Preliminary assessment of the damage of the Feb. 6 Turkey earthquake on Chinese and Turkish buildings

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The M7.8 earthquake in Turkey on February 6 (The magnitude determined by China Earthquake Networks Center is 7.8 + 7.8. The magnitude determined by USGS is 7.8 and 7.5) caused widespread concern. A large number of images and videos of collapsed buildings shocked people, and it is natural for professional researchers to wonder:

1. Why was the damage of this earthquake so severe?
2. Are Chinese structures strong enough to resist an earthquake of this magnitude?

With the rapid advancement of acquisition and sensing instruments, it is now possible to obtain a large number of strong earthquake records near the epicenter after the quake, which provides essential data for quantitative analysis of the destructive power of different earthquakes and reveals the mechanism of earthquake damage.

It was already midnight when I got two M7.8 earthquakes on February 6. I started the RED-ACT system (Real-time city-scale time-history analysis and its application in resilience-oriented earthquake emergency responses, Applied Sciences, 2019) to analyze the recorded ground motion, and I saw horrifying results that had never been seen before (Table 1).

Table 1 Analysis Results of Typical Buildings and Bridges in the RED-ACT system subjected to the First M7.8 Earthquake

1st M7.8 earthquake event	Station 3123	Station 3138	Station 4614
Single-story unconfined masonry	Collapsed	Collapsed	Severe damage
Five-story confined masonry	Severe damage	Collapsed	Moderate damage
Typical bridge #1	Collapsed	Collapsed	Moderate damage
Typical bridge #2	Collapsed	Collapsed	Moderate damage

All of the analysis cases were "collapsed" by the ground motion input of Station 3138, so the response spectra of these ground motions were quickly drawn, as shown in Figure 1.

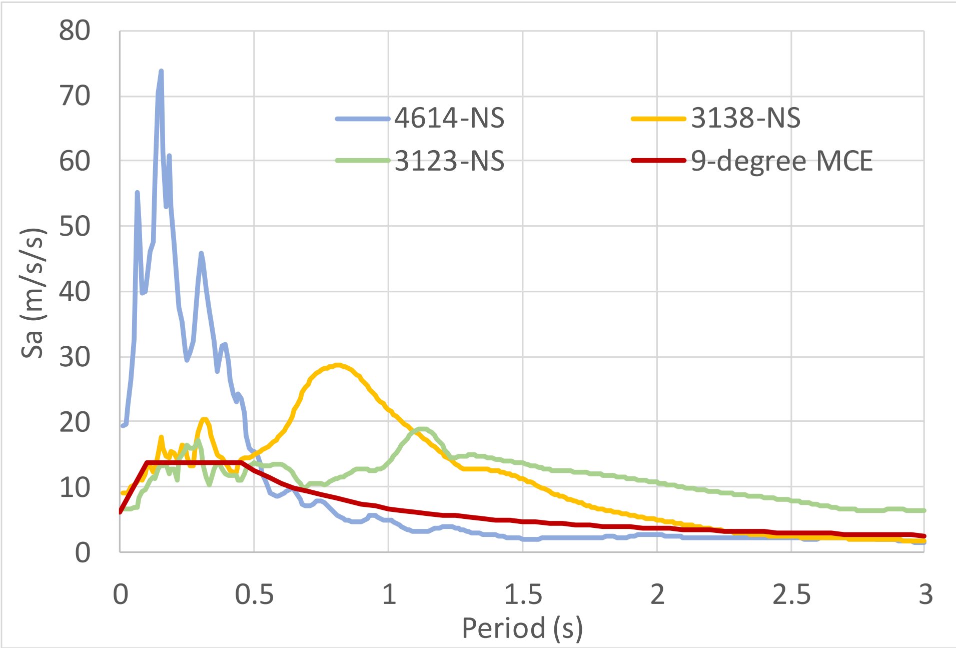

Figure 1 Response Spectrum of Typical Stations for the First M7.8 Earthquake

As can be seen from Figure 1, the M7.8 earthquake provided full-frequency coverage from short-period (station 4614), medium-period (station 3138), to long-period (station 3123). It is particularly worth mentioning that the red line in Figure 1 is the design response spectrum of the 9-degree maximal considered earthquake (MCE) in the Chinese design code. Readers familiar with Chinese earthquake engineering are aware that 9-degree MCE is the highest level for seismic design in China, with only a few areas or projects meeting this standard. However, the actual earthquake intensity of the M7.8 earthquake far exceeded this highest level. It can be seen that this earthquake is powerful.

