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Identification of fracture critical member of an old truss bridge in Bangladesh

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ABSTRACT: Bridges are common and unavoidable component of rail or road network. Performance of these structures is very important for the uninterrupted communication. Collapse of any bridge not only causes huge loss of money but also results in live losses. Number of aging structures is increasing all over the world. Old bridges are built after following the then design standards and material specifications. Recent bridge collapses raised the issue of evaluation of these old structures. Recently, Hardinge Bridge has reached the land mark of 100 years of service. This bridge is still servicing a major rail network in Bangladesh. Bangladesh, a developing country is building new structures and importance on old structures is relatively low. Some recent studies on this bridge also highlight the importance of the complex structural form to the academics. This study is aimed at exploring the fracture critical member considering different conditions. A simple approach is demonstrated to this purpose. A computer aided model is developed and analyzed. The model is developed following the guidelines of previous works on Hardinge Bridge. The study reflects that the current loadings do not create any overstress condition if the structure is intact. However, failure of primary members i.e. upper and lower chords of the bridge manipulates change in stress to adjacent vertical and diagonal members. the study results revealed that the corner upper chord member is the fracture critical member for the Hardinge Bridge.

1 INTRODUCTION

Fracture critical member (FCM) is a steel tension member or tension component of a steel member whose failure may result in a partial or full collapse of the bridge (FHWA, 2012). Failure of bridges results in loss of life, properties, national economy and sufferings to people. And the failure of major bridges suspends communications when traffic can't be diverted. Steel bridges suffer from corrosion and fatigue with time and vulnerable to strength loss. Time-dependent loss of coating and loss of material due to corrosion are very common to steel structures subjected to aggressive environmental condition. This results in degradation of material strengths, reduction in the cross-sectional properties of the members, increased surface roughness, surface irregularities and corrosion pits (Adasooriya et al., 2017).There are many examples of bridge collapse around the world.

On August 1, 2007,due to the loss of a single gusset plate of the I-35W steel deck truss bridge located in the city of Minneapolis in the United States suddenly collapsed killing 13 peoples and injuring 145 peoples (Astaneh, 2008). The national transportation safety board concluded that the collapse was due to the design error and using very thin gusset plate. The plate was only half of the required thickness. There was also another fact that the bridge's key structure lacked redundancy, i.e. when the gusset plate broke much of the bridge collapse. Redundancy has a significant role in the prevention of bridge failures by providing alternate load path. A non-redundant bridge is more susceptible to failure since it is more likely to have a reduced number of members or no alternate load path (FHWA, 2011).

Bridge rating system is also followed to ensure the uninterrupted service. However, failure of I-5 Skagit River Bridge, Washington in 2013 due to the fracture of a single member has raised some issues. According to the national bridge records, the bridge had a sufficiency rating of 57.5 out of 100. There are many bridges in Washington with lower ratings than I-5 Skagit River Bridge and many around USA had single-digit ratings and still were in service (Komo, 2013). This example indicates that the rating system alone is not enough to predict sudden failure of the bridge. Therefore, rating system in bridge maintenance without considering the fracture critical member to evaluate the condition of bridges, catastrophic failure cannot be predicted. Moreover, identification of the fracture critical member of bridges will help the bridge maintenance and management sector to assess the actual condition and predict failure. Researchers proposed different theories and approaches to identify fracture critical member in bridge (Ghosn et al. 2010; Zink et al., 2016). NCHRP (1997) defines abridge as safe if there is reasonable safety level against member failure; the bridge is capable of carrying some traffic loads after damage to a component; deformations of the bridge is not large under expected loading conditions.

Major important railway bridges in Bangladesh are mostly made of steel. So, their serviceable condition must be ensured with safety by proper maintenance. Identification of fracture critical member may be helpful to assess the condition of the bridges and determine safety level. In this paper a simple approach has been demonstrated to identify the fracture critical member. The approach has been demonstrated with the help of an old railway bridge in Bangladesh.

