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REDUNDANCY ANALYSIS OF HARDINGE BRIDGE: EFFECTS OF FAILURE OF LOWER CHORDS ON OTHER MEMBERS OF THE SPAN

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ABSTRACT

The transportation system of Bangladesh has achieved a well-developed communication network with several newly constructed bridges. But, the old bridges still lack proper maintenance. Even then, some of them have shown extraordinary performance, such as the Hardinge bridge. However, it is much more challenging to maintain the old bridges in this country with few resources. Besides, the failure of some bridges may result in huge losses and suffering to the nation. The design and construction of the durable bridge would be a probable solution to these problems. Therefore, this study extended the previous works on the redundancy analysis of the Hardinge bridge. Considering the consecutive failure of lower chords, the stresses in the rest other members were found. However, failure of a few members has shown a drastic increase of stresses in neighboring members which is alarming for the whole truss. Another important finding from this study is the affected joints and their displacement due to the absence of those lower chords. As the joints are more than 100 years old gusset plate, the failure of joints due to the resultant displacement may also cause damage to the truss bridge. Finally, the members and gusset plates which will be affected more due to failure of lower chords should be maintained properly.

Keywords: *Hardinge Bridge, Redundancy, Truss bridge, bridge design, bridge maintenance*

1. INTRODUCTION

Bangladesh, a country of the river has thousands of bridges to build up its transportation system. From the time of the British period, steel truss bridges were constructed connecting important places of Bangladesh.
Among them, the redundancy analysis of the Hardinge bridge is focused in this study. Construction of this through truss bridge began in 1910, completed in 1912 (Eenst, 2014), and trains started moving on it in 1915 (Coleman, 2014). The bridge comprises 15 steel trusses and the main girders are modified "Petit" type.

However, Redundancy is the quality of a bridge to perform as designed in a damaged state due to the presence of multiple load paths. The non-redundant steel members are the fracture critical members (Fu, 2002).

(Awall et al., 2015) described redundancy for the percentage of change in axial stress before and after fracture of a single member using STAAD.pro working with only diagonal and vertical members. After that, (Tabassum & Serker, 2020) predicted the fracture critical member of the bridge based on assumed allowable stresses of members of the truss. Later on, (Tabassum & Serker, 2021) found out the effects of failure of different upper chords on the rest other members of the truss bridge. Finally, this paper aimed to extend the previous study and worked with the effects of failure of lower chords on other members and joints.

2. MODELING AND LOAD APPLICATION

Modeling and moving load applications on Hardinge Bridge on this study were done using STAAD.pro software following (Awall et al., 2015). Sufficient data to predict the present strength of this old bridge is not available. Therefore, the weight of rails and sleepers were taken 0.09 kip/ft uniformly distributed load along the four stringers of the bridge and two trains from opposite directions are crossing the bridge at a time were considered following (Tabassum & Serker, 2020).

3. METHODOLOGY

As the span of the bridge is symmetric, the failure of members from half a portion was considered. Consecutively failure of lower chords was considered and resulting stresses on diagonal and vertical members were studied. Fristly, the stesses of members in intact condition were found out and the members the truss were named as shown in figure 1. Lower chords, Vertical members and Diagonal members are denoted by L, V and II consecutively. Then the methodology of (Tabassum & Serker, 2021) has been repeated for the cases of lower chords.

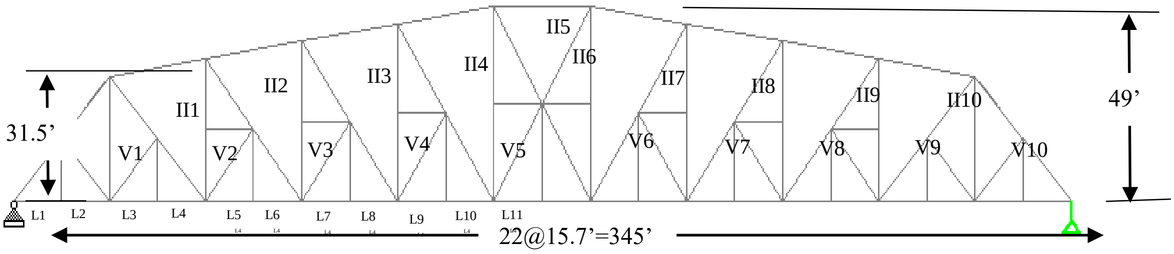
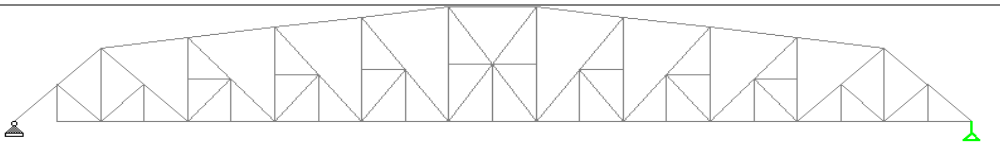
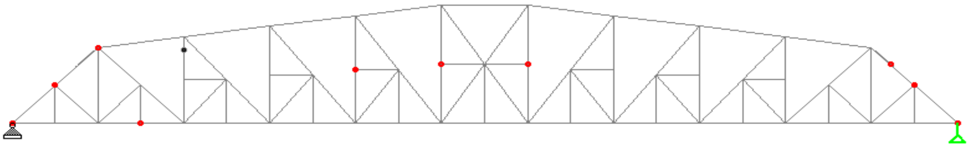
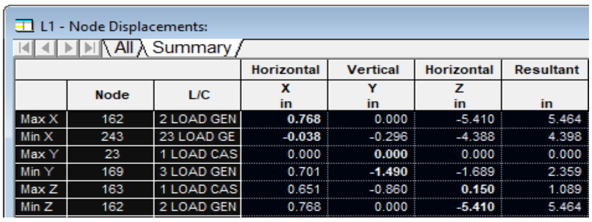


