Study on A Real 8F Steel Building with Oil Damper Damaged During the 2011 Great East Japan Earthquake

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SUMMARY:
Some oil dampers installed in an 8F steel building had been destroyed in the 2011 Great East Japan Earthquake. It is the 1st time real dampers in a real building were damaged during real earthquake in the world. Earthquake records with/without dampers were observed before and after the earthquake. In this paper, numerical results by the FEM simulation have been compared with the real recorded data. The comparison revealed the damaged process for real damper, in the same time the effectiveness of the damper during the earthquake, and also show the fact of the rare handicap cases for the damper.

Keywords: damper, simulation, steel building, damage, the 2011 Great East Japan Earthquake

1. INSTRUCTIONS

An 8F steel Administration Building in the main campus of Tohoku Institute of Technology (located in Sendai City, Japan) had been constructed in 2003. In the meaning of earthquake resistance, the building itself satisfies the Japanese Building Code for School, but for the following two purposes, 56 sets of oil dampers with different sizes have been installed in two directions. The 1st purpose is to verify the effectiveness of the oil damper developed in this university and the 2nd purpose is to increase the earthquake resistance ability.

Unfortunately during the 2011 Great East Japan Earthquake (shortly the 311 earthquake in this paper), the 8 sets of dampers on 1st floor had been destroyed and the oil leaked out (Find the figure in the SUPPLEMENTS). Other way the 8 sets of dampers on 3rd floor kept undestroyed but leaked the oil out. Because of power failure during the earthquake the computer stopped recording the data and fortunately, the ground motion about 50m far away near this building was recorded as EW=354 and NS 280 gal. Because even without the oil dampers, this building had been designed to satisfy the Japanese Earthquake Resistance Code for School, this building is still being in use.

This is the first case in the world that real dampers in a real building have been damaged during real great earthquake. It became necessary to report such damage process. In the same time because many earthquakes occurred before and after the 2011 Great East Japan Earthquake, we have many important data. The data can be divided into two types, one the building with dampers and another without. Comparison of the transfer function of the 8th floor to 1st floor before and after the 2011 Great East Japan Earthquake clearly indicates the effectiveness of the dampers. But in rare cases the comparison revealed that the dampers are not so effectiveness. Such facts also drive us to consider that in what case the damper will be effective and in what case the dampers will be ineffective.

This paper is to present our numerical results by the FEM simulation to show damaged process of the dampers, the effectiveness of the damper and in the same time to show the fact of the rare case which has been recorded.

2. GENERAL SITUATION OF THE BUILDING

2.1. Characteristics of the building

The 8F steel building was constructed in 2003 shown in Figure 1, where the 1st floor and the 2nd floor have been made as one floor to make large space with height of 6m, as you can confirm in the Fig. 1.

Figure 1. The building constructed in 2003

This steel building certainly has been designed to satisfy the Japanese Earthquake Resistance Code for School building without any control equipment. But after designing for the purpose to verify the effectiveness of the newly developed oil damper in this University, also to improve the ability of earthquake resistance, 56 sets of dampers have been installed, with 8 sets on each floor as shown in Figure 2 and Figure 3.

Before the installation of the dampers the building has been excited with the excitation machine on the roof, where we obtained the 1st natural frequency of the building without damper as, the short side (nearly the NS) = 1.050Hz and the long side (Nearly the EW direction)=1.025Hz.After the installation of the dampers the building has also been excited and we obtained the 1st natural frequency of the building with dampers as, the short side (nearly the NS) = 1.125Hz and the long side (Nearly the EW direction)=1.11Hz. It is clear that the dampers increase the stiffness of the building.

2.2. Sensors installed

2-direction acceleration sensors have been located to the building in 3 floors, 1st, 4th and 8th floor to record the earthquake data. And load cell with strain meter have been installed to the dampers in 1st and 8th floor to obtain the force acted on the dampers during vibration.

2.3. Earthquake records

There are many earthquake records to help us to finish this research, before and after the 2011 Great East Japan Earthquake. Especially we used the foreshock record in 2011/03/09 and the aftershock record in 2011/04/07 for comparison.

