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Effects of Impact Loads on Mechanical Performance for Truss Structure

Zongwei Zheng, Yin Bai

School of Transportation Science and Engineering, Beihang University, Beijing, China
Email: zongweizheng@outlook.com

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Abstract

In this paper, ANSYS/LS-DYNA dynamic analysis software was used to establish finite element truss models with six trusses. The models with impact loads aimed to simulate the scenarios that structures were crashed by heavy truck. By changing the crashed position, the impact load intensity and structure height-span ratio, the models could give out the structural performance, including the stress, strain and other impacts in different scenarios. Besides, considering the component failure, this paper analyzed the possibility of structural progressive collapse. Results for the load cases from below indicate that it will be more destructive if impact load is arranged on 3rd side pillar and progressive collapse will occur if pillar fails after crashed.

Keywords

Truss Structure, Impact Loads, Progressive Collapse, Height-Span Ratio

1. Introduction

Truss structure, which is one of the most widely used architectural structures, is generally used in gymnasiums, museums, theaters and terminals, and other public buildings [1]. Numbers of links in truss structure result in complex distributions of natural vibration, which increase the difficulty of analyzing [2]. With the increasing number of automobiles, the possibility of vehicle impact rises [3]. Xingguo Wang and Youpo Su studied the performance of reinforced concrete frame under impact [4]. Yan Xiao and Lin Chen did some researches on truss protection effect under the vehicle impact [5]. Hui Qu and Jingsi Huo verified the truss performance discipline by experiments on dynamic plastic loading of frames [6]. Hyungoo Kang and Jinkoo Kim analyzed the possibility of progressive collapse of steel moment frames subjected to vehicle impact [7]. Currently, most of the researches about vehicle impact mainly focus on bridges. Researches about the performance of truss under impact are limited but meaningful. This paper analyzed the effect of impact loads on mechanical performance for truss structure by finite element truss models built with ANSYS/LS-DYNA dynamic analysis software.

2. Truss Structure Model

The models were established by ANSYS/LS-DYNA dynamic analysis software. The parameter of model is shown in following **Table 1**, **Table 2** and **Figure 1**.

3. Loads Position Effects Exploration

Assuming the truck density is 148 kg/m^3 (weight is 8 t), then the impact load intensity is 8 × 104 kg·m/s (8 t × 10 m/s). Considering the symmetry of the structure, **Table 3** and **Figure 2** show the performance of structure under impact loads on four positons.

The results indicate that loads on the 3rd side pillar will result in maximum stress in the structure, which is most destructive.

4. Bearable Maximum Impact Load Exploration

Through assuming different density of impactors and constant size and velocity, different impact loads could be arranged on truss. **Table 4** shows the performance of structure under different intensity of impact loads and **Figure 3** shows the

Table 1. Parameters of basic truss model.

Element	Truss Structure			Truck
Unit	Link160	Beam161	Shell163	Solid164
Size	diameter: 0.048 m span: 28 m truss number: 6	Inner diameter: 0.20 m outer diameter: 0.14 m height: 9 m	thickness: 0.03 m	length: 6 m width: 3 m height: 2.5 m velocity: 10 m/s

Table 2. Parameters of structural material.

Density	EX	Failure strain	Yield stress	NUXY	Tangent module
7850 kg/m^3	2.06×10^{11}	5%	3.45×10^8 Pa	0.3	6.1×10^9

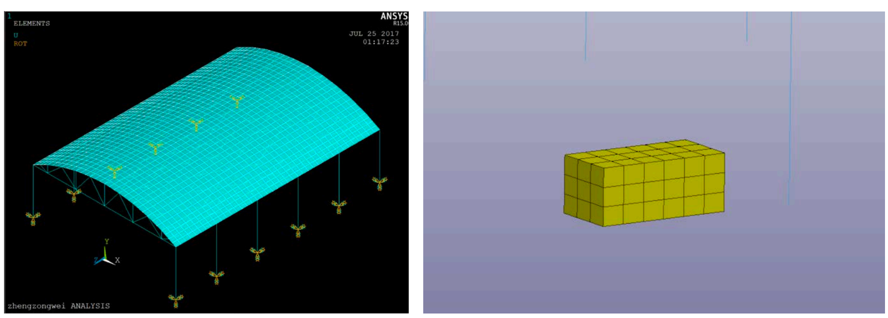

Figure 1. Truss structure model and truck model.

performance of truss under No. 7 load.