1. Assessment of earthquake damage to buildings and urban areas in Turkey

Can Turkish buildings withstand such a powerful earthquake? Our research group has previously collaborated with the Turkish team to conduct regional earthquake damage research in the Istanbul metropolitan area. For more information, see:

A cost-benefit analysis of sensor quality and spatial density for rapid regional post-event seismic damage assessment: Application to Istanbul, *Soil Dynamics and Earthquake Engineering*, 2022
Influence of sensor density on seismic damage assessment: a case study for Istanbul, *Bulletin of the Seismological Society of America*, 2022

We have corresponding Turkish single and regional building models in Turkey (Figure 2). We input the measured ground motions into typical individual and urban buildings in Turkey to assess the damage.

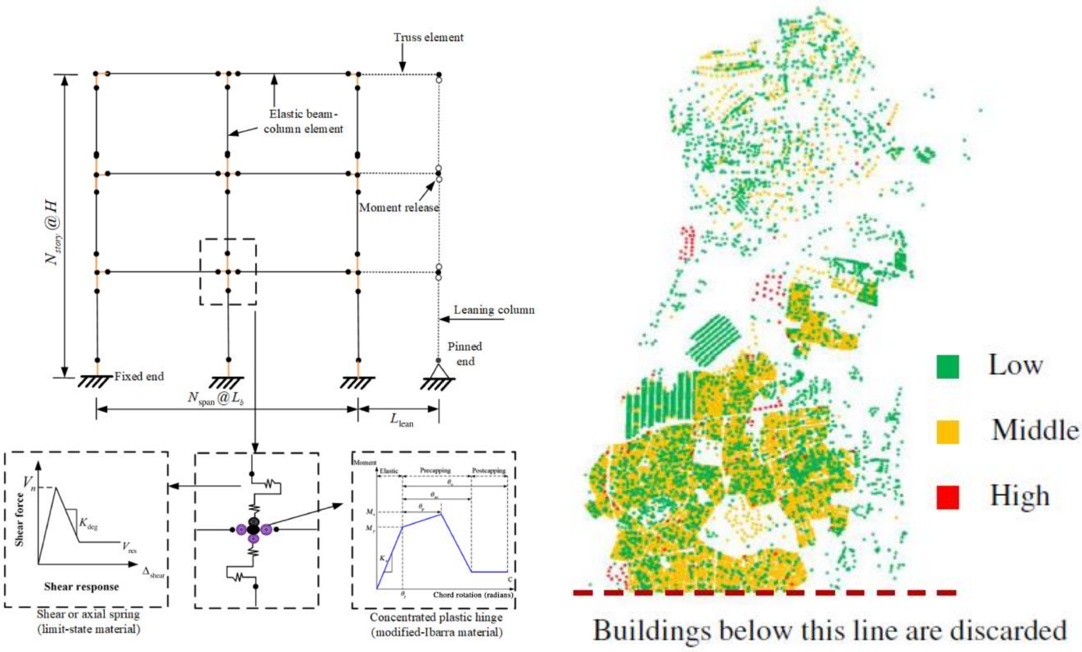

Figure 2 Individual building and regional building models in Istanbul, Turkey

Let’s first look at the damage to individual buildings. We analyzed the responses of three Turkish multi- and high-rise reinforced concrete frame models (2 stories, 5 stories, and 13 stories) subjected to the ground motion recorded at station 3123, and the results were as expected. All three frames collapsed very quickly (Figure 3). Therefore, Turkish buildings seem to be very difficult to resist the strong ground motions near the epicenter of this earthquake.

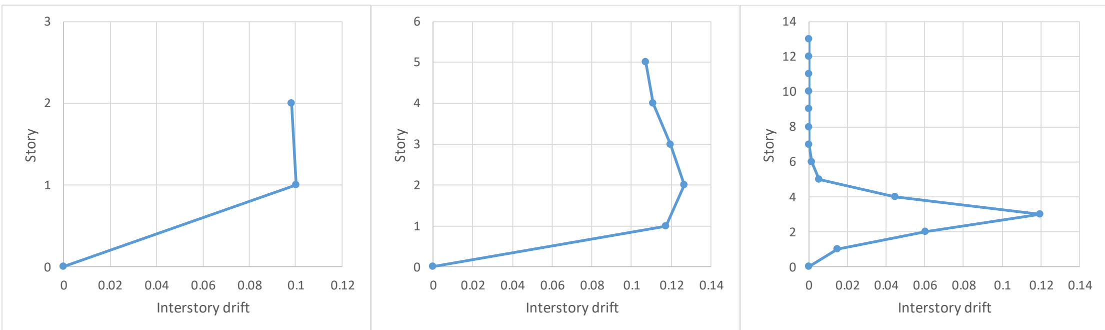

Figure 3 The response of the Turkish multi- and high-rise frames subjected to the ground motion recorded at station 3123

