# Simulation for the Collapse of WTC after Aeroplane Impact

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**Abstract**: Mechanical simulation and parameter discussion for the collapse of WTC (World Trade Center) after aeroplane impact are presented in this paper with the dynamic FEA software of LS-DYNA. The simulation results are very close to the real situation, which means that such type of special damage process can be recurred on the computer with proper parameter and numerical model. The results show that the direct reason for the collapse is the softening of steel under fire and the chain reaction damage of floors under the impact load of upper floors. If improve the fire resistance and the ductility of the structure, the collapse may can be avoided.
**Keywords**: dynamic FEA; world trade center; collapse

## 1. Introduction

The two towers of world trade center in New York were impact by two aeroplanes on Sep. 11 of 2001. The two towers were collapsed completely and more than 3 thousand people died in this affair. This affair obtained everyone's focus and many explanations are put forward for the reason of this collapse, including fire damage, heaped load, second-damage and so on. Because the collapse of the towers is very complex and it is difficult to recur by test, most explanations are based on qualitative analysis. However, the computer technology applied us a chance to simulate the collapse in the computer, so that the reason for the collapse can be discussed, as well as the methods can be raised to avoid this disaster.

## 2. Numerical model

This simulation is based on the dynamic FEA software of LS-DYNA, which is developed by the Software Company of Livemore.

The WTC is topical tube-in-tube structure system, whose outer tube is dense-columns-deep-beams system. The width of the column is 476.25mm while the space between columns is just 558.8mm. The thickness of beams is 1219.2mm. In order to simplify the numerical model and decrease the degree of freedom, the outer dense-columns-deep-beams tube system and inner steel truss tube system are approached with shell elements. The thickness of shell elements is established with equivalent section method. Such approximate tube has the same stiffness of global bending and axial deformation as the real structure, while the local bending stiffness of structure elements is not consisted with the real condition. Since the primary deformation of tube-in-tube structure system is global bending and axial compression deformation, this approximate method should be feasible.

The material of inner and outer tube is set to be steel in the numerical model, with the constitutive relationship of Material 3, Plastic Kinematic model in LS-DYNA. The density of steel is 7800Kg/m$^3$. The Yang's modulus is 200GPa. The Poisson ratio is 0.27. The yield strength is set to be 310MPa, according to Steel A440 in U.S. The hardening modulus is set to be 2GPa, 1% of initial modulus. As the fracture of steel is considered in this analysis, the failure plastic deformation is discussed as parameters, whose value is set as 0.5%, 1% and 5% respectively

The material of floor is set to be RC material, with the constitutive relationship of Material 3, Plastic Kinematic model, too. The density is 2500Kg/m$^3$. The Yang's modulus is 30GPa. The Poisson ration is 0.2. The yield strength is 30MPa. The hardening modulus is 0. All the fracture plastic deformation is set to be the maximum compression strain of concrete, whose value is 0.38%.

Because of the weak fire resistance capacity of steel, the high temperature caused by the burning of aeroplane oil will soften the steel. So the material of steel under fire is needed to be setup, whose other parameter is the same to normal steel except that the Yang's modulus and strength is set as 1/20 of normal ones, to approach the performance of steel at 700℃.

As the collapse analysis is very complex, the Single Face Erosion contact module of LS-DYNA is used in this case. This contact model can search the contact face automatically to establish the contact relationship, and those complex border conditions such as penetration, erosion can be considered, too. The friction factor of material is set to be 0.25.

Since the LS-DYNA is explicit dynamic software, when applying the gravity load, the structure will vibrate for a short time. It is not consisted with the real conditions. So the whole computation should be divided into two stages. In the first stage, the towers have not been impacted. The gravity load is applied to the model and relatively large damp ratio is applied to the towers, whose value is 10%. Computing the model until the vertical vibration disappeared. Then, the second computation stage starts. In the second stage, some elements in the tower are "killed" to approach the hole of airplane impact, and the material property of some survival elements is modified to simulate the fire influence, too.

