Numerical Study on Damage of Bearing in Continuous Composite Twin I-girder Bridge

Waseda University, ○LAM Heang, Weiwei LIN, Teruhiko YODA, Hideyuki KASANO, Haijie GE,

1. Research background

In engineering practice, bridge structures' redundancy is one of the most important criteria for the safety of the bridges against accidents or member damage. A bridge is defined as redundant only if the failure of the critical fracture members will not lead to the failure or collapse of entire system or making the bridge unfit for use. Even with a quite clear definition, currently, there are no standard methods for defining or evaluating the redundancy level of a bridge, that can provide either theoretical or numerical proofs. Despite many years of research, redundancy evaluation methods of bridges still remain in discussion.

In the United States, the National Cooperative Highway Research Program has published two reports about redundancy, in which the NCHRP Report 406 [1)] is concerned with the redundancy of bridge superstructures and the NCHRP Report 458 [2)] is concerned with the redundancy of bridge sub-structures. In their method, the redundancy was defined by using its capability of continuing to sustain load in both intact system and damaged system after the first yielding point or first member failure. In addition, a maximum vertical displacement defined as L/100 (L denotes the span length) is proposed as the limit of the serviceability of the bridge. This method is used in this study to determine the redundancy level of a three-span twin-girder composite bridge.

2. Bridge Model Description

Some typical damaged scenarios and corresponding intact bridge system were already investigated in the previous study. In this study, only damage at the bearings is considered. The purpose is to provide a more complete study of the redundancy of the twin composite I-girder bridge. The bridge was designed as three spans, with the span length of (37.5+43+37.5) m. The cross section is shown in Figure 1.

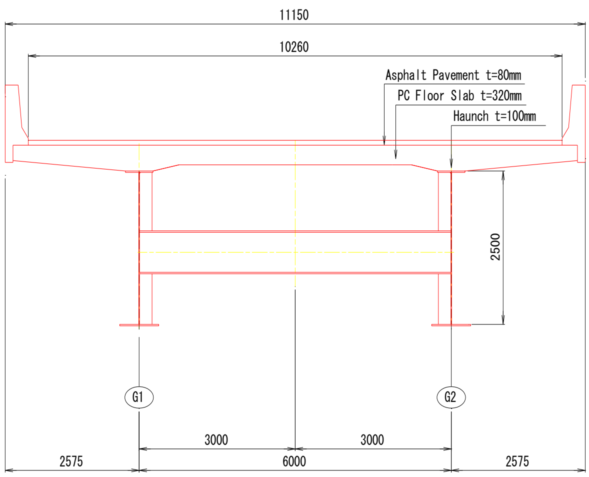

Figure 1: Section view of the bridge

In this study, Finite Element Method was used to analyze the bridge structure with the aid of DIANA Software. Solid elements, shell elements, and spring elements were used for simulating concrete slab, steel girder, and stud connectors, respectively. Interface elements were used to simulate the interface between concrete slab and steel girder. For each stud, three springs were employed for simulating the shear and axial forces in three directions. Re-bar elements were used for modeling reinforcing bars in the concrete slab. Both physical and geometrical nonlinearity are considered in the analysis. Phase analysis was used in this calculation and the live load factor was increased until the failure of the system.

The live load condition is determined by the design code of Japan (JRA 2002) [3)] as shown in Figure 2. Two extreme cases are being considered. Missing of one of the mid-span bearings is considered as Case 1 and missing one of the side span bearings is considered as Case 2.

