Resilient Structures and Sustainable Construction
Edited by Pellicer, E., Adam, J. M., Yepes, V., Singh, A., and Yazdani, S.

ISBN: 978-0-9960437-4-8

INFLUENCE OF MEMBER CONNECTION MODELING FOR REDUNDANCY ANALYSIS OF TRUSS BRIDGES

KEIJI TAJIMA, NAOYUKI OKA, KAZUAKI UCHIYAMA, and TOSHIHIKO ASO

Dept of Civil and Environmental Engineering, Yamaguchi University, Ube, Japan

To assess critical state of bridges, after-fracture-redundancy plays an important role. Therefore, it is necessary to make a correct prediction of redundancy. However, redundancy from numerical analysis is strongly influenced by various analytical conditions. This study aimed to clarify the influence of member connection modeling and shape of gusset plates on redundancy analysis of truss bridges. Redundancy were computed for three types of analysis model of truss bridge. Model A was a frame model of truss bridge, frame members were connected to each other rigidly as it is. On the other hand, in Model B and Model C, members were connected via gusset plates modeled by shell elements. Gusset plates in model B were rectangle and these of model C had curved shape. Using these three models, redundancies under different analytical condition and different gusset plate shape were compared. From the results of calculation, it was found that bending moment on truss members were strongly influenced by difference of member connection modeling. Computed results also indicated that the influence appears more strongly in damage state than normal state (non-damage state). This result suggested the necessity of accurate modeling of member connection. Furthermore, it was indicated that the redundancy of truss bridges could be improved by change in shape of gusset plates.

Keywords: Steel bridge, Numerical analysis, Analytical condition, Gusset plate.

1 INTRODUCTION

A truss bridge is defined as a framework structure in which elongated members are triangularly assembled by pin connection. According to this definition, even if only one member is damaged, the truss structure becomes unstable and falls into a structural collapse. However, since in most of truss bridges, these members are connected by gusset plates, even if one member is broken, the structure does not become unstable structure. In this case, there is concern that a bending moment which does not work in the normal state may act on the remaining member.

In Japan, the redundancy of truss bridges is generally computed by frame analysis models with rigid member connection. There are few studies that analyzing redundancy of truss bridge by the models with gusset plate (Tamakoshi 2014). However, in the redundancy evaluation of a truss bridge with a damaged member, bending moment becomes dominant sectional force. Bending moment is influenced by the rigidness of member connection, so for the proper redundancy evaluation, it is necessary to clarify the influence of member connection modeling. This study aims to examine the influence of the shape of gusset plate in redundancy analysis in addition to member connection modeling.

2 REDUNDANCY ASSESSMENT

According to previous research (Iwasaki 2014), redundancy of truss bridges can be defined as “damage ratio of remaining members in a state where one frame member is broken." This is based on the idea that collapse of the bridge can be avoided as long as the remaining members do not lead to be damaged. That is, If the remaining member lead to be damaged, member damages due to a chain reaction would be caused and the truss bridge would be collapse in the end.

In a truss bridge where a frame member has lost its function, a bending moment which can’t be ignored will be appeared in remaining members. Thus, the damage ratio of it has to be evaluated in consideration of both of axial force and bending moment. Damage ratio R that represents redundancy can be calculated by Eq. (1) for tensile members and Eq. (2) for compressive members, respectively (Fukumoto 1987). If the damage degree of one of the remaining frame members exceeded 1.00, it is judged that the truss bridge would lead to collapse.

$$R = R(N) + R(M_{IN}) + R(M_{OUT}) = \frac{N}{N_P} + \left(\frac{M}{M_P}\right)_{IN} + \left(\frac{M}{M_P}\right)_{OUT} \tag{1}$$

$$R = R(N) + R(M_{IN}) + R(M_{OUT}) = \frac{N}{N_U} + \frac{1}{1-(N/N_E)_{IN}}\left(\frac{M}{M_P}\right)_{IN} + \frac{1}{1-(N/N_E)_{OUT}}\left(\frac{M}{M_P}\right)_{OUT} \tag{2}$$

Here *N:* Acting axial force, *M:* acting bending moment, N_P: fully plastic axial force, M_P: fully plastic bending moment, N_U: buckling strengthen, N_E: Euler buckling strengthen, *IN*: in plane direction, *OUT*: out of plane direction.

