig. 5. Strain comparison of testing and analysis.

3. ROOT STRESS

Two main configurations were considered: 12-mm and 16-mm steel decks. It is then combined with a pavement on top ranging from 0 mm, i.e., unpaved, to 75 mm. The applied load caused a compressive bending behavior at the weld root. It is assumed that high residual tensile stresses are present in the area and thus, the net stress is still in tension. Shown in Fig. 6 and 7 are the critical minimum principal stress at the root. As shown, using an unpaved 16-mm steel deck improves the stress condition significantly (35%), in contrast to using an unpaved 12-mm steel deck. In all configurations, using SFRC with a modulus of elasticity of 40000 MPa has the greatest improvement in the stress condition. By using a 25-mm SFRC overlay, the 12-mm steel deck can be improved by 66%, while the 16-mm steel deck can be improved by 52%. However, as the thickness of the SFRC increases, the improvement becomes marginal. In particular, the 16-mm steel deck is improved by 78% when a 75-mm SFRC overlay is used, which is close to when a 50-mm SFRC overlay is used instead (71%).

Because the temperature affects the stiffness of the asphalt, three types of asphalt were analyzed according to the three seasons: winter, spring, and summer. As the temperature decreases, the stiffness is expected to increase. The modulus of elasticity was set to 5000, 1500, and 500 MPa respectively. It should be noted that the stiffness during spring and autumn is assumed to be the same. For the 12 mm steel deck, the critical principal stress is significantly affected by the temperature. The 38% improvement of using a 25-mm asphalt in winter decreases to 19% during spring and further decreases to 9% during summer. However, when a 16-mm steel deck is used, the change becomes smaller. The 25% improvement using a 25-mm asphalt decreases to 12% during spring and 6% during summer.

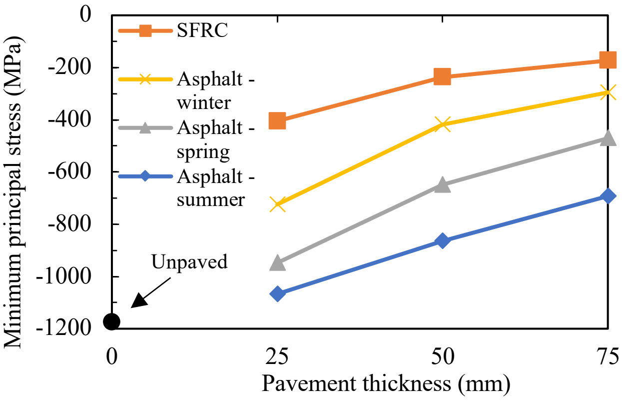

Fig. 6. Critical root stress for 12-mm steel deck.

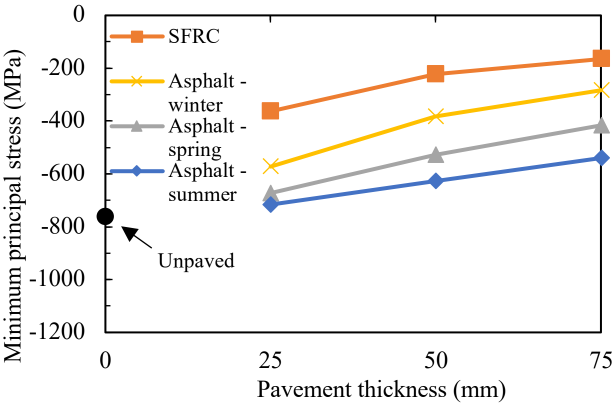

Fig. 7. Critical root stress for 16-mm steel deck.

4. CONCLUSIONS

The effective notch stress approach was conducted to clarify the stress-reduction effect of using a 16-mm steel deck compared to a 12-mm. The reinforcement using an overlay was also considered. It can be concluded that using a 16-mm steel deck significantly improves the stress condition compared to a 12-mm steel deck. On the other hand, if a 12-mm steel deck was already constructed, the use of an SFRC overlay significantly reduces the stress.

REFERENCES

Fricke, W.: IIW recommendations for the fatigue assessment of welded structures by notch stress analysis: IIW-2006-09. Woodhead Publishing, 2012.

Murakoshi, J., Mori, T., Haba, S., Ono, S., Sato, A., & Takahashi, M.: Retrofit Effect of Sfrc Overlay on Fatigue Durability of Orthotropic Steel Decks with Cracks Extending to Deck Plate. Journal of Japan Society of Civil Engineers, Ser. A1 (Structural Engineering & Earthquake Engineering (SE/EE)), 75(2), 2019 pp. 194-205.