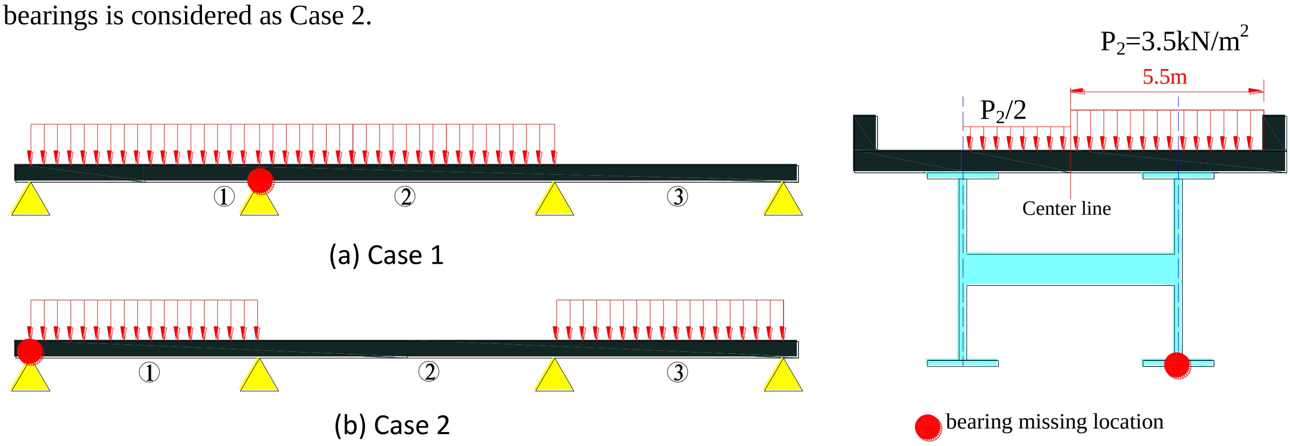

Figure 2: Loading conditions and damaged positions

3. Redundancy Evaluation Method

The redundancy evaluation method proposed in NCHRP Report 406 is used in this study for analyzing the numerical results. LF (Live load factor) denotes the live load ratio applied on the bridge. For undamaged model or what to be called intact system, the first member failure or yielding point is denoted as LF_1. After the yielding point, the bridge can continue to sustain load until a live load factor LF_u that cause the bridge to reach its ultimate state or collapse. Before reaching the ultimate point, the maximum vertical displacement of L/100 might be reached; the live load factor at this point is denoted as LF_f (Serviceability limit state). In damaged bridge system, the live load factor increases until the failure of the system and LF_d is obtained. To evaluate the redundancy of the bridge, the following method was employed:

The redundancy factor $\phi_s = \min\left(\frac{R_u}{1.3}, \frac{R_f}{1.1}, \frac{R_d}{0.5}\right)$, where: $R_u = \frac{LF_u}{LF_1}$, $R_f = \frac{LF_f}{LF_1}$, $R_f = \frac{LF_d}{LF_1}$.

If ϕ_s is larger than 1.0, then this bridge can be considered as redundant.

4. Numerical Results

4.1 Case 1

Figure 3 show the live load factor (LF) versus maximum displacement curve of damaged system. For intact system, the first yielding point is at LF_1=8.25. After the yielding point, the bridge continues to sustain load until LF_u= 20. At this point, the compressive strain of concrete reaches 0.35% and can be considered as the ultimate limit of the structure. On the other hand, the maximum displacement reaches L/100 when the live load factor becomes LF_f=18, which is considered as the serviceability limit state of the bridge. In damaged system, in order to obtain the bearing missing scenario, one right side support of the mid-span is deleted. Before reaching the ultimate limit state, out of plane displacement due to local buckling of steel web is observed when the live load factor is around 2. The bridge system, however, can continue to sustain until the live load factor reaches LF_d=8.3. Since the concrete begins to crash; this point is considered as the ultimate limit state.

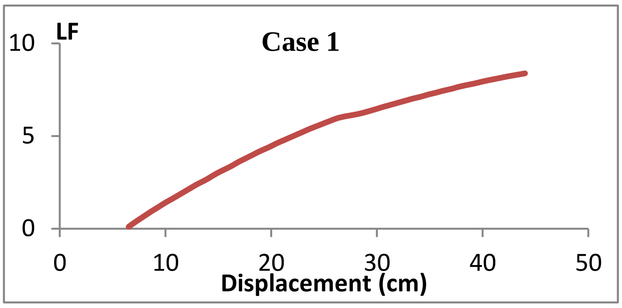

Figure 3: Live load factor-vertical displacement curve

4.2 Case 2

Figure 4 shows the live load factor versus the maximum displacement curve of the damaged system. For intact system, the first yielding point reaches when LF_1=11.2. After the yielding point, the bridge continues to sustain load until LF_u= 19.5. The concrete begins to crash, which means the ultimate limit of the structure. On the other hand, the maximum displacement reaches L/100 when the live load factor becomes LF_f=19. In damaged system, one of the side span support is deleted. Out of plane displacement due to local buckling of steel web appears when the live load factor reaches 2. The bridge system sustains until LF_d=8.2 and the rebar strain reaches 20%. This point is considered as the failure point of the bridge structure.

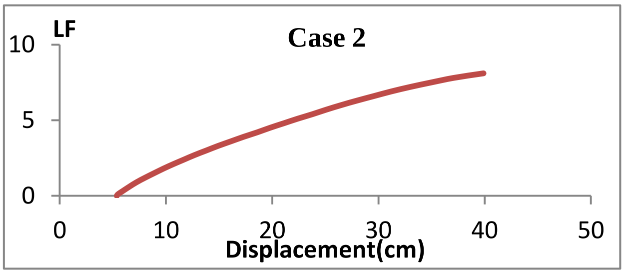

Figure 4: Live load factor-vertical displacement

Table1: Result of Numerical Analysis of Redundancy

Case	LF_1	LF_u	LF_f	LF_d	$R_u/1.3$	$R_f/1.1$	$R_d/0.5$	ϕ_i
1	8.25	20.00	19.80	8.3	1.86	2.18	2.01	1.86
2	11.20	19.50	19.00	8.2	1.34	1.54	1.46	1.34

5. Conclusions

The numerical results show that the three- span continuous composite twin I-girder bridge can be considered as redundant in the case of damage or missing of one bearing. Two types of failure modes were observed from this study, including crash of the concrete and rebar breaking in the concrete slab. Moreover, in the damaged system, local buckling of steel web of I-girder can be observed when the live load factor is relatively small, but this will not affect much on the global behavior of the bridge system.

References

1)Ghosn,M., and Moses, F. (1998). “Redundancy in highway bridge super-structures.” NCHRP Rep. 406, National Cooperative Highway Research Program, Washington, DC.

2)Liu, W.D., Ghosn, M., and Moses, F. (2001). “Redundancy in highway bridge sub-structures.” NCHRP Rep. 458, National Cooperative Highway Research Program, Washington, DC.

3)Japan Road Association (2002), Specification for highway bridges.