3 ANALYTICAL MODELS

In this study, redundancy of steel warren truss railway-bridge was evaluated. Figure 1 displays outline and cross section of truss bridge.

To confirm the influence of connecting condition of each members and shapes of gusset plates, three analytical models (Model A, B and C) were computed. Figure 2 indicates Model A that is a common analytical model, members in this model are connected rigidly. In model B and model C, gusset plate was modeled by shell elements. Gusset plates of model B is a rectangle and model C is a curved shape as shown in Figure 3. In all three models, concrete slab was modeled by shell elements.

In analysis, dead load was considered but live load and impact effect that was caused by member fracture were out of consideration. Three types of damage (Type-1, -2, and -3) were simulated. Figure 4 shows damage types. In each damage type one member was removed respectively. Non-damaged model was also computed to compare with damaged models.

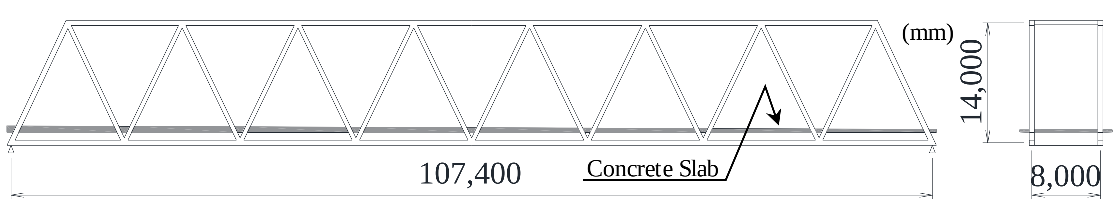

Figure 1. General and cross section of the truss bridge for this study.

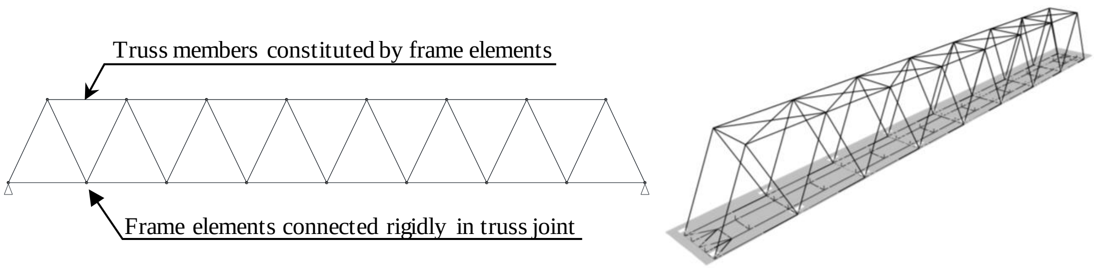

Figure 2. Model A.