Furthermore, we use the city-scale nonlinear time-history analysis method to study the earthquake damage subjected to different ground motions on regional buildings. Since we do not have building data in the area near the epicenter, we temporarily use the regional building data of Istanbul (Figure 2) instead.

We input the ground motion data of the first M7.8 earthquake into the regional model, and the earthquake damage to buildings near the epicenter obtained by the city-scale nonlinear time-history analysis method is shown in Figures 4 and 5. In the figure, the red dot is the epicenter of the first M7.8 earthquake, and the blue dot is the epicenter of the second M7.8 earthquake.

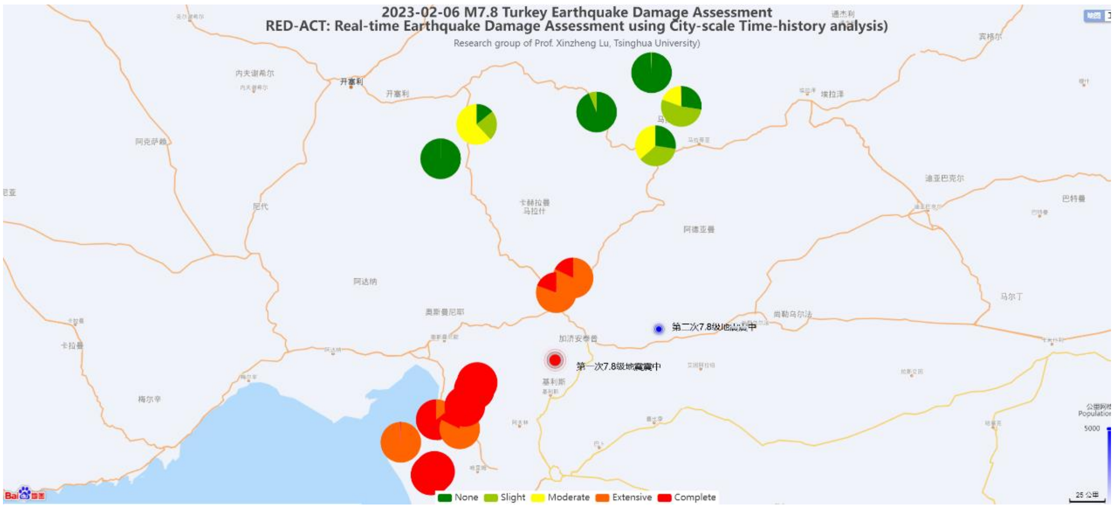

Figure 4 Distribution of regional building damage subjected to the first M7.8 earthquake