2 DESCRIPTION OF THE BRIDGE

Being 100 years old and important two-way railway bridge, it is very significant to find the fracture critical member of the Hardinge bridge. The construction of the bridge started in 1910 and finished 2 years later. It was opened on 4 March 1915. After the Tay Bridge disaster of 1879 in Great Britain, it instituted the need for considering wind pressure on rail bridges including the rolling stocks. The Bridge was originally intended to construct the piers for a double line and to erect at first girders for the single line only. Gales (1918) reported that the bridge was within the cyclone area. Considering the exposure condition, the bridge was designed for a double line in the first instance to ensure better stability (Amin et al. 2015). The bridge is 1.8 kilometers, comprises 15 steel trusses and carries a broad gauge rail line. During liberation war 1971, the bridge was severally damaged and some spans were replaced.

3 MODELING AND LOAD APPLICATION

Modeling and moving load applications were done using STAAD.pro software. Cross sectional properties of different members, as shown in Figure 1, were obtained from Awall et al. (2015).The weight of rails and sleepers is taken as 0.09 kip/ft uniformly distributed load along the four stringers of the bridge. Fully loaded condition of the bridge was considered by considering two trains from opposite directions crossing the bridge at the same time. Different load applications are shown in Figure 4.

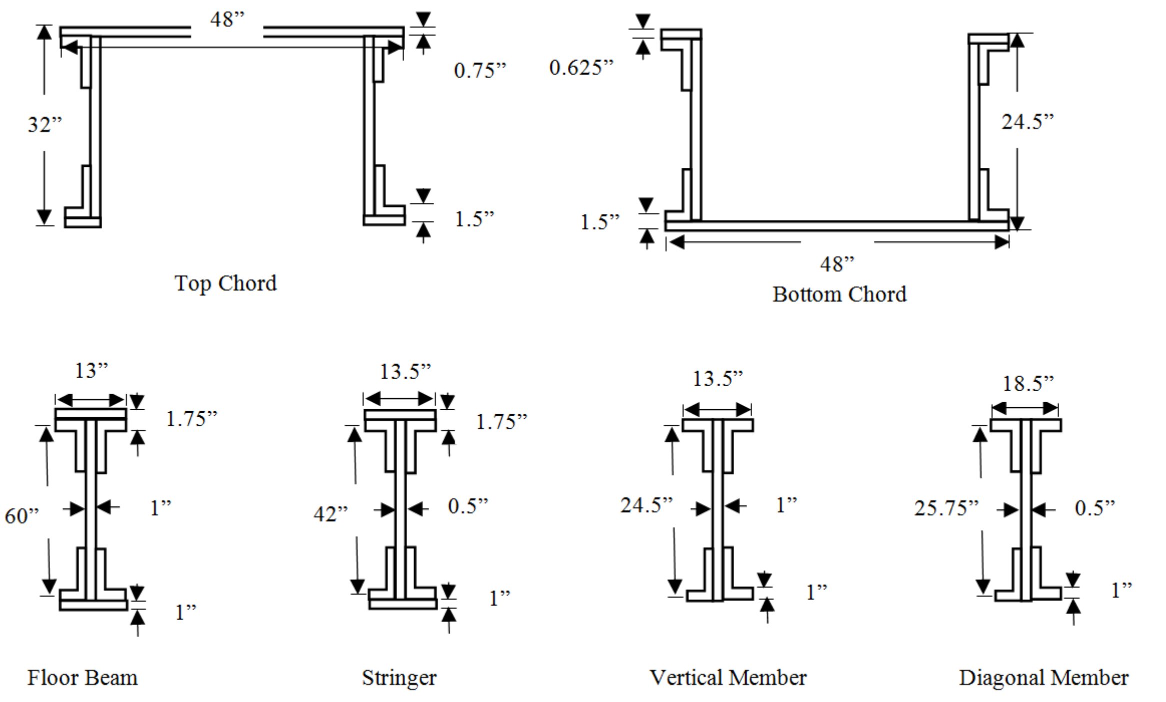


Figure 1. Cross sectional details of different members of Hardinge Bridge.