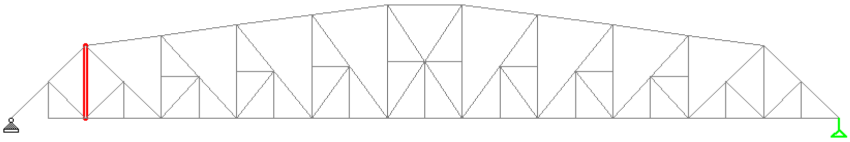
Figure 1: Edge view and nomenclature of different members of Hardinge Bridge.

4. RESULTS AND DISCUSSION

Table 1: Effect of failure of lower chords of truss to different members and nodes

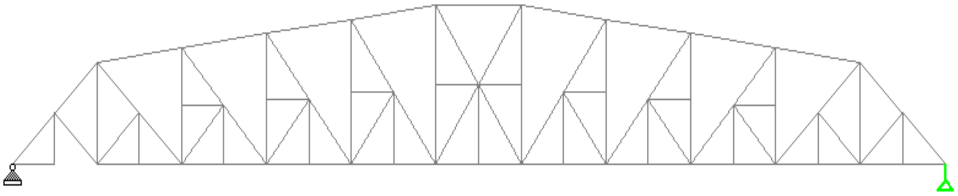
<table>
<tr><th>Failed member</th><th>Effect of failure</th></tr>
<tr><td>L1
max.
stress
53.5 ksi</td><td>



L1 - Node Displacements:

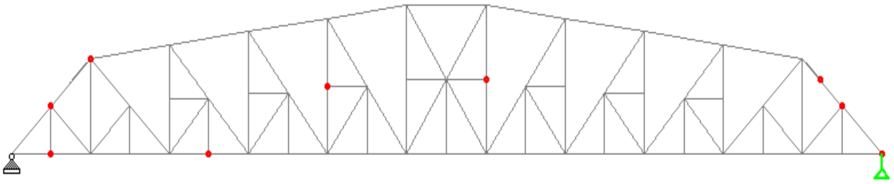
<table>
<tr><th></th><th></th><th></th><th>Horizontal</th><th>Vertical</th><th>Horizontal</th><th>Resultant</th></tr>
<tr><th></th><th>Node</th><th>L/C</th><th>X
in</th><th>Y
in</th><th>Z
in</th><th>in</th></tr>
<tr><td>Max X</td><td>162</td><td>2 LOAD GEN</td><td>0.768</td><td>0.000</td><td>-5.410</td><td>5.464</td></tr>
<tr><td>Min X</td><td>243</td><td>23 LOAD GE</td><td>-0.038</td><td>-0.296</td><td>-4.388</td><td>4.398</td></tr>
<tr><td>Max Y</td><td>23</td><td>1 LOAD CAS</td><td>0.000</td><td>0.000</td><td>0.000</td><td>0.000</td></tr>
<tr><td>Min Y</td><td>169</td><td>3 LOAD GEN</td><td>0.701</td><td>-1.490</td><td>-1.689</td><td>2.359</td></tr>
<tr><td>Max Z</td><td>163</td><td>1 LOAD CAS</td><td>0.651</td><td>-0.860</td><td>0.150</td><td>1.089</td></tr>
<tr><td>Min Z</td><td>162</td><td>2 LOAD GEN</td><td>0.768</td><td>0.000</td><td>-5.410</td><td>5.464</td></tr>
</table>
Maximum nodal displacement 5.46 inch
</td></tr>
</table>