3. SIMULATION MODEL OF THE BUILDING

3.1. Simulation model construction

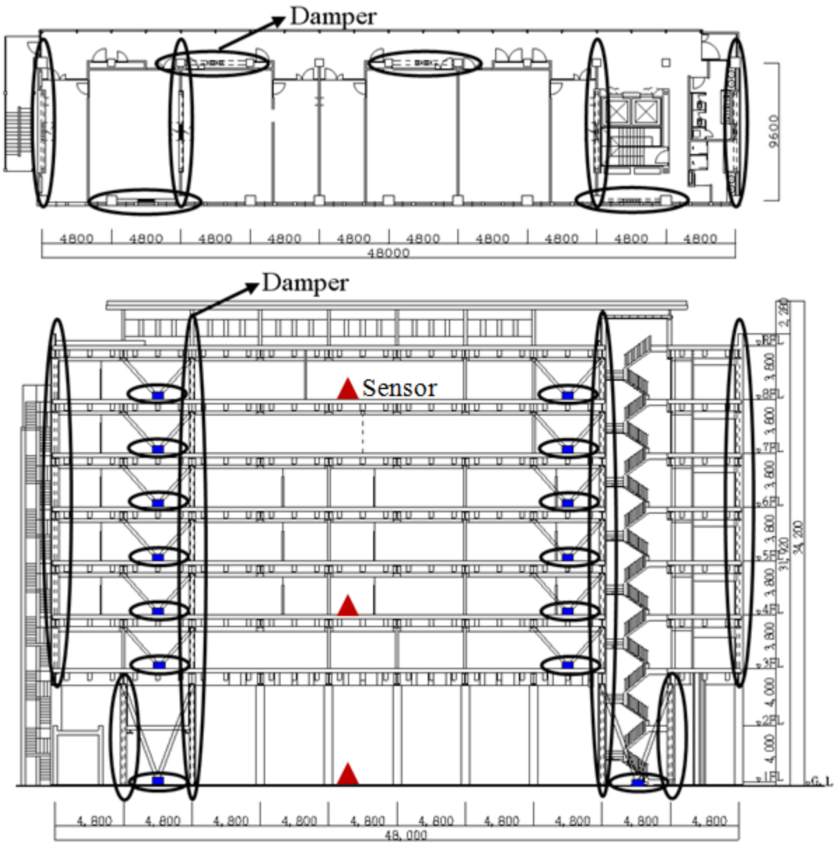


Figure 2. The position of dampers

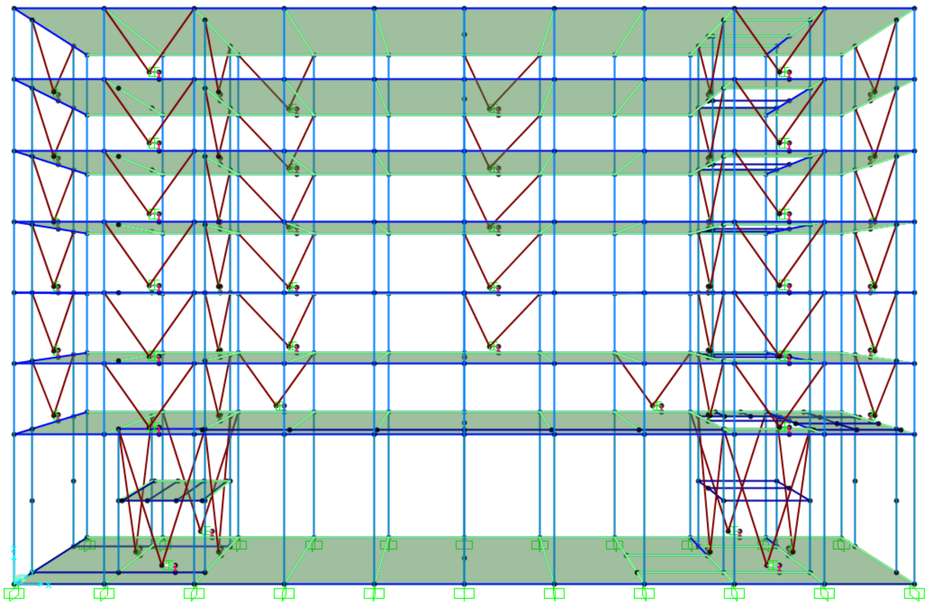


Figure 3. The model of building with dampers

For the purpose of calculation, FEM soft Sap2000 has been used to build the simulation model as shown in Figure 3. The sizes of all the steel columns and beams have been modelled follow the design book and the material parameters have been set following of the Japanese Steel Design Code. The joints between columns and beams have been totally fixed. Because of the steel material, the binary plastic-elastic hysteresis loop has been utilized.