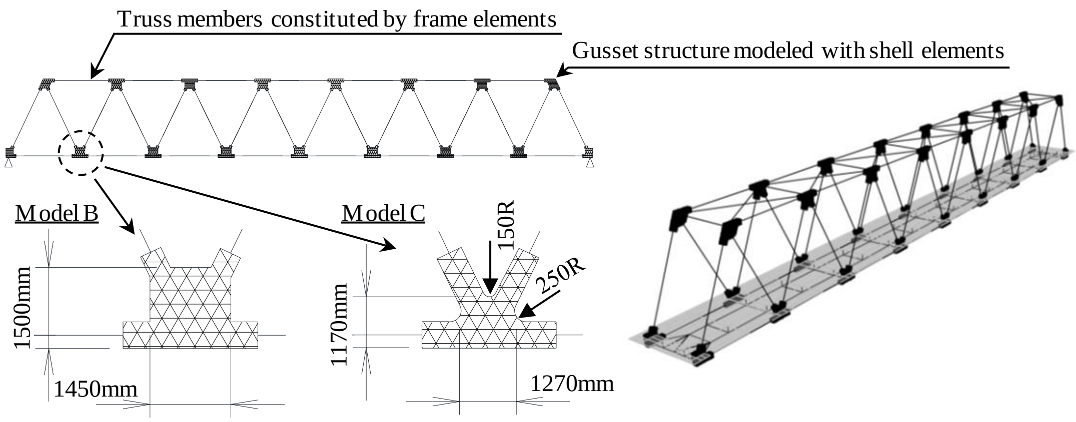

Figure 3. Model B and Model C.

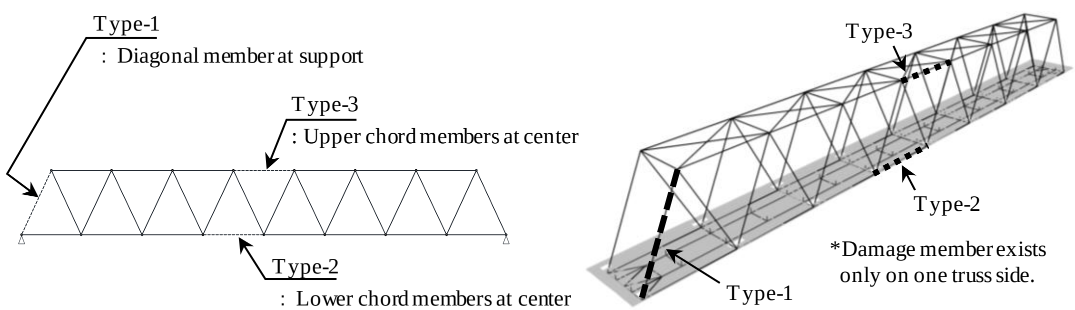

Figure 4. Damage types of analysis.

4 ANALYTICAL RESULTS

Table 1 shows damage ratio on damaged truss side of Model A in each damage types. The first column in this table represents the member number shown in Figure 5. In Type-2 and non-damage, damage ratio of all members is below 1.00, so truss bridge does not become fatal state. In Type-1, maximum damage ratio 2.13 appears on LC-1, in Type-3, D-8 and D-9 is 1.00 exactly.

Table 1. Damage ratio by Model A in 3 damage types and non-damage state.

Member Number	Damage Type-1				Damage Type-2				Damage Type-3				Non-damage			
	UC-#	LC-#	D-#	D-(#)	UC-#	LC-#	D-#	D-(#)	UC-#	LC-#	D-#	D-(#)	UC-#	LC-#	D-#	D-(#)
1(9)	0.30	2.13	DM	0.64	0.43	0.82	0.40	0.22	0.37	0.25	0.41	1.00	0.45	0.25	0.37	0.35
2(10)	0.25	0.87	1.37	0.65	0.39	0.21	0.74	0.21	0.34	0.31	0.75	0.21	0.43	0.37	0.65	0.29
3(11)	0.34	0.51	0.75	1.05	0.41	0.45	0.44	0.51	0.40	0.33	0.43	0.59	0.45	0.41	0.46	0.64
4(12)	0.40	0.49	0.78	0.81	0.41	DM	0.58	0.39	DM	0.41	0.53	0.32	0.44	0.39	0.63	0.47
5(13)	0.46	0.52	0.40	1.06	0.40	0.45	0.39	0.64	0.40	0.41	0.32	0.54	0.44	0.39	0.47	0.64
6(14)	0.52	0.58	0.45	0.79	0.39	0.31	0.49	0.45	0.34	0.33	0.59	0.43	0.43	0.41	0.64	0.47
7(15)	0.58	0.49	0.13	1.26	0.44	0.25	0.38	0.72	0.37	0.31	0.21	0.75	0.45	0.37	0.29	0.65
8(16)		0.60	0.26	0.68		0.68	0.72	0.39		0.25	1.00	0.41		0.25	0.35	0.37