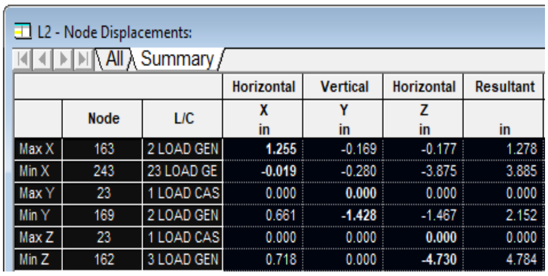


Maximum stress developed at member V1

L2
max.
stress
46.74 ksi



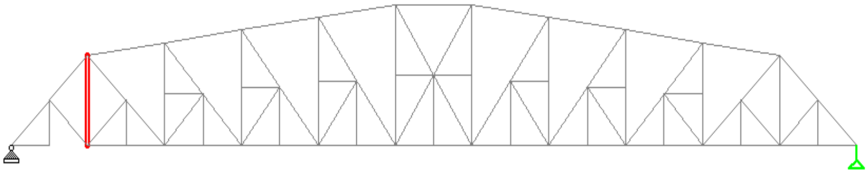




L2 - Node Displacements:

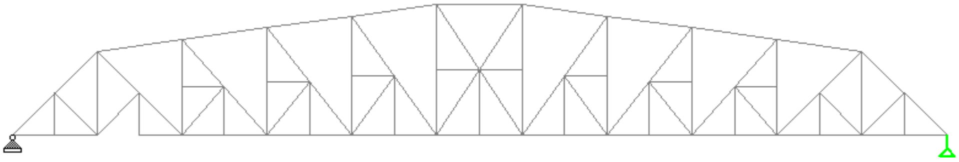
			Horizontal	Vertical	Horizontal	Resultant
	Node	L/C	X in	Y in	Z in	in
Max X	163	2 LOAD GEN	1.255	-0.169	-0.177	1.278
Min X	243	23 LOAD GE	-0.019	-0.280	-3.875	3.885
Max Y	23	1 LOAD CAS	0.000	0.000	0.000	0.000
Min Y	169	2 LOAD GEN	0.661	-1.428	-1.467	2.152
Max Z	23	1 LOAD CAS	0.000	0.000	0.000	0.000
Min Z	162	3 LOAD GEN	0.718	0.000	-4.730	4.784

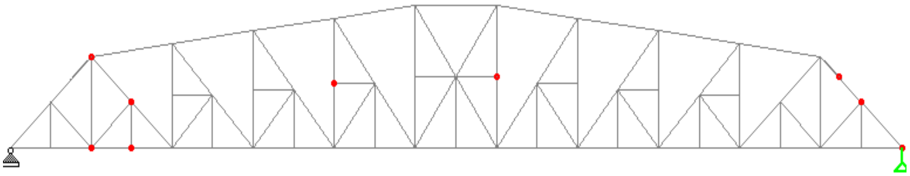
Maximum nodal displacement 4.78 inch

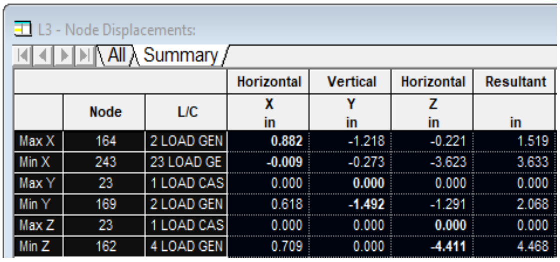


Maximum stress developed at vertical member V1

L3
max.
stress
45.71 ksi



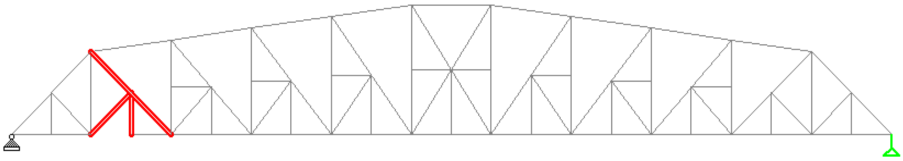




L3 - Node Displacements:

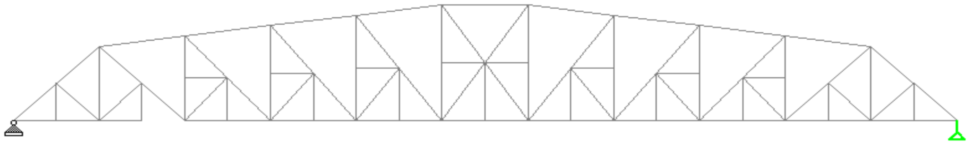
			Horizontal	Vertical	Horizontal	Resultant
	Node	L/C	X in	Y in	Z in	in
Max X	164	2 LOAD GEN	0.882	-1.218	-0.221	1.519
Min X	243	23 LOAD GE	-0.009	-0.273	-3.623	3.633
Max Y	23	1 LOAD CAS	0.000	0.000	0.000	0.000
Min Y	169	2 LOAD GEN	0.618	-1.492	-1.291	2.068
Max Z	23	1 LOAD CAS	0.000	0.000	0.000	0.000
Min Z	162	4 LOAD GEN	0.709	0.000	-4.411	4.468