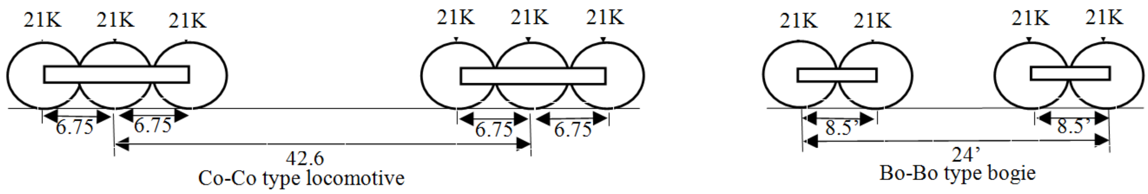
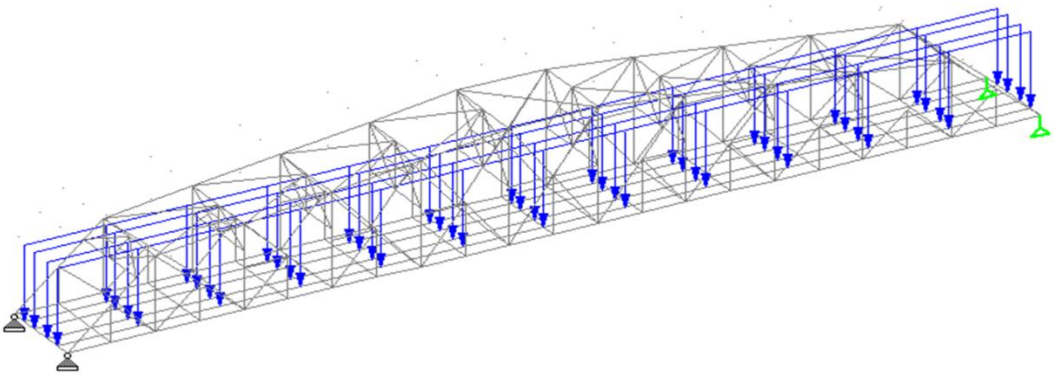
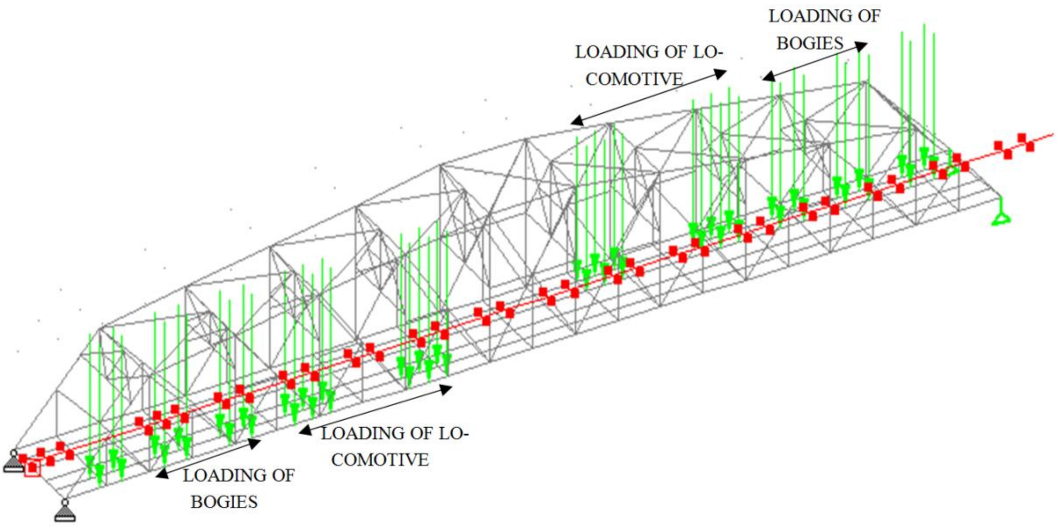


Figure 2. Moving train load.



a) The weight of rails and sleepers are taken 0.09 kip/ft uniformly distributed load along the four stringers of the bridge.



b) Two trains from opposite directions crossing the bridge at a time.
Figure 3. Loads on bridge span.

