Istanbul Bridge Conference
August 11-13, 2014
Istanbul, Turkey

ANALYSIS AND ASSESSMENT OF ARTICULATED SKEW HOLLOW SLAB BEAM BRIDGE

Ying Yang[1] Yiqiang Xiang [2] Xiaoyang He[2] Yuliang He[2]

ABSTRACT

When a bridge crosses a river or road in a skew angle, the structural type becomes a skew bridge. For the skew articulated slab beam bridges, the simplified method is difficult to calculate the complicated static and dynamic behavior accurately. This paper, taking Xiazheyang Bridge- the RC skew hollow slab bridge with 45 degrees oblique angle as the background, which was designed and built in 1999 in terms of The Standard of Loadings for the Municipal Bridge Design(CJJ 77-98,China). With economic development and increase of traffic volume, the load carry capacity of the bridge is requested to enhance by the new Standard of Loadings (CJJ 11-2011). The internal forces and vibration modal shape of this typical skew bridge under the two design load were analyzed by FEM. The field testing was completed. The predicted results were compared with the testing values. It shows that the stiffness and bearing capacity of Xiazheyang bridge satisfy the relevant specification requirements. The measured vibration frequency values and are very closed to or slightly more than the theoretical frequencies.

1 Graduate Student Researcher, Dept. of Civil Engineering, Zhejiang University, Hangzhou, P.R. China,310058
2 Professor, Dept. of Civil Engineering, Zhejiang University, Cyrus Tang Center for Sensor Materials and

Istanbul Bridge Conference
August 11-13, 2014
Istanbul, Turkey

Analysis and Assessment of Articulated Skew Hollow Slab Beam Bridge

Ying Yang[1], Yiqiang Xiang[2], Xiaoyang He[1], Yuliang He[1]

ABSTRACT

When a bridge crosses a river or road in a skew angle, the structural type becomes a skew bridge. For the skew articulated slab beam bridges, the simplified method is difficult to calculate the complicated static and dynamic behavior accurately. This paper, taking Xiazheyang Bridge- the RC skew hollow slab bridge with 45 degrees oblique angle as the background, which was designed and built in 1999 in terms of The Standard of Loadings for the Municipal Bridge Design(CJJ 77-98,China). With economic development and increase of traffic volume, the load carry capacity of the bridge is requested to enhance by the new Standard of Loadings (CJJ 11-2011). The internal forces and vibration modal shape of this typical skew bridge under the two design load were analyzed by FEM. The field testing was completed. The predicted results were compared with the testing values. It shows that the stiffness and bearing capacity of Xiazheyang Bridge satisfy the relevant specification requirements. The measured vibration frequency values and are very closed to or slightly more than the theoretical frequencies.

Introduction

The growing economy leads to the increasing volume of transport. In order to improve road alignment and capacity, skew bridges have been widely used in highway and urban road system. Skew hollow slab bridge, with its small height, simple form and so on, becomes an important part of the skew bridges. As for the research on skew concrete slab bridge, Li [1] analyzed the static and dynamic characteristics of three spans continuous skew slab bridge. Xia [2][3]established the transcendent equation of vibrating frequency of skew girder bridge based on Euler beam theory and Timoshenko beam theory respectively. Babu[4] analyzed the orthogonal isotropic inclined plate vibration frequency with finite strip method. Menassa[5] studied the effect of skew angle on simple reinforced concrete bridges using the finite element method, and conducted the parameters investigation of the span length, slab width, and skew angle. Khaloo[6] studied the load distribution coefficient of skew Bridges, and pointed out the conservatism of the specification. The non-linear finite element method is adopted to analyze skew slab bridge by Kankam[7]. Théoret [8] investigated the determining internal forces, which are required to design skewed concrete slab bridges, using the equivalent-beam method. The results showed that non-orthogonal grillages can be used in the analysis of skewed slab bridges satisfactorily.

