Research on Load Adaptability of Existing Hollow Slab Bridge of Ji-Qing Highway

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Abstract. Throughout the reconstruction and expansion process of the Jinan and Qingdao Expressway, there is a need for the existing Bridge to be demolished first and then reinforced for a better utilization. In order to better evaluate the load capability of the Level 1 lane, the load ability of the Seven-Ministry loads adaptability model and the current Ji-Qing traffic model, this paper examines three models of the load adaptability of existing small span Bridges. The load adaptability of the three load models on the old bridge of Jiqing existing line is analysed by comparing the bearing capacity level of the three load models in the three spans of 5m, 8m, and 13m of the hollow slab bridge.

1. Introduction

Ji-Qing Expressway designing programs includes two parts: expansion from 4 lanes to 8 lanes and reinforcement of the existing highway. The process of lanes expansion from 4 to 8 contained a large part of small-medium span old bridge based on the 85 Standard. The application of the 14th version of project adaptation & expansion details and the 14th version highway project technical guidance has become a critical issue faced by the project. Through the comparison and analysis of the Level 1 Highway Lane Load capability, the Seven Ministries Overloading Model and Ji-Qing Expressway actual load capability model, we can research on the load adaptability of the small-medium spans existing old bridge. This comparison can determine whether we can consolidate and utilize the current old bridge under the existing traffic load model, to avoid demolition and reconstruction.

2. Hollow Slab Bridge Load Capability Analysis

Hollow Slab Bridge Effect is based on the typical road span of 26m, by calculating and comparing respective load ability effect of different spans such as 5m, 8m, 13m. Road width of 26m hollow slabs fracture surface sample is shown in figure 5. According to the load type, we can apply single-lane, two-lane, three-lane load ability by taking into consideration the longitudinal and lateral reduction of impact force on the automobile, and calculating the structural load effect and its resistance.

Figure 1 Typical hollow slab fractual section with width of 26m subgrade
3. Ji-Qing line load capacity evaluation
The highway bridge design baseline period is 100 years, consider that the Ji-Qing Expressway has only been put into use for 20 years, we need to separate the residual predictive period from the general predictive period. For instance, we can basically use the Ji-Qing Highway for 80 years, but in this paper the conservative estimate is 90 years. When using the extreme distribution of 0.95 fractiles as load capacity, we get a load capacity of 58T, compared with load limit defined by the Seven Ministries it exceeds by 5%.

According to Highway Project Structure Reliability Universal Standard GBT50283-1999 clause 436, motorcade load capacity standard value can be shown by applying graph of distributed & concentrated force which possesses certain intensity of pressure. Through the comparative analysis of the total vehicle weight and the total weight level required by Seven Ministries, we can decide the overloading limit of the vehicles, and it can be concluded that the load limit proposed by the Seven Ministries can roughly reflect the actual traffic load level of the Ji-Qing line, however, further evaluation of the old bridge still has to be made.

4. Compare and select the load models based on the bearing capacity of the existing old Bridges
The load-applicability research models of the bearing capacity of the existing old Bridges are highway level 1 lane (standard 14), five-axle truck 2 (standard vehicle model 55T), and special load (load calculation) vehicle model with the adoption of 6-axle full-hung vehicles. The 55T five-axis vehicle model and the 55T six-axis load model calculation are divided into two situation analysis of both normal driving and traffic jam driving. The front and rear wheel distance is 10m and the front and rear net distance is 1m, and both were calculated and analyzed in the normal driving state. Normal driving state is: When the train is equipped with 6-axle full-trailer (or 6-axle semi-trailer), and the wheel distance between vehicles is 10m (according to the vehicle distance of over 20 load level in highway bridge & culvert design code (JTJ 001-97)). Traffic jam: the train is quipped with 6-axis full trailer (or 6-axis semi-trailer) with a net distance of 1.0m. The impact coefficient of the vehicle will not be considered in this condition. During the design and calculation of vehicle distance, the 6-axis full trailer and 6-axis semi-trailer shall be loaded on the structure object by using the above-mentioned two ways respectively.