## 3. Numerical results

### 3.1 Collapse of North tower

Here the impact position was on the center of tower, so the collapse is vertical collapse basically. The simulation results are show in figure 1.1, 1.2.

### 3.2 Collapse of South tower

Here the impact position was near to the corner of tower, so the collapse is inclined. The simulation results are show in figure 21, 2.2.

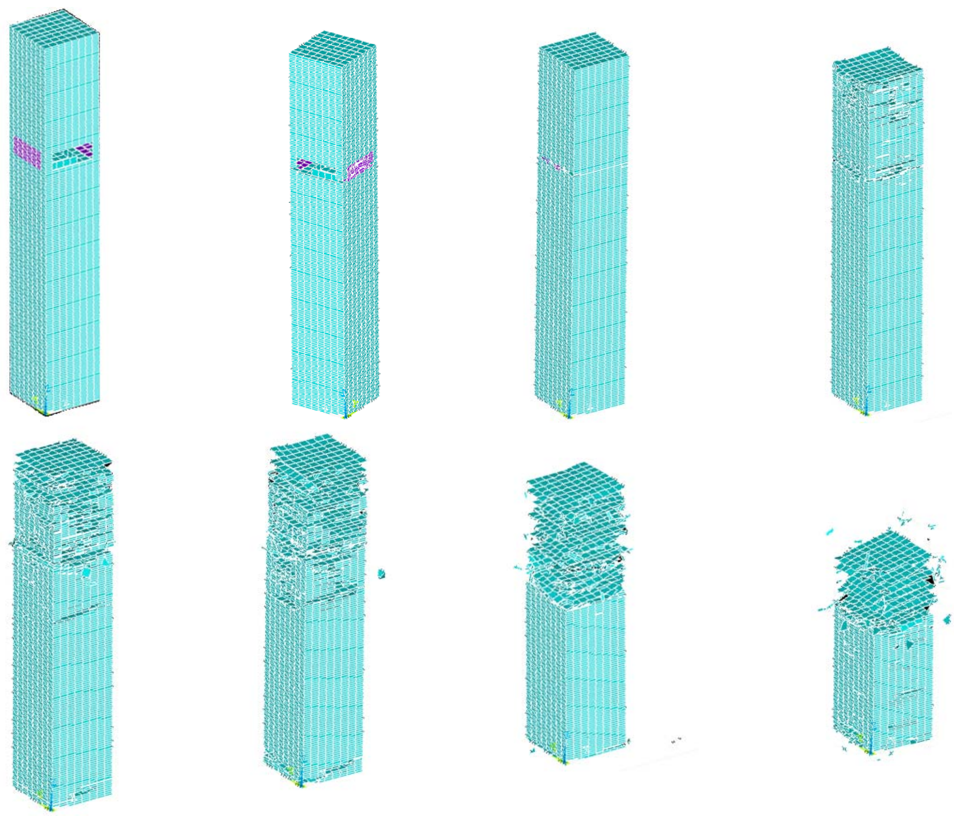

Fig. 1.1 Collapse of north tower----perspective

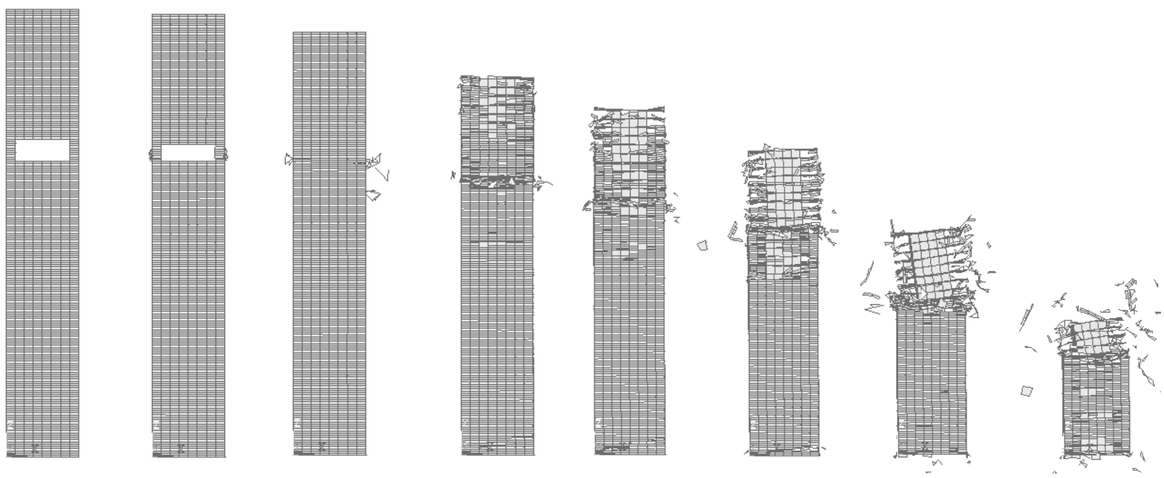

Fig. 1.2 Collapse of north tower----vertical

## 4 Conclusions

The following conclusions are obtained from the simulation.

1) The reasons for the entire collapse of the towers are the structure elements' soften of fire and impact of the upper layers' collapse. From the numerical results, the towers does not collapse immediately after the impact. The north tower can go on standing. Likely, the south one dose not collapse, too, though there are some large deformations in it, which are caused by the asymmetric damage. This is consisted with the real situations.
2) Improving the structure fire resistance ability or control the fire influence area will avoid or

delay the structure collapse, efficiently. We simulate the fire influence by adjusting the material property of elements. From the numerical results, even though the structure has been damaged seriously by the impact, if the influence area is smaller than 20%~25% of the survival section in the tower, the collapse still can be avoided. When more than 30~50% of the survival section near the impact zone fails, the collapse will start.

3) When the towers go into the collapse stage, the reason for the chain failure of un-impact layers is the impulse of upper collapsing floors. The impact force of upper floors is much larger than the heap load. And because there are a lot of bump and eject on the contact surface of collapsing floors and lower floors, the fragment of structure falls consecutively so that there is no chance to form a lot of heap load. So the heap load is not the critical reason for the collapse.

4) Improving the ductility of structure elements is an efficient way to avoid the chain collapse happens. In the simulation above, if the fracture plastic strain of steel structure is 0.5%, the chain collapse will take place entirely. However, if the fracture strain is improved to 1%, the impact energy of upper floors will be absorbed by the lower structures and the chain collapse will be stopped at about 100m under the airplane impact zone. When the fracture strain is improved to 5%, only part of the structure near the airplane impacting zone will be damaged, and no chain collapse will take place. Hence, if the structure has enough ductility to absorb the energy of upper floors' collapse, the chain damage will be controlled. Even though consider the influence of heap load, the towers still have much larger chance to escape from the entire collapse.