Table 4 and **Figure 3** indicate that the bearable maximum impact load intensity truss is about 1.8×10^5 kg·m/s (18 t × 10 m/s). With 2×10^5 kg·m/s (20 t × 10 m/s) loads, the maximum stress in structure will be yield stress (3.45×10^8 Pa) and the relative deformation in some components will exceed 5%, which could result in structure failure.

5. Height-Span Ratio Effects Exploration

8×10^4 kg·m/s (8 t × 10 m/s) impact load was arranged on 3rd side pillar in structures with different height-span ratio, and structural performances show in **Table 5**. The relationship between stress and height/span ratio is displayed in **Figure 4**.

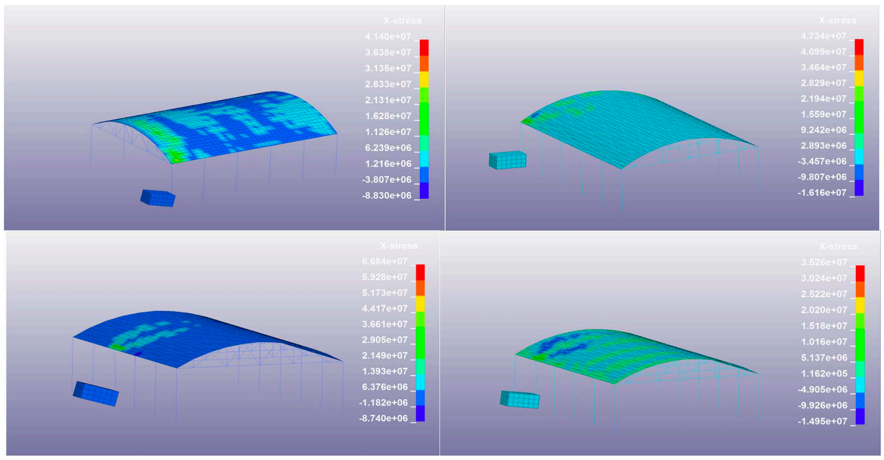

Figure 2. Structure performance plots under impact load on different positions.

Table 3. Different load positions analysis.

No.	Load position	Max-stress	Max-prin strain	Displacement
1	Front-1st	4.14×10^7 Pa	3.38×10^{-4}	0.3414 m
2	Side-1st	4.73×10^7 Pa	3.22×10^{-4}	0.3302 m
3	Side-2nd	5.15×10^7 Pa	3.05×10^{-4}	0.3267 m
4	Side-3rd	6.68×10^7 Pa	2.50×10^{-4}	0.3258 m

Table 4. Impact loads intensity analysis.

No.	Load Intensity	Max Stress	Max-prin Strain	Displacement	Notes
1	8 t × 10 m/s	4.14×10^7 Pa	3.38×10^{-4}	0.3414 m	
2	10 t × 10 m/s	5.73×10^7 Pa	3.92×10^{-4}	0.3302 m	
3	12 t × 10 m/s	7.14×10^7 Pa	4.45×10^{-4}	0.3267 m	
4	14 t × 10 m/s	8.67×10^7 Pa	5.51×10^{-4}	0.3258 m	
5	16 t × 10 m/s	1.043×10^8 Pa	6.77×10^{-4}	0.5914 m	
6	18 t × 10 m/s	1.246×10^8 Pa	8.08×10^{-4}	0.6511 m	
7	20 t × 10 m/s	4.349×10^8 Pa	5.94×10^{-4}	1.1321 m	Fail