Due to the increase of traffic volume and vehicle load, the existing bridges must work under the new load level. So, Code for Design of Municipal Bridge (CJJ 11-2011) [10] was

1 Graduate Student Researcher, Dept. of Civil Engineering, Zhejiang University, Hangzhou, P.R. China,310058
2 Professor, Dept. of Civil Engineering, Zhejiang University, Hangzhou, P.R. China,310058

promulgated and implemented to replace the original Standard of Loadings for the Municipal Bridge Design (CJJ 77-98). The bridge design load is different in these two codes. In this paper, taking the Xiazheyang Bridge, located in Ninghai County, China as the background, did the calculation and comparison of the internal forces for this typical skew bridge under different design load situations, pointed out the differences between them. Field testing was carried out according to the testing scheme. The comparison between the results from field testing and theoretical values is used to evaluate the condition of the bridge.

Project Profile

Xiazheyang Bridge, shown in Fig.1 and 2, is located in Ninghai County. It is a reinforced concrete simply-supported skew hollow slab beam bridge with two span 13m, and its calculated span is 12.45m. The bridge's skew angle is 45°. There are left and right side decks in the bridge, each consists of 10 pieces of hollow slab beams, and is 12.75m wide. The total width is 26.5m. Its original design load level was "Highway truck-20, Trailer - 100"[9] , now the design load level is changed to Urban bridge-A level[11], in accordance with the requirements of the local administrative department. The superstructure is 55cm depth reinforced concrete hollow slab beams, its standard width is 1.24m, the concrete grade is C30. The bridge pavement layer is 13cm thick concrete with C30.

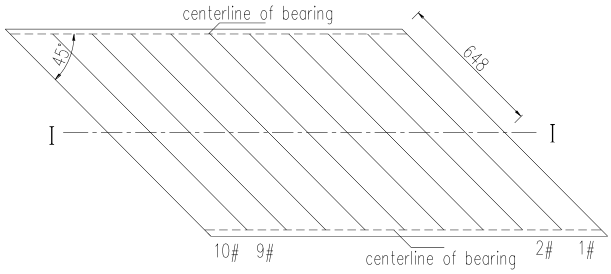


Figure 1. Xiazheyang Bridge

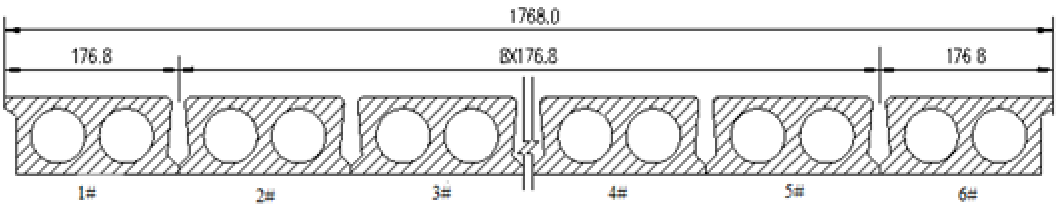


Figure 2. Cross-section of Xiazheyang Bridge
(Parallel to the direction of bearing, Dimension Unit: cm)

Relevant Provisions of Design Loads

There are differences between the load level in CJJ 77-98[10] and the current CJJ 11-2011[11]. The lane load of Urban Bridge-A level in CJJ 11-2011 (hereinafter referred to as the "new Urban Bridge-A level") is listed in table 1.

Lane load of the City-A level in CJJ 77-98 [10] (hereinafter referred to as the "old Urban Bridge-A level") is listed in table 2.

Table 1: Lane load of the new Urban Bridge-A level [11]

Items	$q_k (kN \cdot m)$	$P_k (kN)$		Remarks
Urban Bridge -A	10.5	calculated span $\le 5m$	180	When calculating the shear effect, concentrated load standard values (Pk) should be multiplied by 1.2
		calculated span $\ge 50m$	360	
		$5m <$ calculated span $< 50m$	Linear interpolation	

Table 2: Lane load of the old City-A level [10]

Items	City—A			Remarks
	$q_m (kN/m)$	$q_g (kN/m)$	$P(kN)$	When the span ranges from 20m to 150m, and the lane number ≥4, Urban Bridge-A level 's calculate shear should multiply a magnified coefficient of 1.25
$2m \le$ span $\le 20m$	22.5	37.5	140	
$20m <$ span $\le 150m$	10.0	15.0	300	

Calculation and Analysis

Because the skew angle of Xiazheyang Bridge is relative larger, the traditional transverse distribution calculating method of bridge is not applicable to it. So, a spatial analysis model of Xiazheyang Bridge is established by the finite element program. There are 120284 C3D8R solid elements and 164100 nodes in all, as shown in figure 3. Bending moment in the mid-span and shear force at the neutral axis depth of beams in the bearing were calculated through stress integration respectively under the original design load "Truck-20, Trailer-100", old Urban Bridge- A and new Urban Bridge-A level.