DM: Damaged member

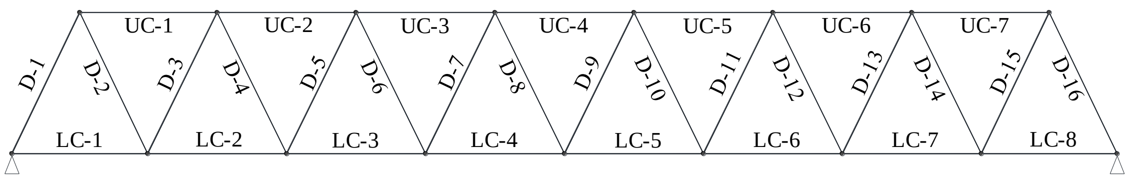

Figure 5. Explanation diagram of member number.

Change rate of Model B compared with damage ratio of Model A is shown in Table 2. The number of members that change rate exceeds 15% are both 4 in Type -1 and 3, respectively, and the maximum of change rate: 21% is shown at UC-1 in Type-1 and LC-8 in Type-3. In non-damage, one member has change rate exceeding 15%. This indicates that difference of connecting conditions in damage state would strongly affect to cross-sectional force than non-damaged state.

Table 2. Change rate of damage ratio by Model B (compared with Model A).

Member Number	Damage Type-1				Damage Type-2				Damage Type-3				Non-damage			
	UC-#	LC-#	D-#	D-(#)	UC-#	LC-#	D-#	D-(#)	UC-#	LC-#	D-#	D-(#)	UC-#	LC-#	D-#	D-(#)
1(9)	21%	20%	DM	6%	2%	9%	1%	-17%	1%	20%	1%	19%	3%	15%	5%	2%
2(10)	1%	6%	17%	3%	-3%	-3%	2%	-1%	-3%	0%	1%	-2%	2%	3%	1%	6%
3(11)	2%	3%	5%	4%	-1%	-5%	4%	0%	-5%	-1%	3%	2%	-1%	1%	3%	4%
4(12)	0%	0%	1%	2%	-1%	DM	2%	4%	DM	1%	6%	-3%	0%	0%	6%	2%
5(13)	1%	-2%	0%	3%	-2%	-6%	2%	4%	-5%	1%	-4%	4%	1%	0%	2%	5%
6(14)	1%	-1%	-1%	2%	1%	-2%	3%	4%	-3%	-1%	2%	4%	2%	1%	4%	1%
7(15)	2%	-1%	-63%	-1%	2%	-58%	4%	3%	2%	0%	-1%	1%	3%	3%	5%	1%
8(16)		16%	-10%	0%		11%	14%	0%		21%	19%	1%		16%	1%	5%

DM: Damaged member

Change rate of Model C compared with Model A is shown in Table 3. Overall, change rate of Model C is smaller than Model B. Size of gusset plate of Model C is smaller than Model B, i.e. constraint on bending deformation is small, so change rate is presumed small, too. Difference of change rate between Model B and C reaches 7% (UC-1 in Type-1). This result shows a possibility that redundancy may be improved by the difference in shape of gusset plate.

Table 3. Change rate of damage ratio by Model C (compared with Model A).