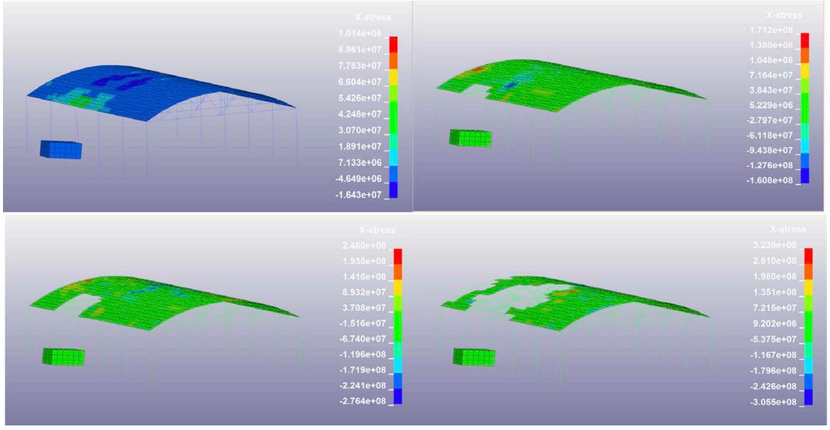

Figure 3. Structure performance plots under No. 7 load.

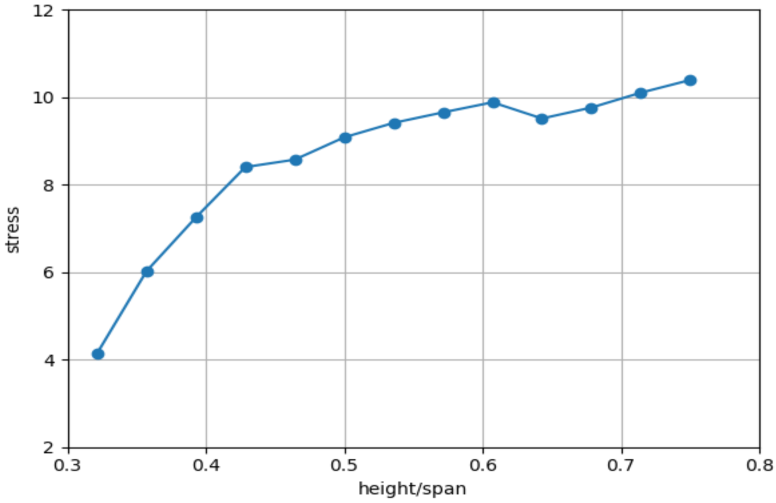

Figure 4. Plot of stress and height/span ratio.

Table 5. Height-span ratio impact analysis.

No.	Height-span ratio	Max-stress	Max-prin strain	Displacement
1	0.3214	4.14×10^7 Pa	3.38×10^{-4}	0.3414 m
2	0.3571	6.02×10^7 Pa	2.07×10^{-4}	0.3623 m
3	0.3929	7.25×10^7 Pa	2.40×10^{-4}	0.3645 m
4	0.4286	8.40×10^7 Pa	2.20×10^{-4}	0.3551 m
5	0.4643	8.57×10^7 Pa	3.51×10^{-4}	0.3498 m
6	0.5000	9.08×10^7 Pa	3.30×10^{-4}	0.3492 m
7	0.5357	9.41×10^7 Pa	3.09×10^{-4}	0.3497 m
8	0.5714	9.65×10^7 Pa	2.75×10^{-4}	0.3501 m
9	0.6071	9.88×10^7 Pa	3.48×10^{-4}	0.3578 m
10	0.6429	9.51×10^7 Pa	2.62×10^{-4}	0.3521 m
11	0.6786	9.76×10^7 Pa	2.67×10^{-4}	0.3499 m
12	0.7143	1.01×10^8 Pa	2.79×10^{-4}	0.3541 m
13	0.7500	1.039×10^8 Pa	3.82×10^{-4}	0.3614 m

6. The Possibility of Progressive Collapse Analysis

The axial load in the 3rd side pillar was about 20 kN. For analyzing the possibility of progressive collapse, the failure part (3rd pillar) was removed and the inverse axial load was arranged on the same position, which was demonstrated in **Figure 5**. Besides the slack load, showed in **Table 6** was arranged on the truss.

As it was showed in **Figure 6**, components will progressively fail and truss will collapse finally if the 3rd side pillar fails due to impact.