The oil dampers have been modelled as the damper model in Sap2000 by the data of the test, which is considered to be most suitable to the real case before construction. Before construction of the building, we have finished the test of oil damper where the hysteresis loop is shown in Figure 4.

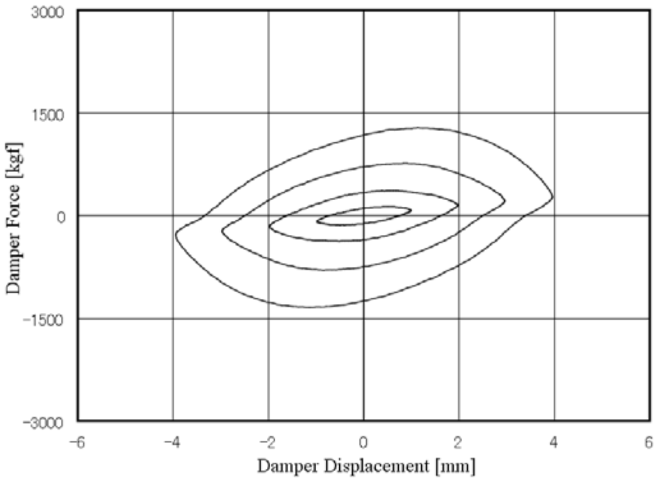


Figure 4. Damper with oil, 1.0Hz excitation, tested in 2003

3.2. Identification results

Using many earthquake records, the simulation model has been identified. This 8F steel building will certainly have 7 natural frequencies for each direction, the most agreement results is that the simulated one coincide totally the 7 frequencies to the recorded one. But unfortunately for simulation it is very difficult to reach such perfect agreement. In general, as the 1st natural frequency is the most important one for vibration, it is thus chosen to be the identification aim. Certainly as in usual, the masses of each floor have been adjusted to do identification.