4 METHODOLOGY

In this study, fracture-critical member of Hardinge Bridge is identified considering allowable stress of steel members as a criterion. As the bridge is symmetric, members of half of a span were considered in failure cases. Firstly, analyses were carried out to find redundant members using the flow chart of Figure 4. Stresses in members were computed considering the bridge is in intact condition. Failure of a member was considered by providing zero cross-sectional area of that particular member. This condition illustrates the incapability of the member to carry any load. Under this condition, stresses in other member was determined and compared to the allowable stress. Then FCM was identified from analyses with non-redundant members using the procedure of Figure 5.

The performance of bridges was evaluated under service load from the analysis in intact condition. Later, stresses in members due to failure of different members were compared with that of intact condition to illustrate failure scenario.

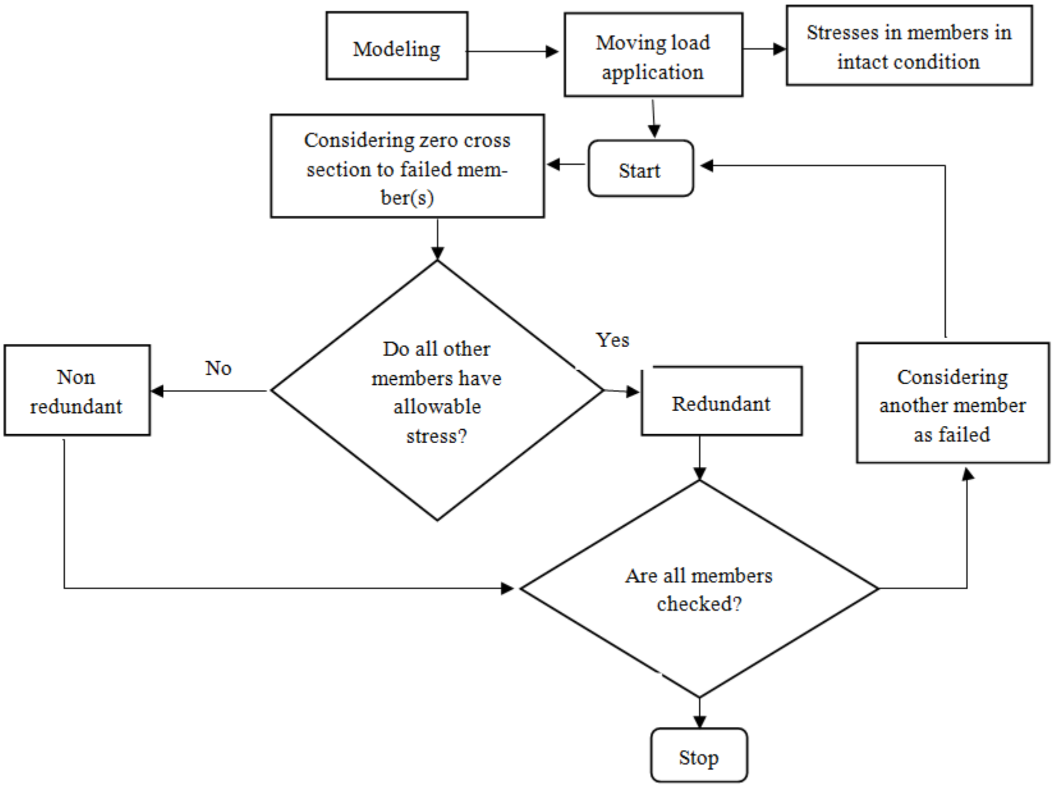


Figure 4. Flow diagram to identify redundant and non-redundant members.