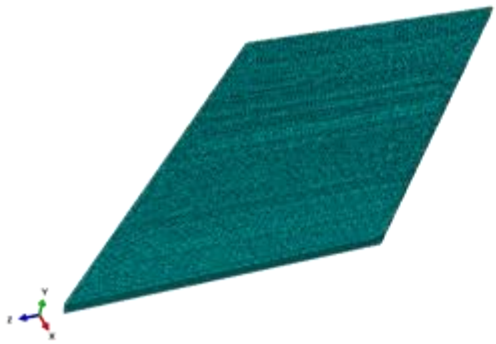


Figure 3. Finite element model of Xiazheyang Bridge

Result

Comparison of Internal Forces by Different Specifications

From the calculation results, it is noted that the largest longitudinal bending moment at mid-span occurs when two-lane-loading is exerted on the bridge. The bending moments at mid-span under different design loads are shown in the figure 4.

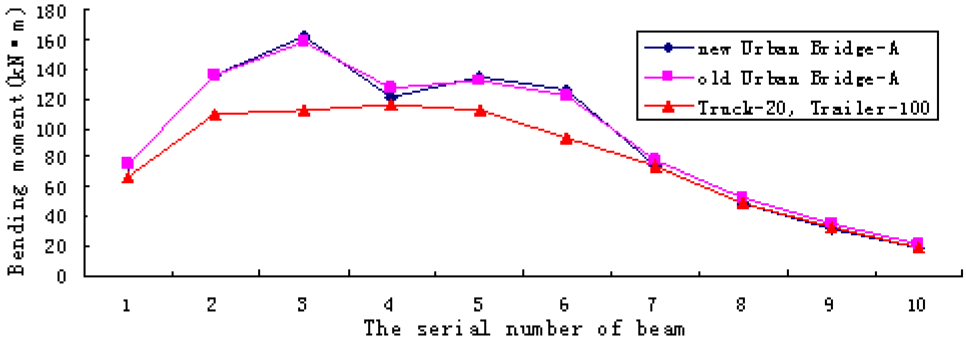


Figure 4. Bending moments at mid-span under different design loads

According to the results, the longitudinal bending moments at mid-span in Xiazheyang Bridge have not much difference under the loads of old Urban Bridge-A and new Urban Bridge-A. The maximum longitudinal bending moment appeared in 3# slab beam, with a difference of 3%. The rest beams' differences are within 10%. Therefore, when calculating the bending moment, new Urban Bridge-A and old Urban Bridge-A can be regarded as the same level approximately. Compared with the original design load "Truck-20, Trailer-100", the longitudinal bending moment under the Urban Bridge-A increased obviously, the largest increase was 45%. Thus, the design load level has larger ascension to "Truck-20, Trailer-100".

Shear Force near Bearing

The position for shear force is the neutral axis depth distance from the center line of bearing. The calculated shear forces of the beams under different design loads are shown in the Fig. 5.

