Progressive Collapse Analysis of A Truss Bridge

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1. Introduction

The truss bridge over the Mississippi River in Minneapolis, Minnesota, United States, collapsed on the 1st of August 2007 and there were reports of casualties. In Japan, there are many aging bridges as well, that need prompt inspection, reinforcements and maintenance. We carried out progressive collapse analysis for a two dimensional truss bridge model using large deformation elastic plastic analysis with the software called FRAME FORUM8. Especially, we try to clarify how the live load intensity and distribution affect structural safety and redundancy.

2. Structural Model and Analytical Method

Fig.1 and Fig.2 show the bridge model, a Warren truss bridge with 3 spans in two dimensions, with the concrete slab, with a total length of 230m, a main-span of 115m, a side span of 57.5m and a height of 10m. The length of each upper chord and lower chord is 11.5m. The materials are either SM490Y or SS400 and the stress-strain curve is shown in Fig.3. Fig.4 shows typical cross sections of the structure members. To simplify this truss bridge, all diagonals were assumed to have rectangular cross sections. The sizes and steel grades of the members were determined by allowable stress design method based on the current design specification.

For the dead load (P_D) and the design live loads (P_L: combination of uniformly-distributed and concentrated loads), static structural analysis was conducted, and sectional forces and deformations were obtained. The design live loads are taken from the specifications for highway bridges. Three load cases, $P_D + P_{L1}$, $P_D + P_{L2}$, $P_D + P_{L3}$, are considered in this progressive collapse analysis (Fig.5).

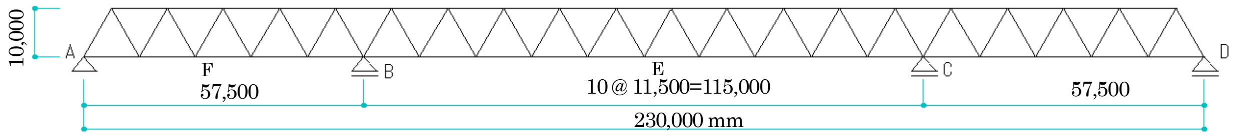


Fig.1 Side View

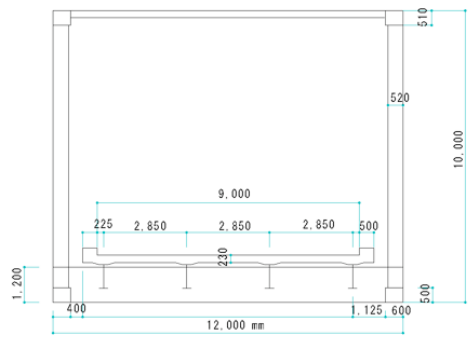
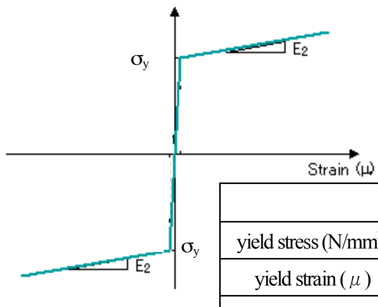


Fig.2 Cross-Section (mm)



	SM490Y	SS400
yield stress (N/mm²)	σ_y=355	σ_y=235
yield strain (μ)	ε_y=1775.0	ε_y=1775.0
Young's modulus (N/mm²)	Es=2.0×10^5	Es=2.0×10^5
	E$_2$=2.0×10^3	E$_2$=2.0×10^3

Fig.3 Stress-Strain Curve of Steel

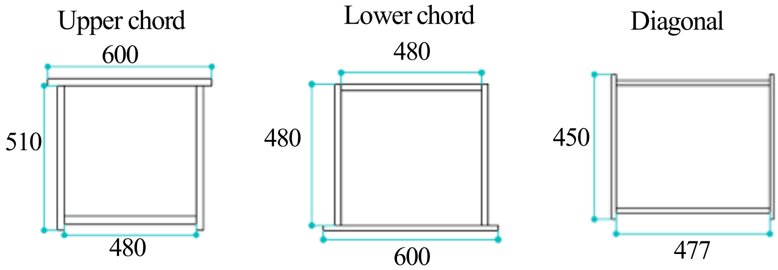


Fig.4 Cross-Section of Structural Members (mm)