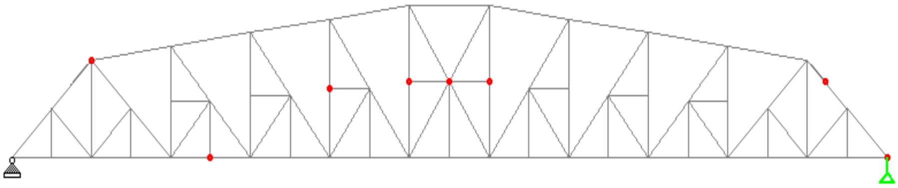
Maximum nodal displacement 4.47 inch

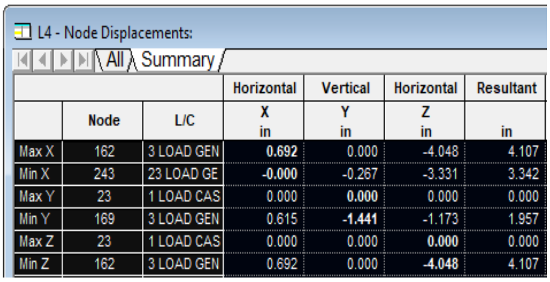


Maximum stress developed at diagonal member II1

L4 max. stress 42.2 ksi



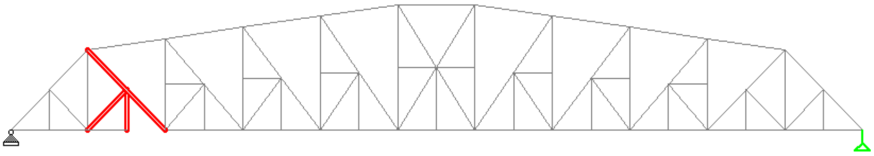




L4 - Node Displacements:

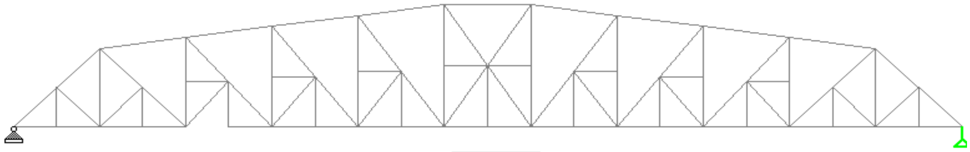
			Horizontal	Vertical	Horizontal	Resultant
	Node	L/C	X in	Y in	Z in	in
Max X	162	3 LOAD GEN	0.692	0.000	-4.048	4.107
Min X	243	23 LOAD GE	-0.000	-0.267	-3.331	3.342
Max Y	23	1 LOAD CAS	0.000	0.000	0.000	0.000
Min Y	169	3 LOAD GEN	0.615	-1.441	-1.173	1.957
Max Z	23	1 LOAD CAS	0.000	0.000	0.000	0.000
Min Z	162	3 LOAD GEN	0.692	0.000	-4.048	4.107

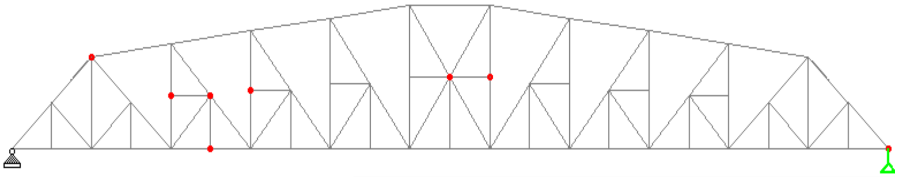
Maximum nodal displacement 4.1 inch

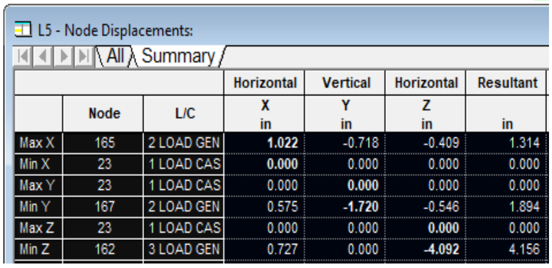


Maximum stress developed at diagonal member II1

L5 max. stress 42.7 ksi



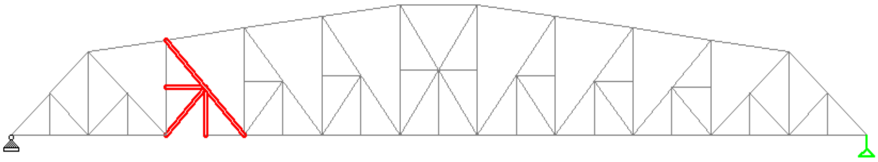




L5 - Node Displacements:

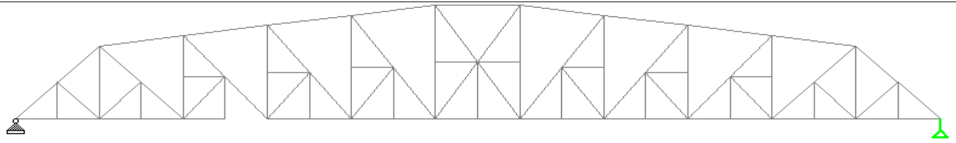
			Horizontal	Vertical	Horizontal	Resultant
	Node	L/C	X in	Y in	Z in	in
Max X	165	2 LOAD GEN	1.022	-0.718	-0.409	1.314
Min X	23	1 LOAD CAS	0.000	0.000	0.000	0.000
Max Y	23	1 LOAD CAS	0.000	0.000	0.000	0.000
Min Y	167	2 LOAD GEN	0.575	-1.720	-0.546	1.894
Max Z	23	1 LOAD CAS	0.000	0.000	0.000	0.000
Min Z	162	3 LOAD GEN	0.727	0.000	-4.092	4.156

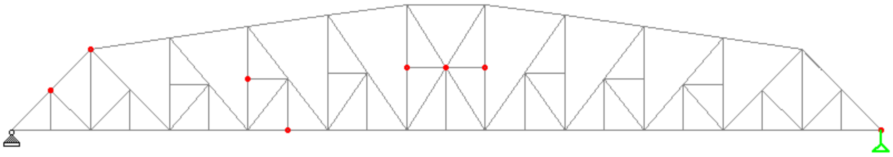
Maximum nodal displacement 4.16 inch

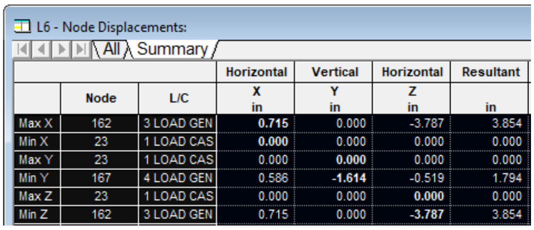


Maximum stress developed at diagonal member II2

L6 max. stress 39.19 ksi

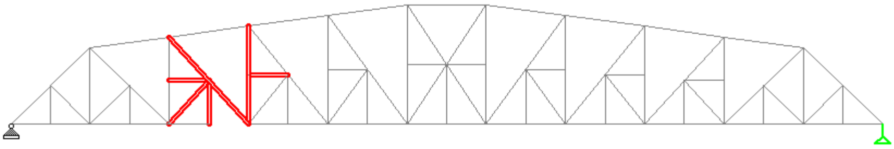






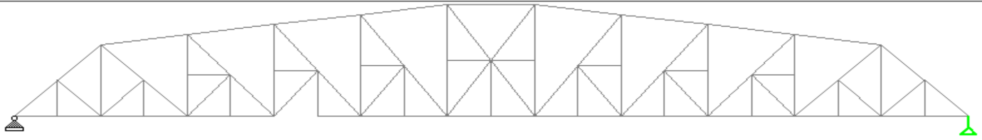
			Horizontal	Vertical	Horizontal	Resultant
	Node	L/C	X in	Y in	Z in	in
Max X	162	3 LOAD GEN	**0.715**	0.000	-3.787	3.854
Min X	23	1 LOAD CAS	**0.000**	0.000	0.000	0.000
Max Y	23	1 LOAD CAS	0.000	**0.000**	0.000	0.000
Min Y	167	4 LOAD GEN	0.586	**-1.614**	-0.519	1.794
Max Z	23	1 LOAD CAS	0.000	0.000	**0.000**	0.000
Min Z	162	3 LOAD GEN	0.715	0.000	**-3.787**	3.854