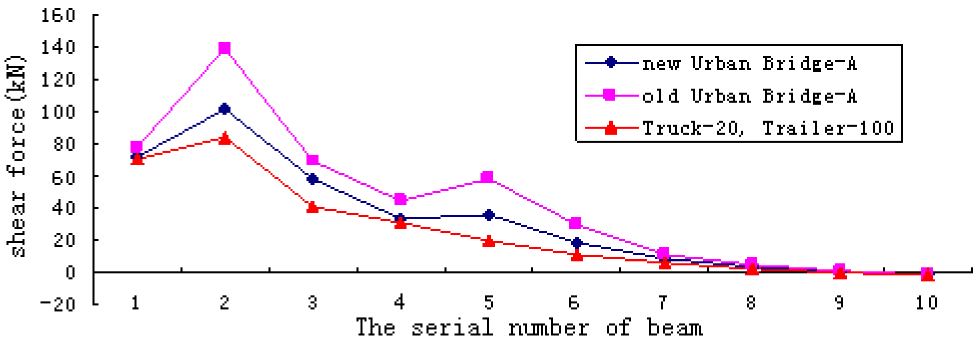


Figure 5. Shear force of the beams under different design loads

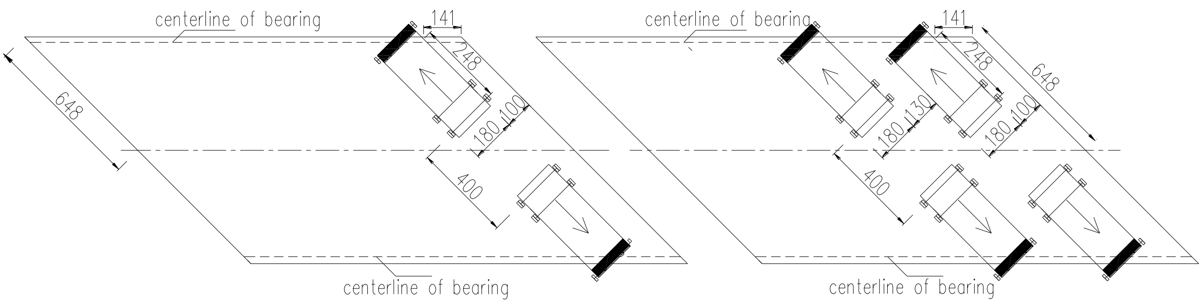
From the shear forces, it is found that the new Urban Bridge-A and old Urban Bridge-A level were not the same load level, there are relatively large differences between them. The shear forces were controlled by the old Urban Bridge-A, and the largest difference reached to 37%. For the rest beams, shear forces were greater than those calculated by new Urban Bridge-A. Among three design loads, the shear forces gained by "Truck-20, Trailer-100" are the smallest. The maximum shear force appeared in 2 # beam, and it showed a trend of gradual decrease in the direction from obtuse angle to acute Angle. Negative shear force even appeared in the acute Angle. This accords with the mechanical characteristics of general skew bridges.

Field Test

Field load testing for Xiazheyang Bridge was carried out. The loads in this testing are large trucks. The gross weight of a single truck is about 300 kN (60 kN for front axle, 240 kN for middle and back axles, wheelbase from front axles to middle axles is 350cm, wheelbase of middle and back axles is 130cm). Specific truck load position for each control section under different working cases are shown in figure 6 and 7. The truck would be added step by step according to the load levels.

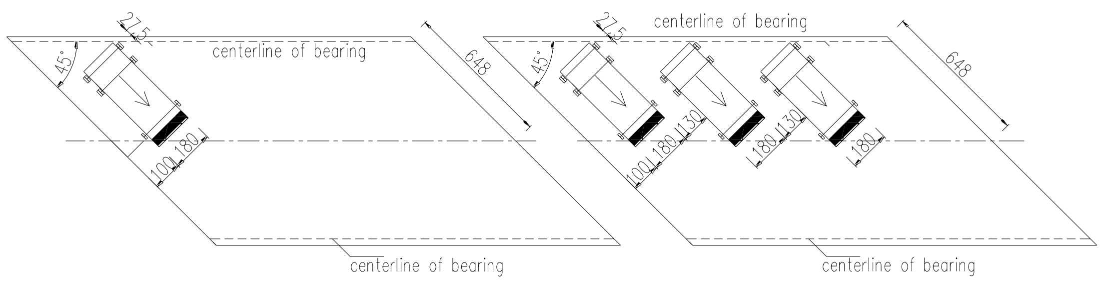
Table 3. Design internal forces, control internal forces of field test bridge and static loading efficiency

Working cases	**control section**	**Internal forces**	**Design Load**		**Control Value**	**Loading Efficiency**	
			Truck-20, Trailer-100	**Urban bridge-A**		**Level 1**	**Level 2**
1	I-I	Mx (N.m)	1.108E+5	1.62E+5	1.47E+5	0.52	0.91
2	II-II	V(N)	7.43E+4	9.54E+4	8.55E+4	0.74	0.90



（1）load level 1 （2）load level 2

Figure 6. Loading position for bending moment in mid-span (Dimension. unit: cm)



（1） load level 1 （2）load level 2

Figure 7. Loading position of shear force near the bearing (Dimension unit: cm)

Comparison of Theoretical and Measured Values

Deflections and concrete strains in slab beams under each loading case are measured in the field testing. Because the structure is a reinforced concrete bridge, which commonly works in a micro-cracking status. So, for deflection calculation of bridge, in general, the stiffness reduction of the beam should be considered. The comparison of the measured and theoretical deflection is shown in Figure 8.