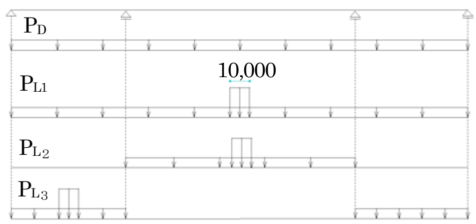


Fig.5 Load Cases

Keywords: Progressive collapse analysis, load intensity, structural safety, redundancy, elastic plastic analysis
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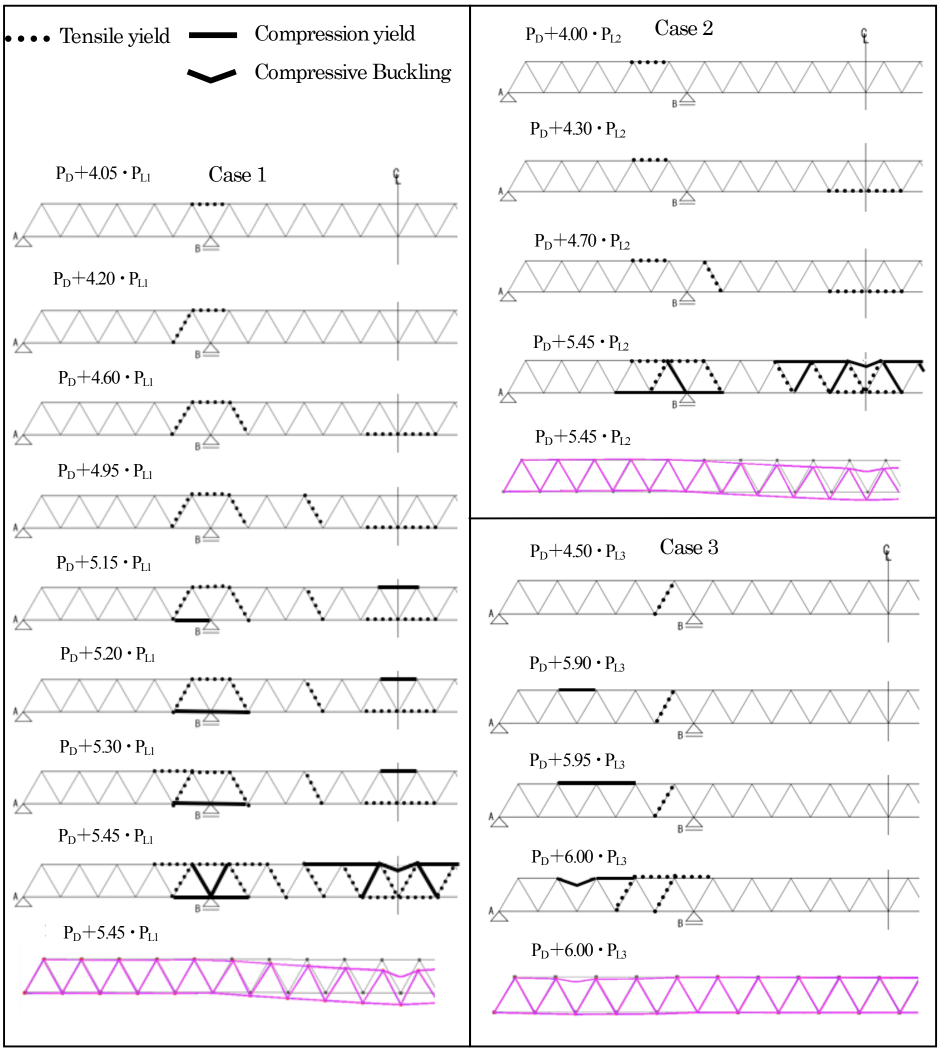

Fig.6 Collapse Process and Final Deformation

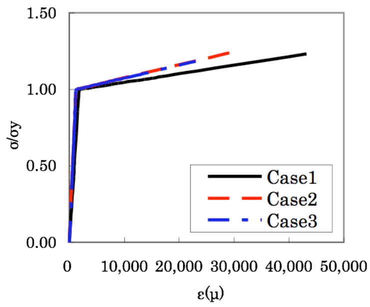

Fig.7 Stress-Strain (Tension)

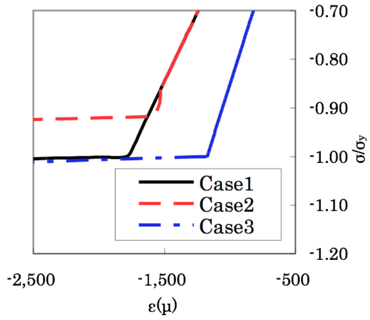

Fig.8 Stress-Strain (Compression)

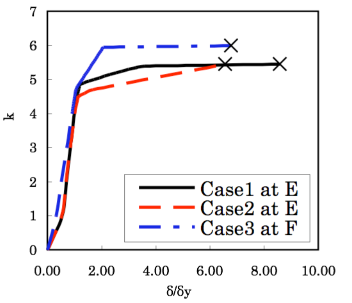

Fig.9 Load amplification - deformation

3. Calculation Results

Collapse process and final deformations of three load cases are shown in Fig.6. In Case1, first, the members near support B became yield in tension. Then, tensile yield expanded in the span center. Next, compression yield appeared. Finally, when the load amplification coefficient *k* became 5.45, the upper chord buckled at the span-center. Maximum strain of tensile members was 4.3%. In Case2, first, tensile yield appeared in the side span. Then, tensile yield expanded in the span center. When the load amplification coefficient *k* became 5.45, the upper chord suddenly buckled at the span-center. Maximum strain of tensile members was 3.1%. In Case3, tensile members yielded first in the side span. However, tensile yield didn't expand until the bridge collapsed. When the load amplification coefficient *k* became 5.90, compressive members started yield. By a small load increment *k* of 0.1, the upper chord buckled. Lower chord didn't yield. Maximum Strain of tensile members was 2.3%.

Fig.7 and Fig.8 show the relationship of stress and strain. Theses results show that the model truss bridge collapsed because of plastic buckling in Case1 and Case3. In Case2 the bridge collapsed at σ/σ_y of -0.92, which means the bridge collapsed because of elastic buckling. Fig.9 shows the relationship of load-deformation. In all three cases, the deformation sharply increased after the buckling. As the final strain of tension members was well below the critical value, it was judged that the buckling of the compression members caused bridge collapse. Since the ultimate load amplification coefficients *k* were over 5.0 in all the cases, the model bridge was found to be safe.

4. Conclusions

In this study, we carried out progressive collapse analysis of a truss bridge. The collapse process is clarified by the large deformation elastic plastic method. Although the collapse process is quite different depending on live load distribution, the truss bridge collapsed due to plastic buckling or elastic buckling. It is found that the truss bridge has ample safety against the design live loads when it is designed by the current design specification.