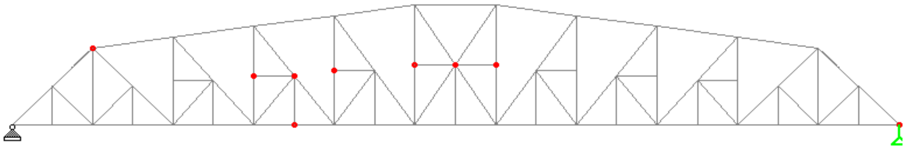
Maximum nodal displacement 3.85 inch

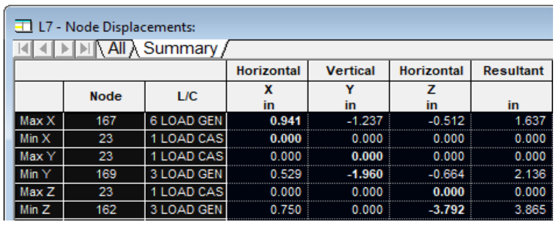


Maximum stress developed at vertical member V3 and diagonal member II2

L7 max. stress 37.9 ksi

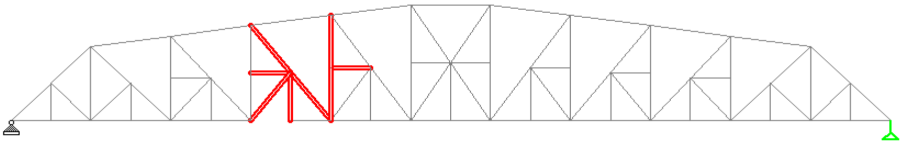






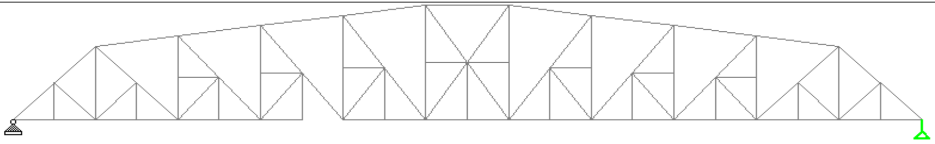
			Horizontal	Vertical	Horizontal	Resultant
	Node	L/C	X in	Y in	Z in	in
Max X	167	6 LOAD GEN	**0.941**	-1.237	-0.512	1.637
Min X	23	1 LOAD CAS	**0.000**	0.000	0.000	0.000
Max Y	23	1 LOAD CAS	0.000	**0.000**	0.000	0.000
Min Y	169	3 LOAD GEN	0.529	**-1.960**	-0.664	2.136
Max Z	23	1 LOAD CAS	0.000	0.000	**0.000**	0.000
Min Z	162	3 LOAD GEN	0.750	0.000	**-3.792**	3.865

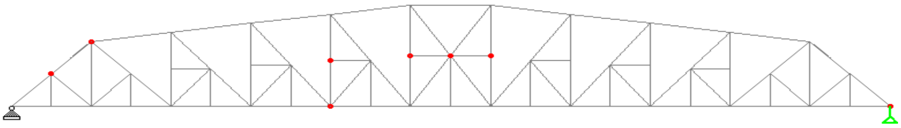
Maximum nodal displacement 3.86 inch

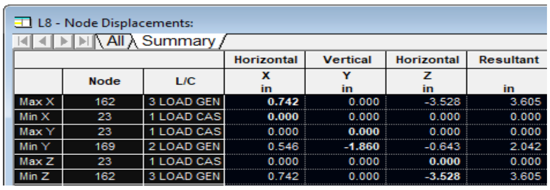


Maximum stress developed at vertical member V4 and diagonal member II3

L8 max. stress 34.32 ksi



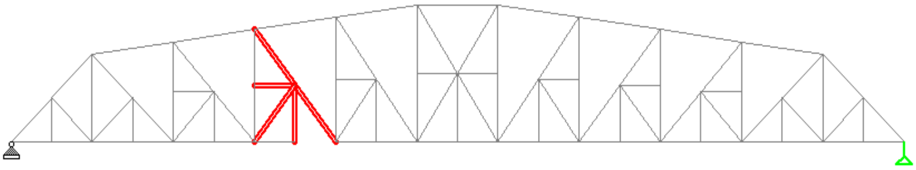




L8 - Node Displacements:

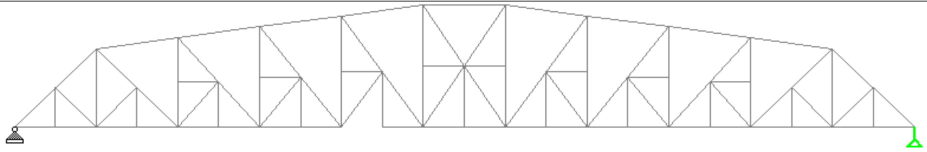
			Horizontal	Vertical	Horizontal	Resultant
	Node	L/C	X in	Y in	Z in	in
Max X	162	3 LOAD GEN	**0.742**	0.000	-3.528	3.605
Min X	23	1 LOAD CAS	**0.000**	0.000	0.000	0.000
Max Y	23	1 LOAD CAS	0.000	**0.000**	0.000	0.000
Min Y	169	2 LOAD GEN	0.546	**-1.860**	-0.643	2.042
Max Z	23	1 LOAD CAS	0.000	0.000	**0.000**	0.000
Min Z	162	3 LOAD GEN	0.742	0.000	**-3.528**	3.605