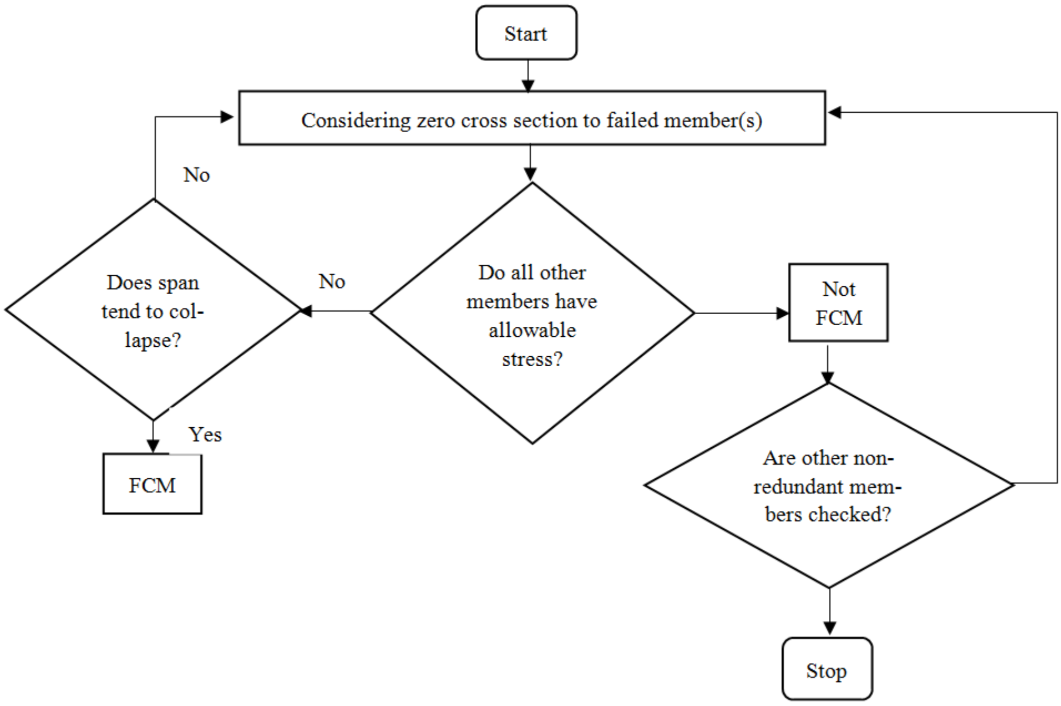
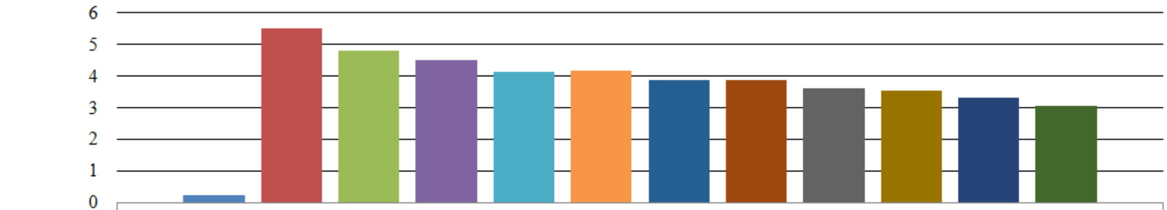


Figure 5. Flow diagram to identify critical member.

5 ANALYSIS

Actual material properties of the bridge members are not available. Therefore, assumptions were made to estimate the yield strength. Firstly the strength was assumed as 40 ksi(275 MPa). Some researchers also suggest to consider a reduced strength for old steel bridges (Adasooriya, 2017). Therefore analysis was also conducted considering yield strength of 30 ksi(207 MPa). Failure of member was applied by reducing the cross-sectional area of the particular member.