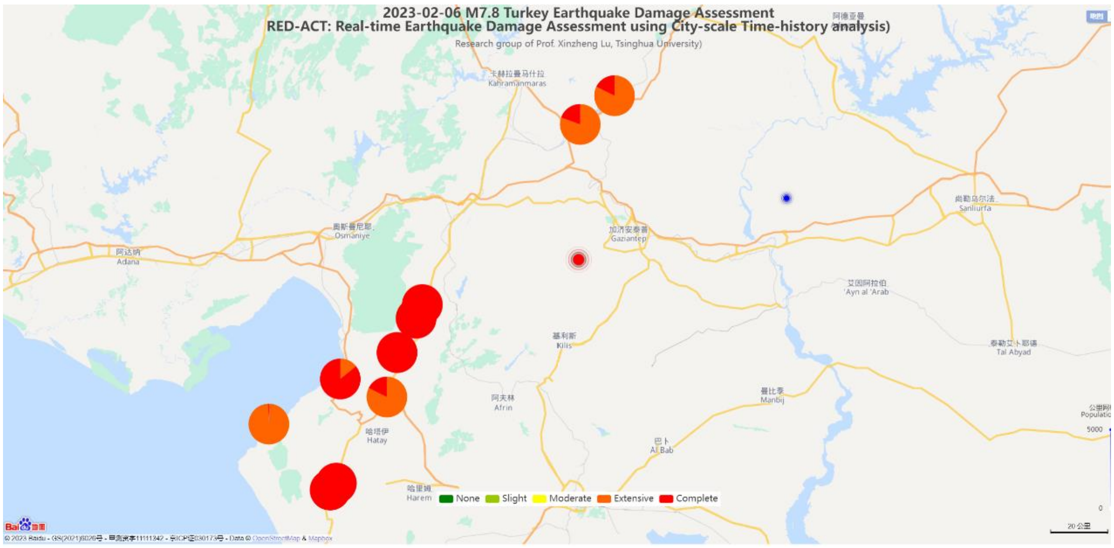

Figure 5. Distribution of regional building damage subjected to the first M7.8 earthquake (zoom-in)

It can be seen from Figures 4 and 5 that the earthquake damage on the south side of the map is very serious, and most buildings approach the state of collapse or severe damage (red or orange).

Note that Figure 4 is only the damage caused by the first M7.8 earthquake. The buildings near the epicenter of the second M7.8 earthquake (the blue dot) will definitely suffer serious damage after the second M7.8 earthquake!

Indeed, after the second M7.8 earthquake, the building damage will definitely change further. But this kind of damage is definitely not the same as the result of directly suffering a single M7.8 earthquake. Because the first earthquake has already caused damage, the second earthquake will cause further damage to the building, and the superposition of the two earthquakes will make the problem more complicated.

How to analyze the regional building damage after the superposition of the two earthquakes? We have studied this problem (Regional seismic-damage prediction of buildings under mainshock-aftershock sequence, Frontiers of Engineering Management, 2020), and the results will be provided in the following reports. This report only discusses the impact of the first magnitude 7.8 earthquake.

2. Assessment of earthquake damage to Chinese buildings

Is it possible for Chinese buildings to resist the ground motion of this earthquake? Our team had accumulated a lot of building models before, so we input the earthquake motions of the M7.8 earthquake into them.

(1) Reinforced concrete frame structure

The design ECADI and BIAD institutes jointly designed a 7-story reinforced concrete frame with an 8-degree design intensity (PGA = 0.2 g, 10% / 50 years) (Figure 6). The first-order period of the structure is approximately 1.3-1.4 s.

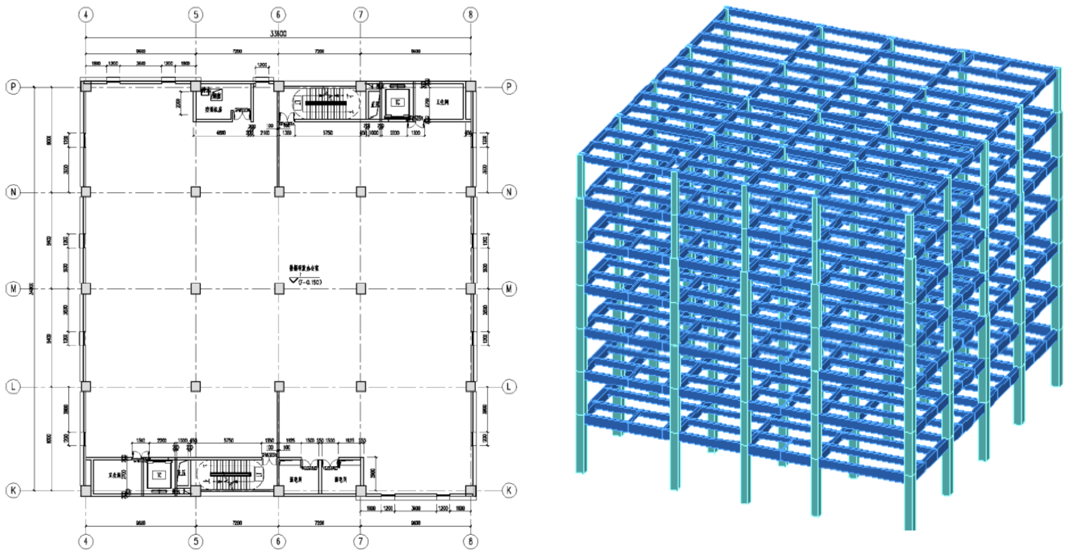

Figure 6 Chinese 7-story reinforced concrete frame (8-degree)

We input the ground motion records of station 3123 into the reinforced concrete frame, and the collapse process of the structure is shown in Figure 7.