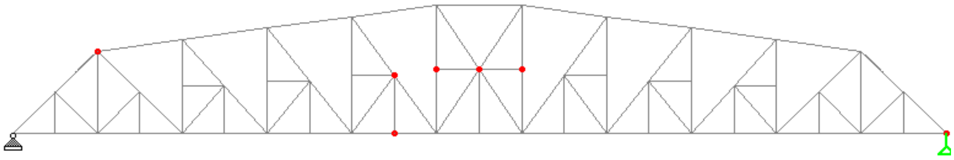
Maximum nodal displacement 3.61 inch

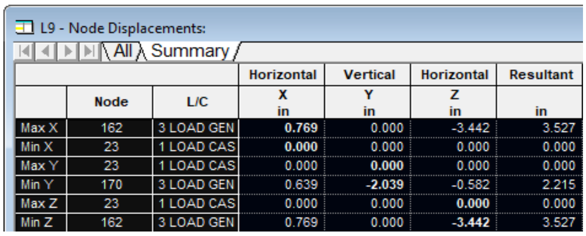


Maximum stress developed at diagonal member II3

L9 max. stress 31.19 ksi



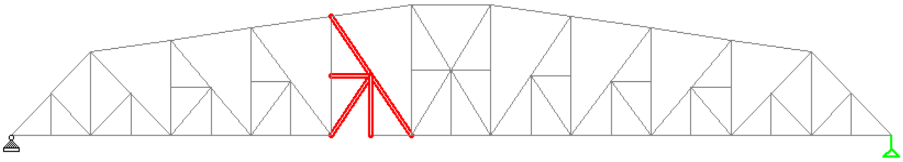




L9 - Node Displacements:

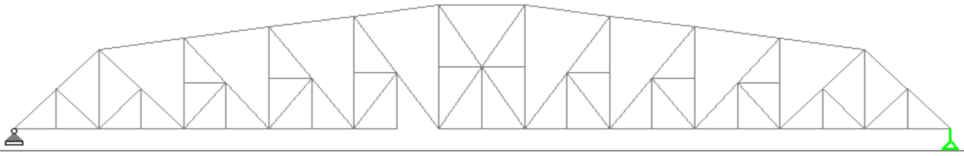
			Horizontal	Vertical	Horizontal	Resultant
	Node	L/C	X in	Y in	Z in	in
Max X	162	3 LOAD GEN	**0.769**	0.000	-3.442	3.527
Min X	23	1 LOAD CAS	**0.000**	0.000	0.000	0.000
Max Y	23	1 LOAD CAS	0.000	**0.000**	0.000	0.000
Min Y	170	3 LOAD GEN	0.639	**-2.039**	-0.582	2.215
Max Z	23	1 LOAD CAS	0.000	0.000	**0.000**	0.000
Min Z	162	3 LOAD GEN	0.769	0.000	**-3.442**	3.527