5. Adaptive capability analysis of the current load model
Results of the adaptability analysis of the existing load model are shown in the following table (the resistance force in this table refers to the force bearing effect of the 5cm cast-in-situ layer)

| Table 1 26m hollow slab roadbed middle span load effect |
|----------------------------------------------------------|
| Span | Board no. | 20T-2 Axial load kN.m | 30T-3 Axial load kN.m | 40T-4 Axial load kN.m | 55T-5 Axial load kN.m | 55T-6 Axial load kN.m | 55T-5 Axial load1 kN.m | 55T-6 Axial load2 kN.m | Resistance kN.m |
| 5.00 | Middle | 145.61 | 178.73 | 192.97 | 195.99 | 185.84 | 180.61 | 187.45 | 221.965 |
| Side | 142.62 | 168.33 | 179.39 | 181.73 | 173.85 | 169.79 | 175.01 | 221.965 |
| 8.00 | Middle | 262.18 | 334.28 | 357.89 | 382.55 | 350.21 | 353.63 | 365.4 | 384.497 |
| Side | 301.83 | 367.13 | 388.51 | 410.85 | 381.56 | 384.65 | 395.31 | 390.696 |
| 13.00 | Middle | 535.38 | 648.4 | 675.31 | 720.15 | 662.13 | 675.52 | 721.37 | 978.428 |
| Side | 681.56 | 795.07 | 822.09 | 867.13 | 808.86 | 822.3 | 868.35 | 990.685 |

| Table 2  Load effect of 26m subgrade hollow slab fulcrum |
|----------------------------------------------------------|
| Span no. | Board Axial load kN.m | 30T-3 Axial load kN.m | 40T-4 Axial load kN.m | 55T-5 Axial load kN.m | 55T-6 Axial load kN.m | 55T-5 Axial load1 kN.m | 55T-6 Axial load2 kN.m | Resistance kN.m |
| 20T-2 | Middle | 145.61 | 178.73 | 192.97 | 195.99 | 185.84 | 180.61 | 187.45 | 221.965 |
| Side | 142.62 | 168.33 | 179.39 | 181.73 | 173.85 | 169.79 | 175.01 | 221.965 |
| 30T-3 | Middle | 262.18 | 334.28 | 357.89 | 382.55 | 350.21 | 353.63 | 365.4 | 384.497 |
| Side | 301.83 | 367.13 | 388.51 | 410.85 | 381.56 | 384.65 | 395.31 | 390.696 |
| 40T-4 | Middle | 535.38 | 648.4 | 675.31 | 720.15 | 662.13 | 675.52 | 721.37 | 978.428 |
| Side | 681.56 | 795.07 | 822.09 | 867.13 | 808.86 | 822.3 | 868.35 | 990.685 |
Since the normal driving state plays a dominant role in the calculation of hollow slab bridge (mainly because the small span bridge is used by a single vehicle and the larger impact coefficient figure has to be considered under normal driving), the load adaptability analysis of the current load model only includes comparative analysis of the normal driving state. The current load model is in good condition. The bearing capacity with span of 5m is not enough.

6. Scheme analysis of the load limit of divided lanes
The hollow slab bridge has insufficient bearing capacity under the current load requirement. If the bridge is to be used, it needs to carry out lane limit test. Consider that the hollow slab is insufficient in shear bearing capacity under the current automobile load, and the transverse distribution coefficient of shear bearing capacity is determined by the lever method, the peripheral plate is of little help to the plate calculation, and it is necessary to limit the width of the old bridge. If no reinforcement measures are taken, the total load limit is 20T if we use the old bridge directly.

