Fracture Critical Members of Continuous Composite Twin I-girder Bridge

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

1. Research background

In Japan, a report shows that around 6% of 150,000 bridges whose span length are exceeding 15meters were in service over 50 years by 2006, and this ratio will increase to around 50% by 2026. For this reason, the safety consideration for old bridges is becoming more and more important for current bridge infrastructures in Japan. Continuous composite twin I-girder bridges are commonly used for medium span bridge due to their low cost in comparison with other types of bridges. However, these types of bridges are considered as non-redundant according to the current AASHTO design specification. It is said that this classification is based on unrealistic concepts, resulting from the oversimplified assumptions normally used in design, but not on the realistic behavior of the as-built three-dimensional structures. Referring to the National Bridge Inspection Standards (NBIS) and the AASHTO Manual for Bridge Evaluation, redundancy analysis is very important for maintaining the safety of bridge and identifying Fracture Critical Member (FCM) is needed to study the redundancy rating and evaluation of bridge structures. Insufficient researches have been done on defining such member due to the unclear definition and the complex respond of bridge structures in damaged state. The FCMs are defined in AASHTO as “Steel tension members or steel components of members whose failure would be expected to result in collapse of the bridge”. NBIS defines FCM as “a steel member in tension, or with a tension element, whose failure would probably cause a portion of or the entire bridge to collapse”. With multiple interpretations for “failure,” “probably,” “expected” and “collapse”, just as for redundancy, a good and universally accepted definition does not exist for fracture-critical members of bridges. In this study, a five span continuous composite twin I-girder bridge is selected as a study target to define the Fracture Critical Member in the continuous composite twin I-girder bridge and the critical position that would be called fracture critical member.

2. Modeling of Bridge and Damage Condition

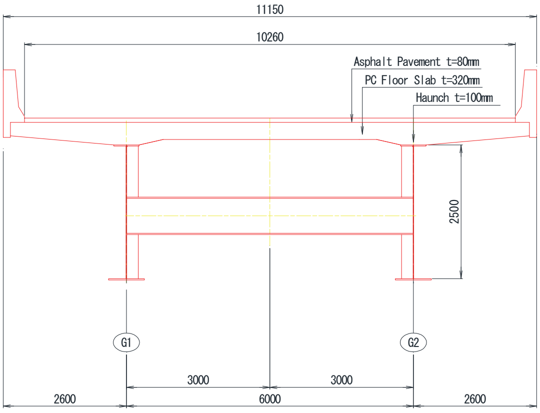


Figure 1 shows the cross sectional view of Kanayago Highway Bridge. This bridge was designed as a 5 span continuous composite twin I-girder bridge with the span length of (34.6+38.3+38.3+38.3+34.6) m. This bridge was select as the target of this study. In order to study the bridge response under damaged condition, Finite Element Analysis was used with the aid of DIANA Software. Solid elements and shell elements were used for simulating concrete slab and steel girders, respectively. The interface between concrete slab and steel girders is considered as intact before the failure of the bridge. Grid elements were used for modeling reinforcing bars in the concrete slab. Both physical and geometrical nonlinearities are considered in the analysis. The phase analysis was used in this calculation and the live load factor was increased until the collapse or the final failure of the system rather than the ultimate capacity of single element.

The live load condition, according to the design code of Japan (JRA 2002), is the combination of P1+P2 as shown in Figure 2. P1 is a 10kN/m^2 with a maximum of 10 meters long distribution load while P2 is a 3.5kN/m^2 distribution load which can be placed to maximize the loading effect. In damaged condition, fracture of full web and bottom flange is considered as reasonable and possible condition for this type of bridge. However, there are no methods to determine the position of the fracture that would likely to appear. It can be said that the fracture location is a random variable and therefore, it cannot be pre-determined. Instead of predicting the fracture position, this study aims to provide engineers or researchers the most dangerous fracture location that could appear on this type of twin I-girder composite bridges. Several damage conditions were assumed along the girder in separate cases as shown in Table 1. Under the same application of the live load condition that is based on the influence line analysis, the damage case that causes the most harmful to the bridge or reduces the load carrying capacity of the bridge to the lowest, is considered as the most dangerous case and thus, would be considered as the Fracture Critical Member of this bridge.