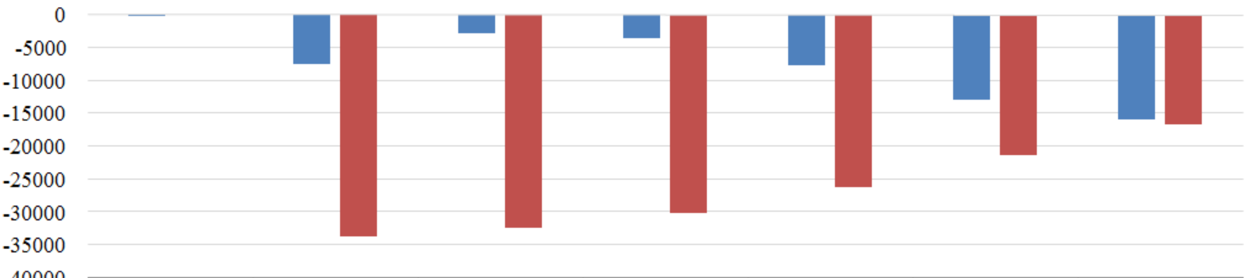


	Nodal Displacement
INTACT	0.22
L1	5.464
L2	4.784
L3	4.468
L4	4.107
L5	4.156
L6	3.854
L7	3.865
L8	3.605
L9	3.527
L10	3.298
L11	3.054

Figure 6. Variation of nodal displacement of opposite side due to failure of different lower chords.

Figure 6 shows the displacement of the node of the opposite corner (in inch) due to the removal of lower chords. According to AASHTO, the defection limit= (span length/800). The span length of the truss is 345ft so the allowable deflection is (345×12)/800=5.175inch. However, the deflection at the failure of lower chord L1 is 5.464inch which was only 0.22 inch in intact condition.

Figure 7 shows a drastic increase in stresses in corner floor beams of both sides due to the removal of upper chords. Maximum stress 33599.10 psi develops in corner floor beam of opposite side cb2 at the failure of upper chord U1.