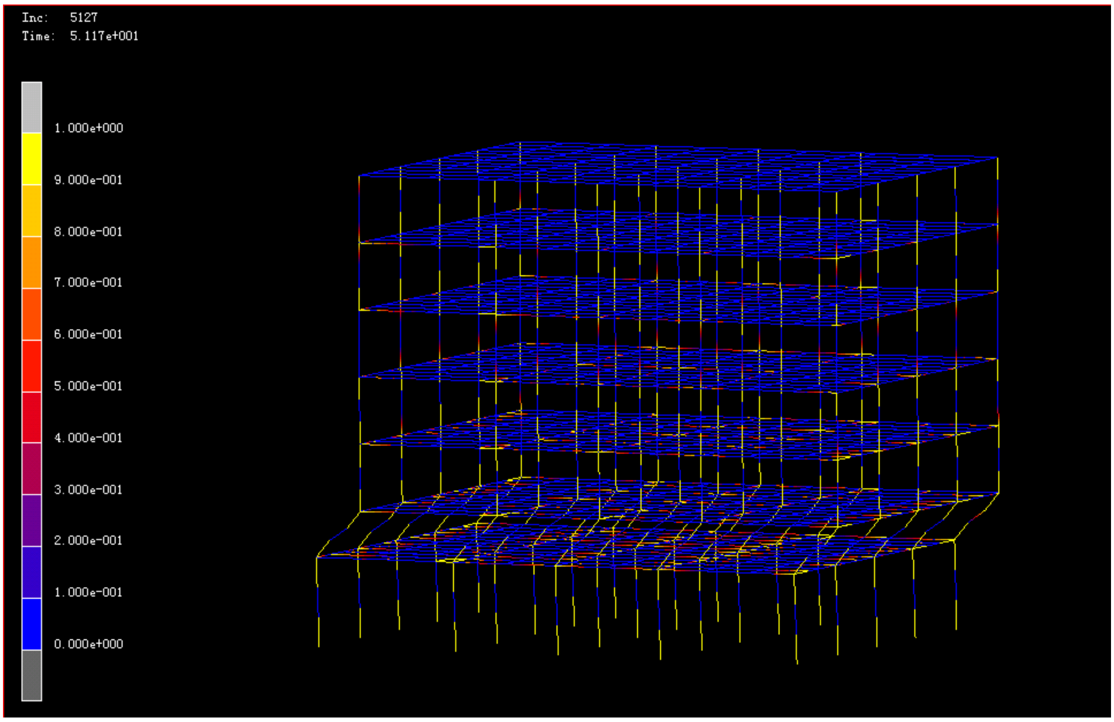

Figure.7 The collapse mode of the Chinese 7-story reinforced concrete frame subjected to the ground motion records of station 3123 (displacement amplification factor = 1)

(2) Steel braced-frame structure

The CABR design institute designed a steel braced-frame structure with a height of 166 m and 37 stories. The height of the first story is 12.9 m. The height of the remaining stories is 4.2 m. The plane size is 50.2 m x 48.6 m, and the core tube size is 21.8 m x 20 m (Figure 8). The design intensity is also 8-degree (PGA = 0.2 g, 10% / 50 years). The first-order period of the structure is approximately 5.9 s.