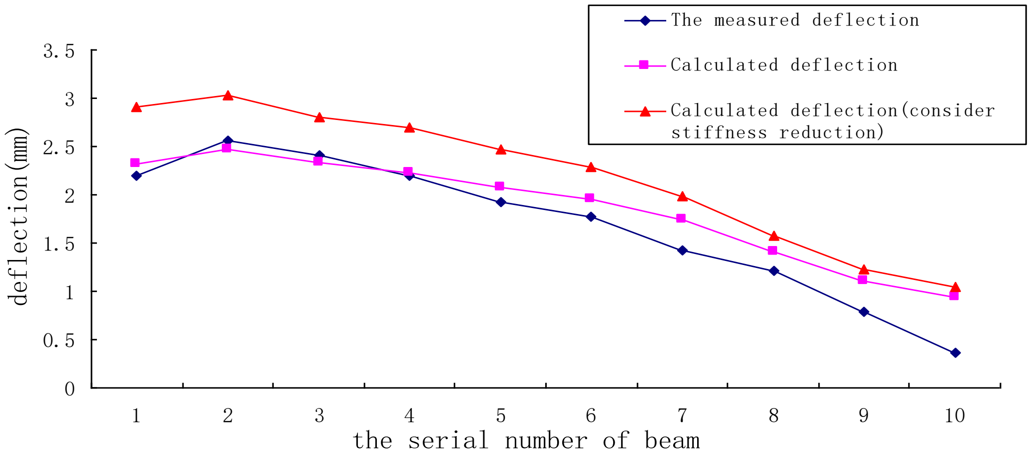


Figure 8. Comparison of the measured deflection and theoretical values at mid-span along transverse direction of bridge

From the result, it is found that some of the mid-span test deflections of bridge (1 # ~ 3 #) are greater than the theoretical results without stiffness reduction, the largest calibration coefficient is 1.07, but the measured deflections are less than the values with stiffness reduction. The relative residual deflections of bridge are less than 10% when is unloaded. The maximum measured deflection is 2.81mm, about 1/4626 of the calculated span length, far less than the specification limit It shows the vertical stiffness of the bridge can satisfy the requirement of specification.

Table 4: Comparison of maximum measured concrete stresses and theoretical values

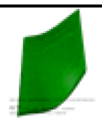
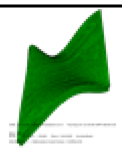
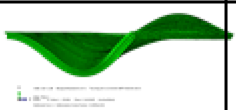
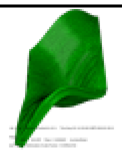
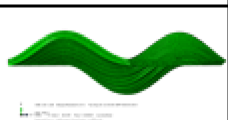
Testing Section	**Beam**	**Urban Bridge-A Calculating Stresses (MPa)**	**Theoretical Stresses under Test Load (MPa)**	**Measured Stresses (MPa)**	**Calibration Coefficient**
Mid-span	1#	3.11	3.37	2.22	0.66
	2#	3.34	3.45	2.15	0.62
	3#	3.61	3.04	1.82	0.60
	4#	2.95	2.92	1.84	0.63
	5#	3.2	2.79	3.05	0.73
	6#	3.16	2.71	2.88	0.69
	7#	2.91	2.72	3.18	0.43
	8#	3.44	2.49	2.12	0.61
	9#	3.28	2.55	1.86	0.40
	10#	3.12	2.46	0.97	0.39

Table 4 further gives the comparison of the measured values and the theoretical stresses under the maximum level of loading cases. As can be seen, the measured concrete stress values at the mid-span section are less than the calculated ones. The largest calibration coefficient is 0.73, less than 1.0. The small calibration coefficient may be the reason for the appearing of cracks under load.