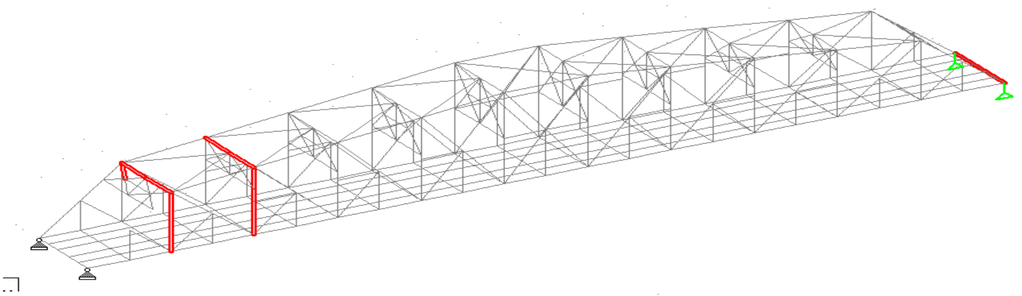
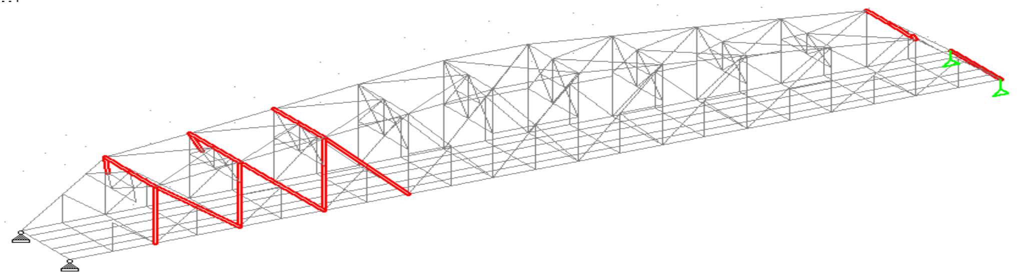
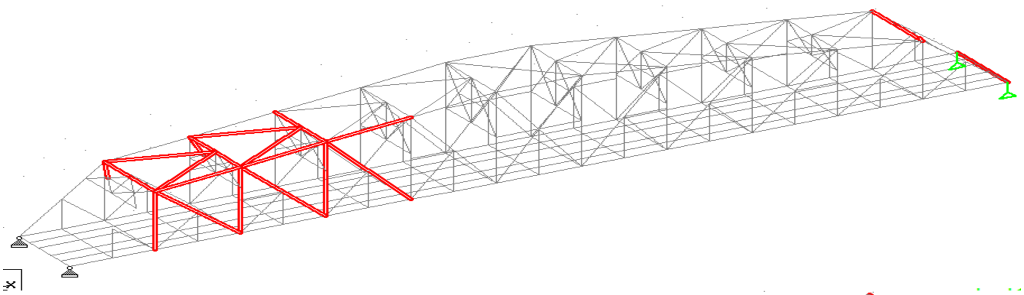
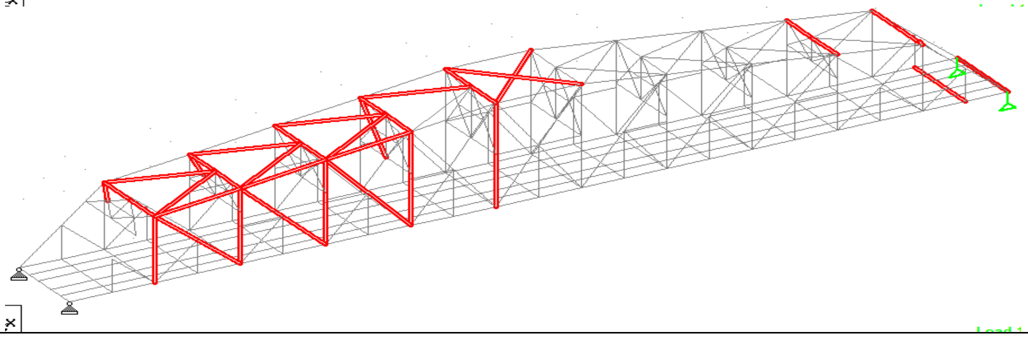


	INTACT	U1	U2	U3	U4	U5	U6
cb1	-174.151	-7516.298	-2790.074	-3580.785	-7749.227	-12863.553	-15880.849
cb2		-33599.1	-32328.74	-30165.32	-26110.78	-21262.57	-16642.36

Figure 7. Variation of stresses in corner floor beams of both sides.

In different codes and analysis, tension members were considered FCM as they were prone to fatigue and easy to break as fracture failure. However, compression member deterioration might still be able to cause joint displacement increasing rapidly, which could aggravate the load to other members as same as fracture member failure (Chien and Zhang, 2017). From Table 1, it can be seen that on the removal of compression member U1, other members of the spans fail at about 32 ksi. The floor beams on the opposite side failed in tension and made stringers unstable. Thus the collapse of the span gets initiated.

Table 1. Propagation of collapse of span due to failure of U1.

Stage	Failed members
1	
2	
3	
4	

6 CONCLUSIONS

Actually, FCM identification is a complex and clumsy task. Different Codes and authors suggested different methods. However, a simple approach has been illustrated in this study. Allowable stress was set as a criterion to identify the FCM. Based on the analysis and results following conclusions can be drawn:

– The application of the train loads at intact condition results in stresses lower than the allowable stress.
– All the diagonal and vertical members are redundant if the minimum yield stress is 30 ksi.
– The corner upper chord is FCM.
– Failure of lower chords is significant as it increases the joint displacement. This may cause failure of gusset plates.

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