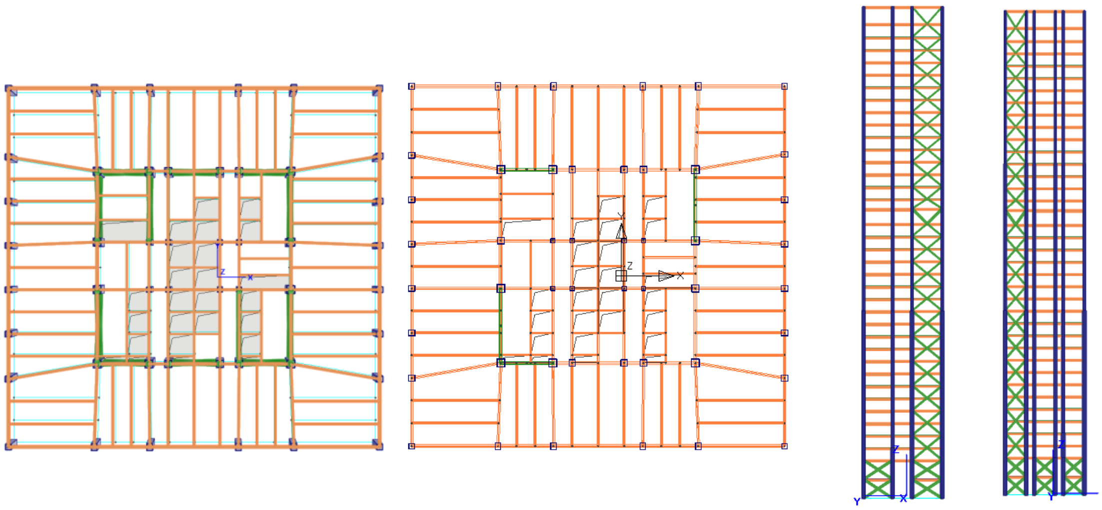

Figure 8 Chinese 37-story steel braced-frame structure (8-degree)

We input the ground motion records of station 3123 into the steel braced-frame structure, and the damage state of the structure is shown in Figure 9.