7. Analysis of effective measures to improve the bearing capacity of hollow plate end filling by considering the total section force
The improvement of load adaptability resulted from the shear force measures with hollow plate end filling is shown in the following table (the resistance force in this table is the result from the total section force). The results show that the hollow plate end filling with solid section only works in the hollow plate structure. For the solid plates with insufficient shear capacity, 5m is not going to be enough for the requirements.

| Span | Middle | Side |
|------|--------|------|
| 5.00 | 212.63 | 244.79 | 265.88 | 251.08 | 259.44 | 215.94 | 224.87 | 234.469 |
| | 141.79 | 176.93 | 190.1 | 188.58 | 186.24 | 168.73 | 174.46 | 267.375 |
| 8.00 | 232.91 | 293.37 | 317.98 | 302.98 | 306.94 | 265.44 | 275.64 | 457.916 |
| | 174.83 | 219.15 | 233.41 | 238.95 | 229.12 | 218.27 | 224.73 | 475.959 |
| 13.00 | 265.09 | 343.94 | 369.96 | 368.04 | 361.55 | 330.22 | 341.58 | 377.575 |
| | 232.27 | 278.55 | 292.59 | 303.67 | 301.36 | 291.13 | 302.66 | 418.383 |

| Span | Middle | Side |
|------|--------|------|
| 5.00 | 212.63 | 244.79 | 265.88 | 251.08 | 259.44 | 215.94 | 224.87 | 234.469 |
| | 141.79 | 176.93 | 190.1 | 188.58 | 186.24 | 168.73 | 174.46 | 267.375 |
| 8.00 | 232.91 | 293.37 | 317.98 | 302.98 | 306.94 | 265.44 | 275.64 | 457.916 |
| | 174.83 | 219.15 | 233.41 | 238.95 | 229.12 | 218.27 | 224.73 | 475.959 |
| 13.00 | 265.09 | 343.94 | 369.96 | 368.04 | 361.55 | 330.22 | 341.58 | 377.575 |
| | 232.27 | 278.55 | 292.59 | 303.67 | 301.36 | 291.13 | 302.66 | 418.383 |

| Board no. | 20T-2 | 30T-3 | 40T-4 | 55T-5 | 55T-6 | 55T-7 | 55T-8 |
|-----------|-------|-------|-------|-------|-------|-------|-------|
| Middle | 145.61 | 178.73 | 192.97 | 195.99 | 185.84 | 180.61 | 187.45 |
| Side | 142.62 | 168.33 | 179.39 | 181.73 | 173.85 | 169.79 | 175.01 |
| Middle | 262.18 | 334.28 | 357.89 | 382.55 | 350.21 | 353.63 | 365.40 |
| Side | 301.83 | 367.13 | 388.51 | 410.85 | 381.56 | 384.65 | 395.31 |
| Middle | 535.38 | 648.40 | 675.31 | 720.15 | 662.13 | 675.52 | 721.37 |
| Side | 681.56 | 795.07 | 822.09 | 867.13 | 808.86 | 822.30 | 868.35 |

Table 3 26m Mid-span load effect of hollow slab roadbed

Table 4 Roadbed load effect of hollow slab fulcrum

| Board no. | 20T-2 | 30T-3 | 40T-4 | 55T-5 | 55T-6 | 55T-7 | 55T-8 |
|-----------|-------|-------|-------|-------|-------|-------|-------|
| Middle | 212.63 | 244.79 | 265.88 | 251.08 | 259.44 | 215.94 | 224.87 |
| Side | 141.79 | 176.93 | 190.1 | 188.58 | 186.24 | 168.73 | 174.46 |
| Middle | 232.91 | 293.37 | 317.98 | 302.98 | 306.94 | 265.44 | 275.64 |
| Side | 174.83 | 219.15 | 233.41 | 238.95 | 229.12 | 218.27 | 224.73 |
| Middle | 265.09 | 343.94 | 369.96 | 368.04 | 361.55 | 330.22 | 341.58 |
| Side | 232.27 | 278.55 | 292.59 | 303.67 | 301.36 | 291.13 | 302.66 | 559.609 |
8. The hollow slab casting layer involved in the study of stress scheme of 13cm