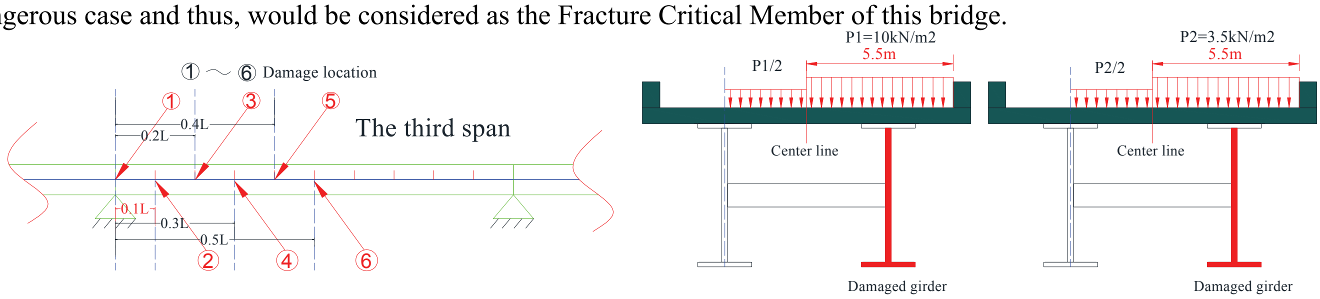
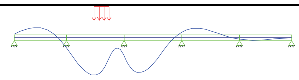
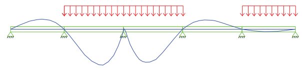
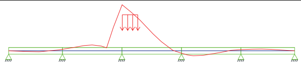
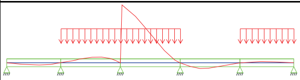
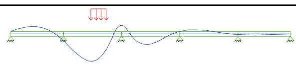
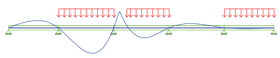
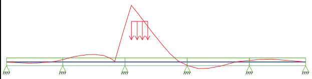
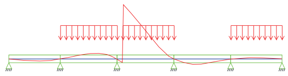
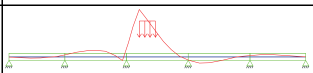
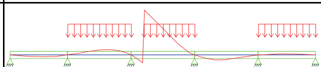
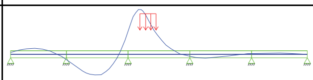
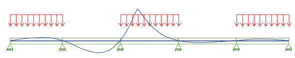
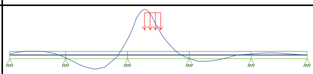
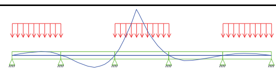
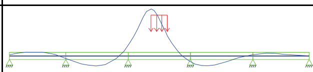
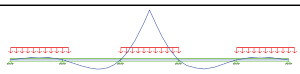


Figure 2: Loading conditions and damaged positions

3. Numerical Results

Table 1: Load carrying capacity and failure mode corresponding to each type of damage and load distribution

Damage Location	Influence Line Type	Distribute load of P1*	Distribute load of P2**	Load Carrying Capacity	Failure Mode
0.01L*	Bending (negative)			DL+2.8LL	Concrete crash and steel buckling
	Shear			DL+1.67LL	Rebar breaking
0.1L	Bending (negative)			DL+3.2LL	Concrete crash and steel buckling
	Shear			DL+2.4LL	Rebar breaking
0.2L	Shear			DL+2.5LL	Rebar breaking
0.3L	Bending (positive)			DL+4.75LL	Concrete crash and steel buckling
0.4L	Bending (positive)			DL+4.55LL	Concrete crash and steel buckling
0.5L	Bending (positive)			DL+2.7LL	Concrete crash and steel buckling

*L is the span length and equal to 38.3m in this case.
**The graph shows the bending moment or shear force at damage location created by distribute load P1 (influence line created by load P1 at damage location)
*** The graph shows the bending moment or shear force at damage location created by unity load (influence line created by unit load at damage location)

Table 1 shows the results of numerical analyses. The damage near the support location (0.01L) is the most critical case in this study according to the remaining load carrying capacity after the fracture of whole web and bottom flange. Two types of failure modes were observed from the results, the first type is the failure caused by the shear force and lead to the failure of rebars (rebar breaking) on the top of the girder damaged location. This type of failure is observed when the damage location is near the support location where the shear force is at maximum. The second type is the failure or collapse of the system governed by buckling of the steel web near the support location just after the initiation of concrete crash near the damage location.

4. Conclusions

The numerical results show that even after the fracture of whole web and bottom of flange, a continuous composite twin I-girder bridge is safe under self-weight or dead-load, and still has some reserve strength for live load. Two types of failure modes were observed in this study, including crash of the concrete in conjunction with the buckling of steel web and the shear failure of concrete slab with rebar breaking. Due to the dual failure modes, 2 positions of the fracture critical member are suggested corresponding to each failure mode. It is suggested that the fracture location near the support location should be considered as the Fracture Critical Member which corresponds to shear failure with rebar breaking, and the fracture at the mid span should be considered as fracture critical member which correspond to concrete crash along with steel web buckling.

References

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2)Ghosn, M. Moses, F. and Frangopol, D.M., Redundancy and robustness of highway bridge superstructures and substructures, Structures and Infrastructure Engineering Vol. 6, Nos. 1-2, pp.257-278, Taylor & Francis, 2008.
3)Japan Road Association (2002), Specification for highway bridges.