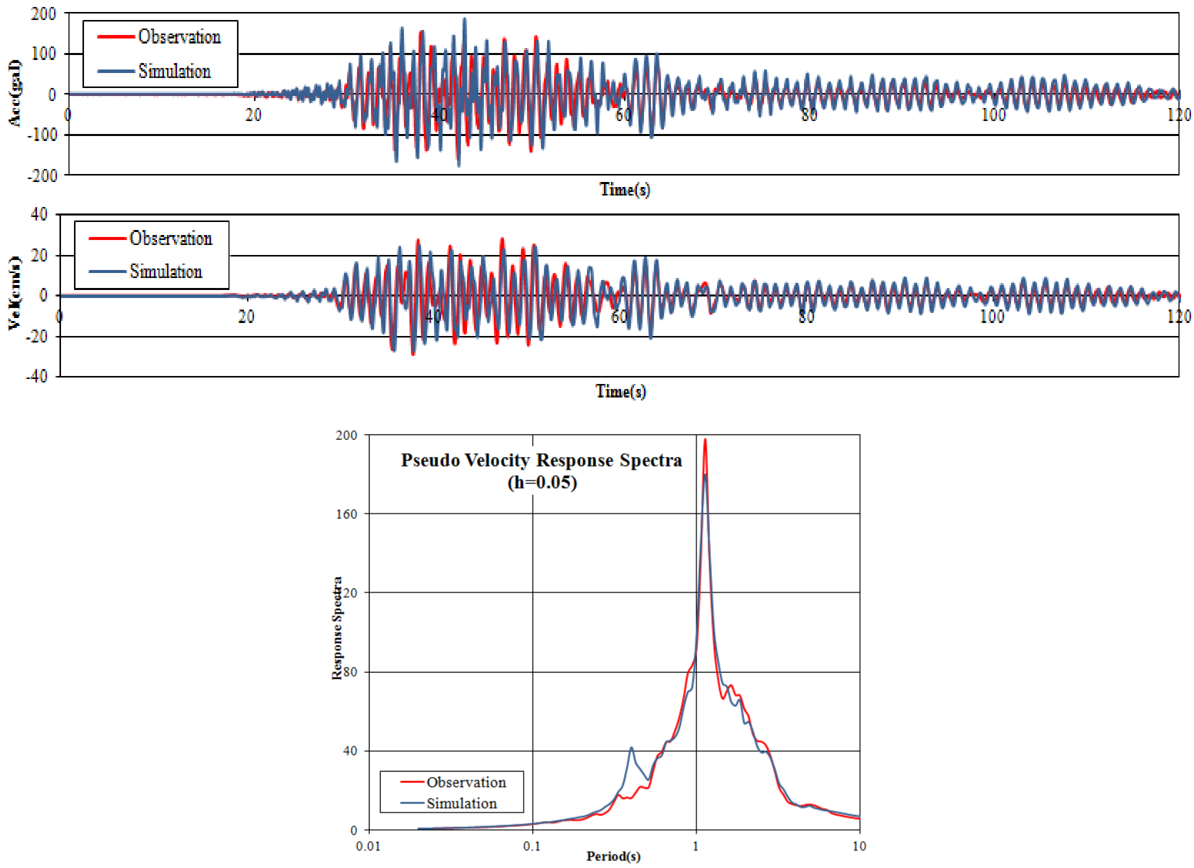


Figure 5. Comparison of the observation and simulation (2003/05/26)

Two Figures in Fig. 5 show the acceleration response and velocity response in time domain and frequency domain respectively for the earthquake of 2003/05/26 in EW direction, where red line is the recorded one and black one is the calculated one. It is clear that the simulation data coincides with the recorded one well.

4. SIMULATION ANALYSIS AROUND THE 311 EARTHQUAKE

4.1. Foreshock occurred in 2011/03/09

Before the 311 Earthquake, we have a big foreshock in 2011/03/09 11:45, almost 2 days before the main shock. Because intensity was about 4 degree in Sendai city, this earthquake at that time had been thought to be the re-come one (the repetition) of 1978 Miyagi Earthquake which have made the scientist in Japan to do research and as result the Japanese Government revised the Japan Earthquake Resistant Code in 1981. But unfortunately this time they failed.

The acceleration waves recorded and simulated are shown in Figure 6 in time domain and frequency domain respectively. The transfer functions from 1F to 8F are shown in Figure 7, where it is clear that the transfer functions has been excited about the frequency of 1.13Hz and the maximum magnification is about 4.2 times in EW direction and the frequency of 1.27Hz and the maximum magnification is about 3.8 times in NS direction.