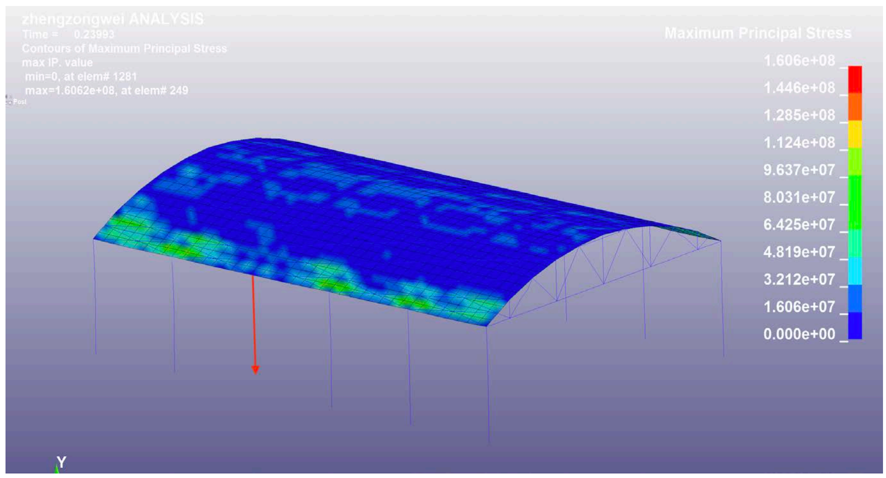

Figure 5. Inverse axial load on failed pillar position.

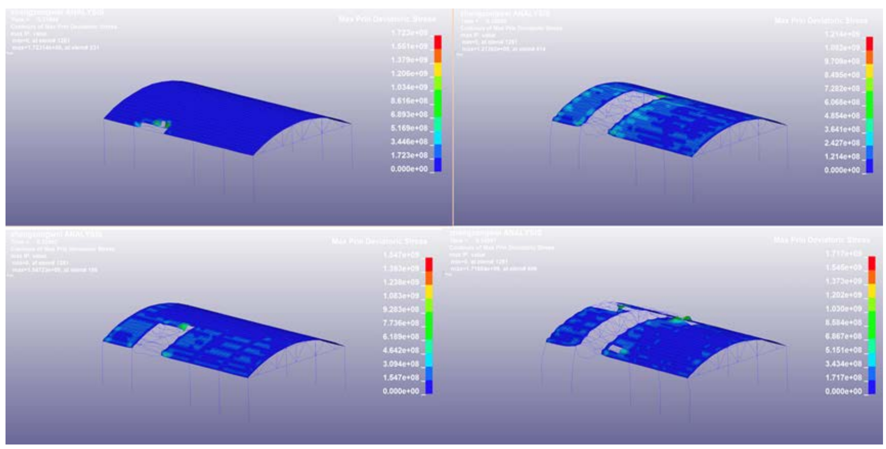

Figure 6. Results of progressive collapse analysis.

Table 6. Time groups and loads groups.

Group	1	2	3
T	0 s	1 s	
Q	−20 kN	−20 kN	
F	1000 kN	1000 kN	
T1	0 s	0.033 s	1 s
FT		−1000 kN	−1000 kN

7. Conclusions

In this paper, the finite element truss model with six trusses was established with ANSYS/LS-DYNA dynamic analysis software. It simulated the situations that structures were crashed by heavy truck. Through changing variables, such as the crash positions, the impact load intensity and structural height-span ratio, this paper concluded their effects to the stress and strain in truss structure. Besides, considering the component failure, this paper analyzed the possibility of structural progressive collapse. Conclusions are shown as below:

1) Impact load on the 3rd side pillar will result in maximum stress in the structure, which is most destructive. The bearable maximum impact load intensity truss is about 1.8×10^5 kg·m/s (18 t × 10 m/s).

2) The stress will be stronger in truss with greater height-span ratio. When the ratio is less than 0.6, the maximum stress in structure will increase by 1×10^7 Pa with ratio increasing by 0.05. When the ratio is more than 0.6, is has not significant effect to the stress.

3) If the 3rd side pillar fails due to impact, components will progressively fail and the truss structure will collapse even though the impact load intensity is less than 1.8×10^5 kg·m/s (18 t × 10 m/s).

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