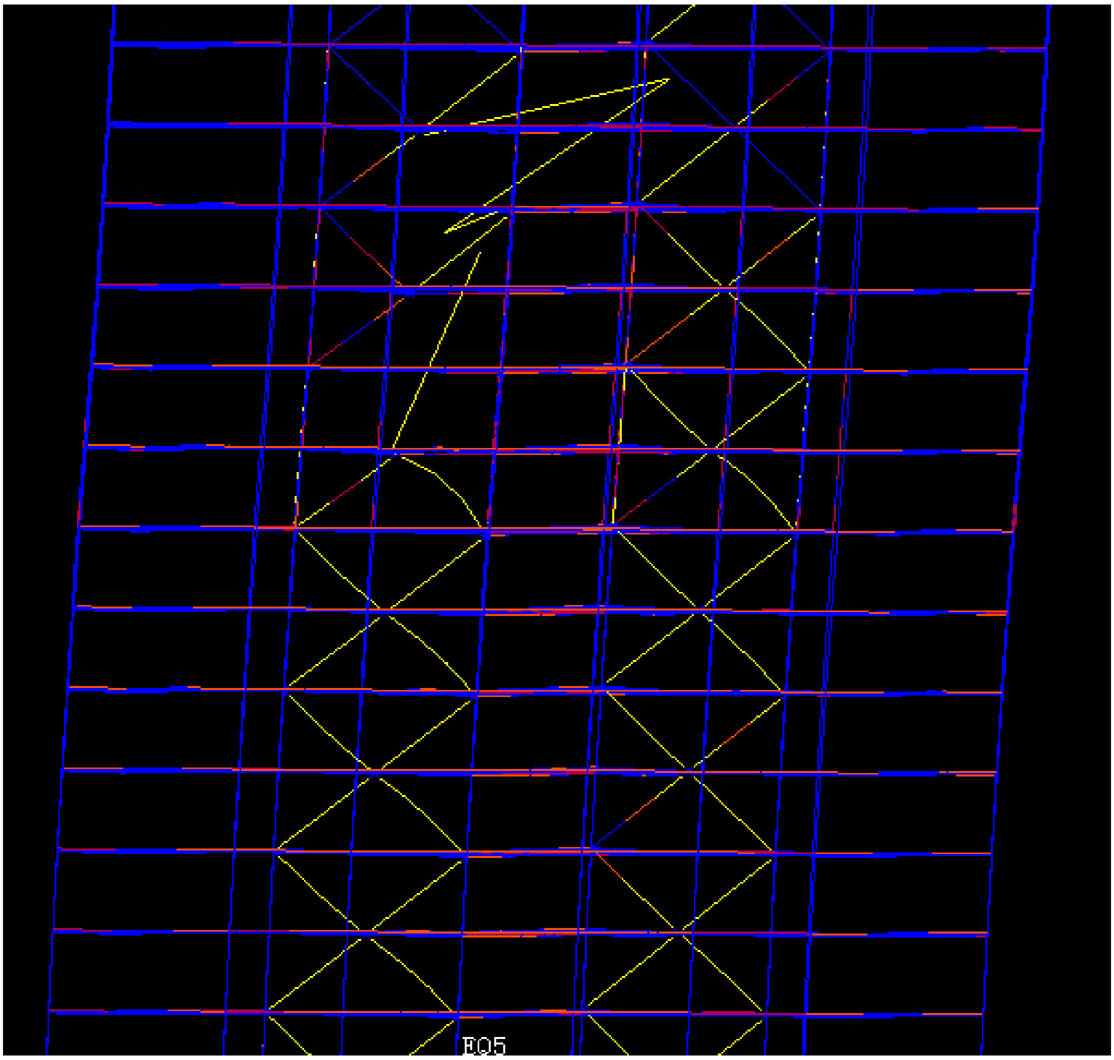

Figure 9 The damage mode of the Chinese 37-story steel braced-frame structure subjected to the ground motion records of station 3123

The steel braced-frame structure vibrates violently under the earthquake. The braces in the medium stories (ordinary rectangular steel tube braces, not BRB) buckled and failed, and finally, the overall structure was unstable and collapsed.

(3) Steel frame structure

The design institutes CEEDI and CSWADI jointly designed a steel frame structure, which is a 6-story office building (partially 7-story). The height of the first story and the roof story is 5.0 m, and the height of the remaining stories is 3.6 m (Figure 10). The design intensity is also 8-degree (PGA = 0.2 g, 10% / 50 years). The first-order period of the structure is approximately 2.2 s.

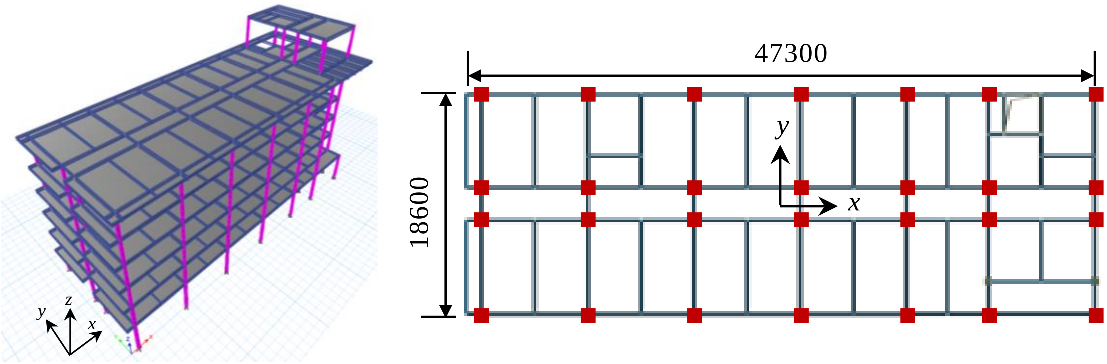

Figure 10 Chinese 6-story steel frame (8-degree)

We input the ground motion records of station 3123 into the frame and obtained the structural damage status and inter-story drift envelope, as shown in Figure 11. The inter-story drift has also far exceeded the limit value of the Chinese seismic design code (code requirement: 2%, the calculated result: 6.7%).

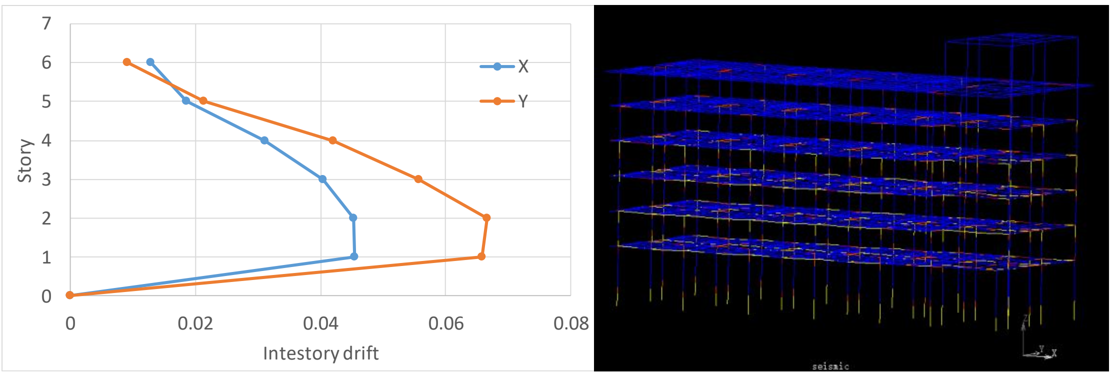

Figure 11 Damage state and inter-story drift envelope of Chinese 6-story steel frame