The cast-in-situ layer is designed to be 18cm, and the load adaptability research results are shown in the following table according to the effect of 13cm calculation result (the resistance in this table refers to the stress results of the cast-in-situ layer of 13cm). It can be learned from the results that, thickening the cast-in-situ layer and letting it engage the stress can improve the bending and bearing capacity. For the span of 5m, due to the thinness of the plate (5m hollow plate section is only 30cm high), effective result is shown and requirements can be met.

| Span | 5.00 | 8.00 | 13.0 |
|------|------|------|------|
|      | Middle | Side | Middle | Side | Middle | Side |
| 20T-2 Axial load kN.m | 152.23 | 149.3 | 279.94 | 319.76 | 583.69 | 730.34 |
| 30T-3 Axial load kN.m | 185.35 | 175.01 | 352.04 | 385.06 | 696.71 | 843.84 |
| 40T-4 Axial load kN.m | 199.59 | 186.07 | 375.65 | 406.44 | 723.62 | 870.86 |
| 55T-5 Axial load1 kN.m | 202.6 | 188.41 | 400.31 | 428.77 | 768.46 | 915.9 |
| 55T-5 Axial load2 kN.m | 192.46 | 180.53 | 367.97 | 399.49 | 710.44 | 857.63 |
| 55T-6 Axial d1 kN.m | 187.23 | 176.47 | 371.39 | 402.58 | 723.83 | 871.08 |
| 55T-6 Axial load2 kN.m | 194.07 | 181.69 | 383.15 | 413.24 | 769.68 | 917.13 |
| Resistance kN.m | 287.942 | 287.942 | 472.467 | 478.665 | 1137.222 | 1149.478 |

9. The adaptability evaluation of the current load model under various reinforcement measures

The bending and bearing effect of hollow slab bridges with span lengths under various reinforcement measures of the current automobile load is shown as follows:

Figure 2 Bending moment effect of 5m span slab
Figure 3 Shear effect of 5m span slab
It can be learned from the figure that under the effect of the overload model of the Seven Ministries, the slab bridges which mostly show the span of 5m is insufficient the bearing capacity. Among them, the reinforcement method of end filling makes no difference on the 5 and 6m span of solid plate section. However, the bearing capacity of this section can be significantly increased by adding thick cast-in-situ layer. If this scheme is adopted, the three lanes of the old bridge shall be measured according to the same load limit, and the maximum load limit is 20T.

10. Conclusion
Through the 26 m hollow slab with span of 5 m, 8 m and 13m load limit analysis, we can draw the following conclusions: (1) Based on the current Ji-Qing Expressway vehicle load model investigation and statistical analysis, and by comparing the weight limit proposed by the Seven Ministries regarding vehicles, the actual traffic load on Ji-Qing Expressway is basically aligned with the current vehicle load level requirement. (2) Direct adoption of the inspection and calculation of the first-level lane load by applying the new 2014 Highway Standard will lead to demolition of the upper structure of the small span hollow slab bridge and excessive reinforcement of the lower structure. (3) The cross-span hollow plates of 8 and 13m can basically meet the bearing capacity requirements (the 8m one is only slightly higher than the limit of the bending and bearing capacity of the side plate), but moderate reinforcement and general reinforcement are required for 5 and 10m. (4) The cast-in-place layer thickness is designed at 18cm (the calculation considered the degree of stress participation of 13m), the effect of improving the bending and bearing capacity of the structure is obvious, which can be used to reinforce the old bridge. (5) The scheme of dividing into 3 lanes and applying traffic restriction on them is not feasible. By comparing the results of the hollow slab under various load models, it can provide useful suggestions to determine the adaptive level of the bearing capacity of the old bridge,
thus reinforcement methods can be taken to regulate the use of the old bridge, which has certain practical and guiding significance for the other similar projects in China.

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