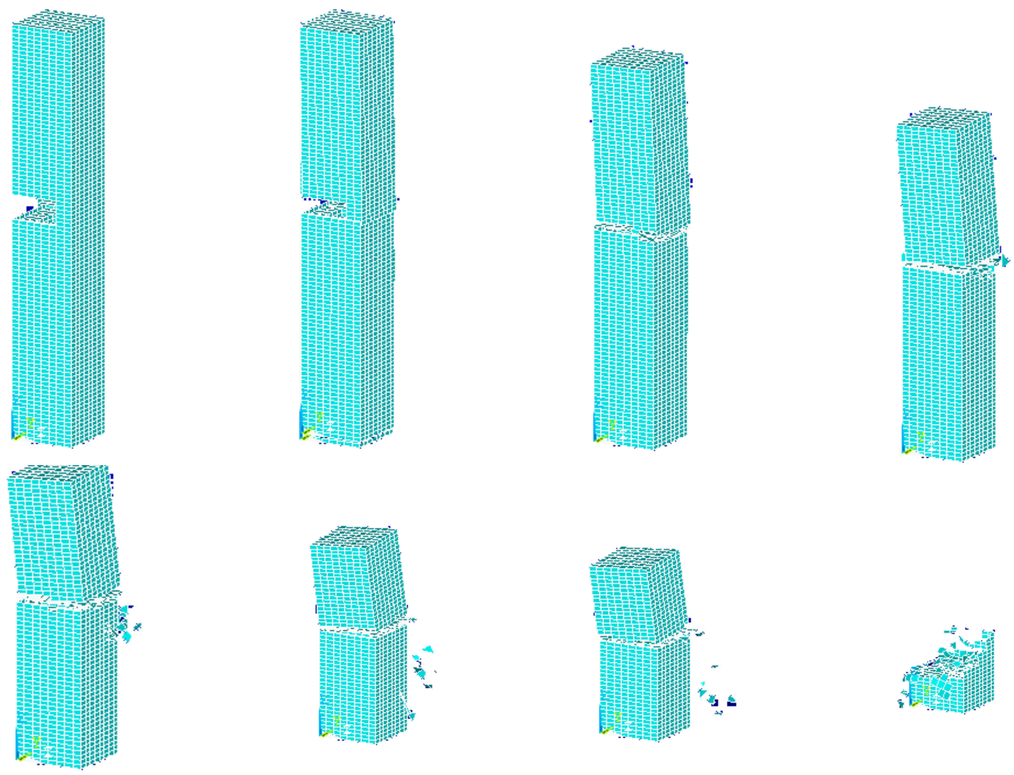

Fig. 2.1 Collapse of south tower----perspective

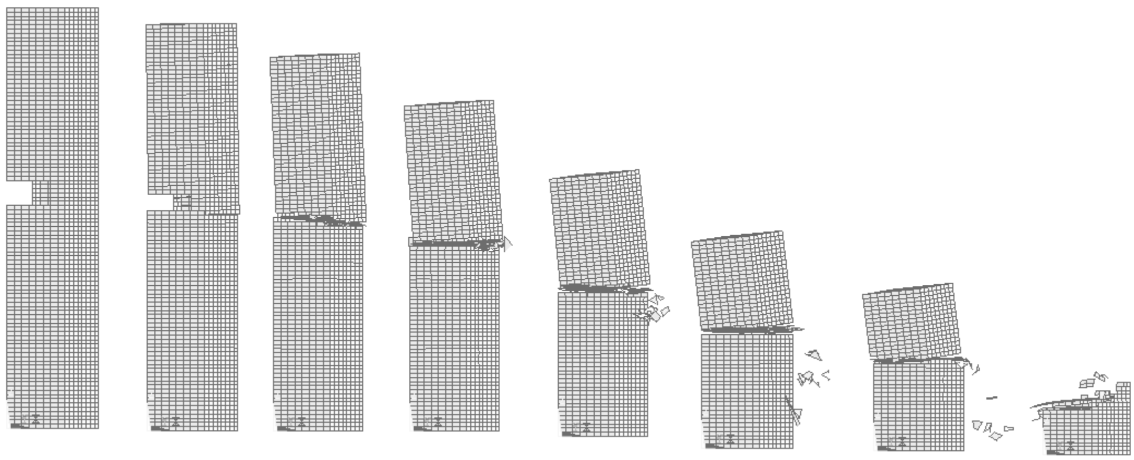

Fig. 2.2 Collapse of south tower----vertical

Reference


1. Wang Guozhou, Qu luqian. Steel structure----principles and design. Beijing: Tsinghua University Press, 1993
2. Bao Shihua, Fang Ehua. Design of Tall Buildings. Beijing: Tsinghua University Press, 1994
3. Jiang Jianjing, Gong Xiaonan, Wang Yuanqing, Cui Jinghao. Analysis and dispose for building accidence. Beijing: China Building Industry Press, 1998
4. Manual of ANSYS/LS-DYNA, ANSYS Agency in Beijing, 1999