Member Number	Damage Type-1				Damage Type-2				Damage Type-3				Non-damage			
	UC-#	LC-#	D-#	D-(#)	UC-#	LC-#	D-#	D-(#)	UC-#	LC-#	D-#	D-(#)	UC-#	LC-#	D-#	D-(#)
1(9)	14%	19%	DM	3%	0%	9%	1%	-19%	0%	19%	2%	14%	1%	15%	6%	-2%
2(10)	-1%	10%	12%	1%	-2%	-2%	0%	-1%	-2%	1%	-2%	-3%	2%	3%	-1%	4%
3(11)	2%	4%	2%	1%	0%	-5%	2%	-2%	-4%	0%	2%	1%	-1%	1%	3%	1%
4(12)	0%	1%	2%	0%	-1%	DM	1%	3%	DM	1%	4%	-4%	0%	0%	4%	1%
5(13)	1%	-2%	-1%	1%	-2%	-5%	1%	2%	-4%	1%	-4%	2%	1%	0%	1%	3%
6(14)	0%	-1%	0%	0%	1%	-2%	1%	3%	-2%	0%	0%	2%	1%	0%	1%	1%
7(15)	0%	-1%	-63%	-3%	0%	-58%	1%	0%	0%	1%	-2%	-2%	2%	3%	3%	-1%
8(16)		16%	-12%	0%		10%	8%	0%		20%	14%	2%		15%	-3%	5%

DM: Damaged member

Two cases of damage ratio and change rate are shown in Table 4. The case that damage ratio and change ratio are both large is LC-1 in Type-1, and small change rate case is UC-1 in Non-damage. R(N), R(M_{IN}) and R(M_{OUT}) shown in Table 4 was described with Eq. (1) and Eq. (2). In the case of Type-1, from the comparison of components of R, it becomes clear that in-plane bending moment is dominant factor. On the other hand, in case of Non-damage, axial force performs as dominant factor. Truss bridge in damaged state does not constitute triangular structure partially, so bending moment is likely to occur in members, and damage degree of the model B, which constrains the bending deformation of member connection, would tend to be larger than in non-damaged state.

Table 4. Damage ratio and change rate of it with breakdown in two representative cases.

Damage type	Member Number	Damage ratio:R [breakdown] by Model A				Change rate of R [breakdown] of Model B			
		R	R(N)	R(M_{IN})	R(M_{OUT})	R	R(N)	R(M_{IN})	R(M_{OUT})
Damage Type-1	LC-1	2.13	[0.16]	[1.68]	[0.29]	20%	[0%]	[17%]	[3%]
Non-damage	UC-1	0.45	[0.39]	[0.04]	[0.02]	2%	[0%]	[2%]	[0%]

The displacements at center of Model A, B, and C are compared in Table 5. This suggests that the model with gusset plate may tend to constrain deformation than the model without gusset plate.

Table 5. Comparison of displacement at center of damaged truss side by dead load.

MODEL	Displacement at center of damaged truss side (mm) [Ratio:compare with Model A]			
	Damage Type-1	Damage Type-2	Damage Type-3	Non-damage
Model A	414[1.00]	281[1.00]	324[1.00]	196[1.00]
Model B	392[0.95]	271[0.96]	310[0.96]	189[0.96]
Model C	397[0.96]	273[0.97]	314[0.97]	191[0.97]

5 CONCLUSIONS

This paper clarified influence of member connection modeling and shape of gusset plate of truss bridge in redundancy analysis. Main results obtained from numerical analysis are follows:

- Modeling method of connection had a significant influence on redundancy assessment. In frame model, there was a risk estimating redundancy 21% lower than gusset model.
- Truss bridge in damaged state that was the subject of the redundancy assessment was more susceptible to modeling method of truss joint than normal state.
- It would be possible that redundancy was improved by change in shape of gusset plates.

References

Fukumoto, Y., *Guidelines for Stability Design of Steel Structures*, Japan Society of Civil Engineers, Japan, 1987.

Iwasaki, E., Case Study of Structural Redundancy Evaluation using Method of Linear Analysis for Steel Truss Bridges, *Proceedings of the 17th Symposium on Steel Structures and Bridges*, 21-37, 2014.

Tamakoshi, T., Strategic Considerations for Redundancy Evaluation Research in Highway Bridge Design, *Proceedings of the 17th Symposium on Steel Structures and Bridges*, 1-14, 2014.