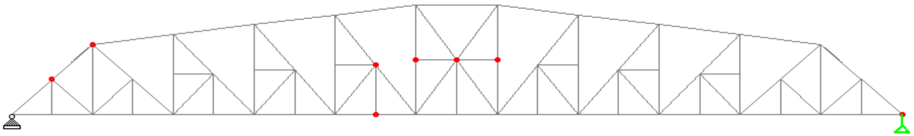
Maximum nodal displacement 3.53 inch

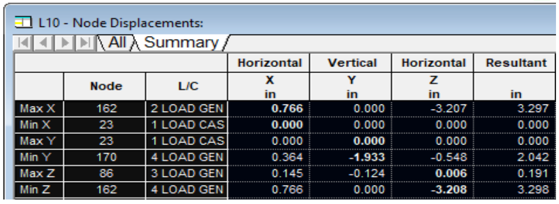


Maximum stress developed at diagonal member II4

L10 max. stress 27.88 ksi



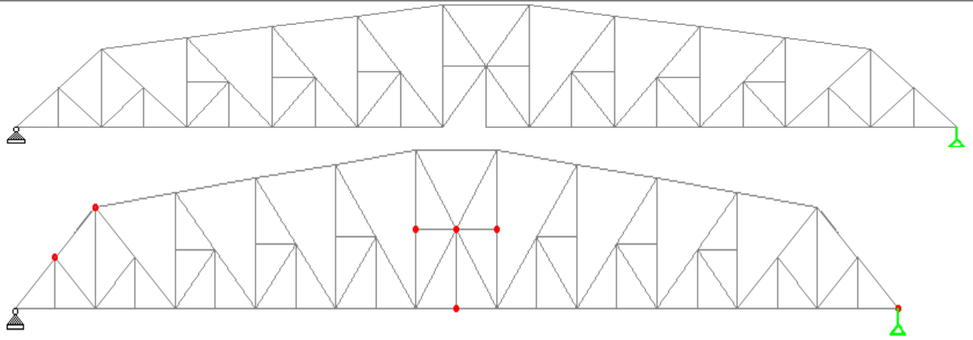


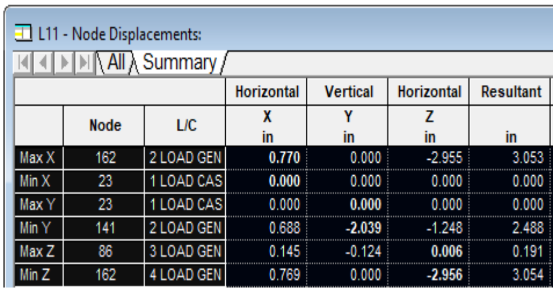


	Node	L/C	Horizontal X in	Vertical Y in	Horizontal Z in	Resultant in
Max X	162	2 LOAD GEN	0.766	0.000	-3.207	3.297
Min X	23	1 LOAD CAS	0.000	0.000	0.000	0.000
Max Y	23	1 LOAD CAS	0.000	0.000	0.000	0.000
Min Y	170	4 LOAD GEN	0.364	-1.933	-0.548	2.042
Max Z	86	3 LOAD GEN	0.145	-0.124	0.006	0.191
Min Z	162	4 LOAD GEN	0.766	0.000	-3.208	3.298

Maximum nodal displacement 3.3 inch

L11
max.
stress
26.8 ksi





	Node	L/C	Horizontal X in	Vertical Y in	Horizontal Z in	Resultant in
Max X	162	2 LOAD GEN	0.770	0.000	-2.955	3.053
Min X	23	1 LOAD CAS	0.000	0.000	0.000	0.000
Max Y	23	1 LOAD CAS	0.000	0.000	0.000	0.000
Min Y	141	2 LOAD GEN	0.688	-2.039	-1.248	2.488
Max Z	86	3 LOAD GEN	0.145	-0.124	0.006	0.191
Min Z	162	4 LOAD GEN	0.769	0.000	-2.956	3.054

Maximum nodal displacement 3.05 inch

From Table 1, the effects on different members and joints due to the absence of different lower chords are illustrated. Firstly, for the failure of corner lower chord L1, maximum stress induced in neighboring vertical member V1 is 53.5 ksi and the joint on the opposite corner of the truss suffers a maximum displacement of 5.46 inches. Secondly, for the failure of the second corner lower chord L2, maximum stress induced in neighboring vertical member V1 is 46.74 ksi and the joint on the opposite corner of the truss suffers a maximum displacement of 4.78 inches. Thirdly, for the failure of lower chord L3, maximum stress induced in neighboring diagonal member II1 is 45.71 ksi and the joint on the opposite corner of the truss suffers a maximum displacement of 4.78 inches. Forthly, for the failure of lower chord L4, maximum stress induced in neighboring diagonal member II1 is 42.2 ksi and the joint on the opposite corner of the truss suffers a maximum displacement of 4.1 inches. Fifthly, for the failure of lower chord L5, maximum stress induced in neighboring diagonal member II2 is 42.7 ksi and the joint on the opposite corner of the truss suffers a maximum displacement of 4.16 inches. Sixthly, for the failure of lower chord L6, maximum stress induced in neighboring diagonal member II2 and vertical member V3 is 39.19 ksi and the joint on the opposite corner of the truss suffers a maximum displacement of 3.85 inches. Seventhly, for the failure of lower chord L7, maximum stress induced in neighboring diagonal member II3 and vertical member V4 is 37.9 ksi and the joint on the opposite corner of the truss suffers a maximum displacement of 3.86 inches. Eighthly, for the failure of lower chord L8, maximum stress induced in neighboring diagonal member II3 is 34.32 ksi and the joint on the opposite corner of the truss suffers a maximum displacement of 3.61 inches. Ninthly, for the failure of lower chord L9, the maximum stress induced in neighboring diagonal member II4 is 31.19 ksi and the joint on the opposite corner of the truss suffers a maximum displacement of 3.53 inches. Tenthly, for the failure of lower chord L10, maximum stress induced in the neighboring member is 27.88 ksi and the joint on the opposite corner of the truss suffers a maximum displacement of 3.3 inches. Lastly, for the failure of lower chord L11, maximum stress induced in the neighboring member is 26.8 ksi and the joint on the opposite corner of the truss suffers a maximum displacement of 3.05 inches. Therefore, it can be concluded that the induced stresses and joint displacements gradually decreased while the failure of lower chords was from exterior towards the interior portion of the truss with little exception. However, as the value of joint displacement is significant, the old and rusted gusset plate may suffer failure. Besides, the stresses due to the failure of corner lower chords are a matter of big deal.

5. CONCLUSIONS

From this study, the importance of maintenance of lower chords of truss of Hardinge bridge can easily be understood. Most importantly, the gusset plates will suffer huge displacements if lower chords fail. That is why proper maintenance and strengthening of the gusset plate is one of the precautions to increase the life of the bridge. Besides, due to the failure of lower chords, neighboring diagonal and vertical members may fail. However, the presence of multiple load paths neutralizes the increased stress among the neighboring members and cease the propagation of failure of the truss. Therefore, the adjacent members should be given importance as soon as any lower chord is affected. Increasing the cross-sections of vertical and diagonal members in the truss can be a solution to design new bridges having similar load paths as the truss off Hardinge Bridge.

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