Dynamic Analysis

The natural vibration of skew bridge has a lot relationship with skew angle, boundary conditions and wide-span ratio, and there's bend-torsion coupling phenomenon [2,3]. The general finite element program was used to analyze the dynamic characteristics of Xiazheyang Bridge. In order to simulate the influence of continuous deck and the adjacent spans, the contribution of stiffness and mass of the 13cm thick reinforced concrete bridge pavement is considered. The constraint form is simply-supported. Table 5 gives the front three order vibration mode for one span of bridge.

Table 5 The front three order vibration mode for one span of bridge

Vibration Mode	Axonometric Views	Side View	Theoretical Value of Frequency	Measured Value of Frequency
1st order vertical vibration			11.6Hz	12.7Hz
2nd order Lateral antisymmetric vibration			18.2Hz	18.6Hz
3rd order Lateral symmetry vibration			24.9Hz	25.8Hz

As can be seen from the analysis results, the natural vibration characteristics of the skew bridge have obvious difference to that of orthogonal bridge. Because of skew angle with 45°, 0.98 wide-span ratio, the torsion and bending were coupled in the vibration modal of Xiazheyang bridge. There are torsion parts in each order of natural vibration modal. The measured vibration frequency values and the theoretical frequencies are very close.

Conclusions

Aiming at a real bridge from "Truck-20, Trailer-100" design load change into the new Urban Bridge-A load, by the analysis and field test of Xiazheyang Bridge under different design loads, some conclusions can be drawn.

1) There are a little difference between new Urban Bridge-A and old Urban Bridge-A for bending moment calculation of bridge. When comes to the shear force, for the calculated short bridge, old Urban Bridge-A is the control load, they do not belong to the same load level any more.

2) For the skew hollow slab beam bridge with relatively large skew angle and wide-span ratio, the bending and torsion are coupled in the vibration modal, and torsion exists in each order modal.

3) Comparison of field test results and theoretical values show that the stiffness and bearing capacity of Xiazheyang Bridge satisfy the relevant specification requirements. The measured vibration frequency values and are very closed to or slightly more than the theoretical frequencies.

References

1. Z. Li , Static and dynamic analysis of skew slab bridge, *Changsha university of science and Technology*, master's degree thesis, Changsha, Hunan, China,2011. (in Chinese)

2. G. Xia, M. Yu and C. Li, Vibrating characteristics of skew bridge. *Journal of Traffic and Transportation Engineering*, 2009,9(4): 1-5. (in Chinese)

3. G. Xia, M. Yu and C. Li, 2010. Frequency and Vehicle-Bridge Vibration Analysis of Skewed Bridges Considering Shear Deformation Effect. *Engineering Mechanics*, 2010 (3): 30-37. (in Chinese)

4. Babu, P. V. and Reddy, D. V. Frequency analysis of skew orthotropic plates by the finite strip method, *Journal of Sound and Vibration*, 1971, 18(4): 465-474.

5. Menassa, C. Mabsout, M. Tarhini, K. et al. Influence of skew angle on reinforced concrete slab bridges, *Journal of Bridge Engineering*, 2007, 12(2): 205-214.

6. Khaloo, A. R. and Mirzabozorg. H. Load distribution factors in simply supported skew bridges, *Journal of Bridge Engineering*, 2003, 8(4): 241-244.

7. Kankam, J. A. and Dagher, H. J. Nonlinear FE Analyses of RC skewed slab bridges. *Journal of structural engineering*, 1995.121(9): 1338-1345.

8. Théoret, P. Massicotte, B. and Conciatori, D. Analysis and design of straight and skewed slab bridges, *Journal of Bridge Engineering*, 2011, 17(2): 289-301.

9. *General Code for Design of Highway Bridges and Culverts (JTG 021-89)*, China Communications Press, Beijing, China. 1989. (in Chinese)

10. *The Standard of Loadings for the Municipal Bridge Design (CJJ 77-98)*, China building industry press, Beijing, China. 1998. (in Chinese)

11. *Code for Design of Municipal Bridge (CJJ 11-2011)*, China building industry press, Beijing, China. 2011. (in Chinese)