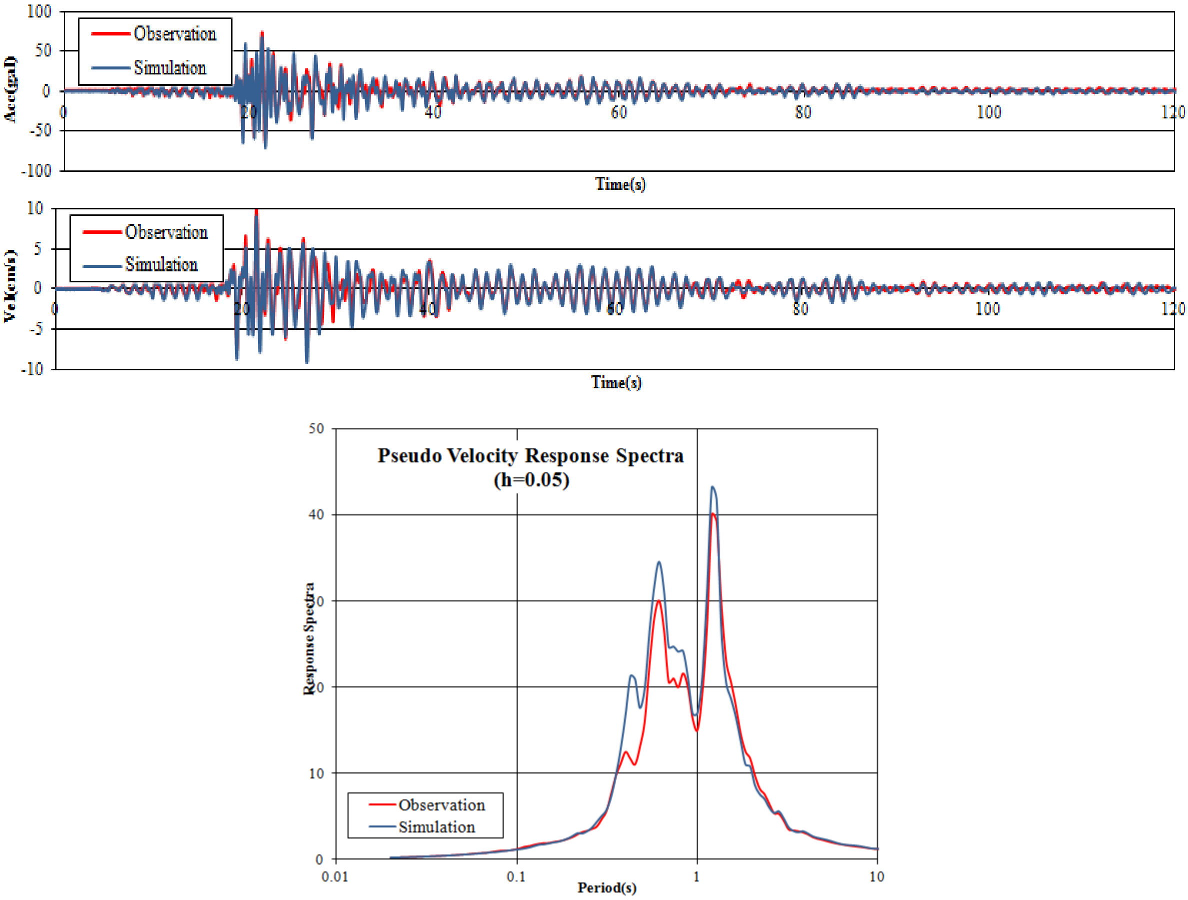


Figure 6. Comparison of the observation and simulation (2011/03/09)

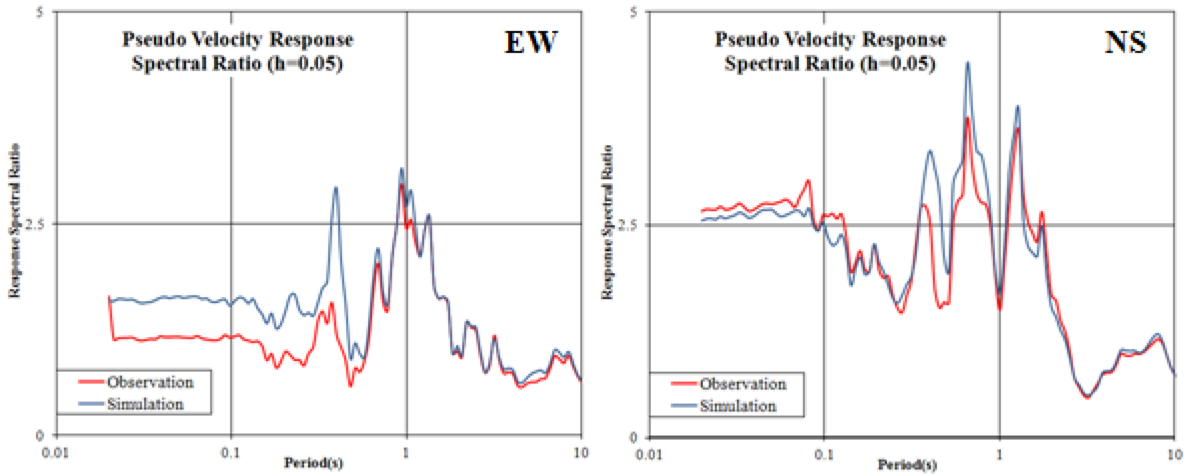


Figure 7. Comparison of the transfer function (8F/1F) (2011/03/09)

4.2. Aftershock occurred in 2011/04/07

After the 2011 Great East Japan Earthquake, we also have a very big aftershock in the middle night of 2011/04/07, almost one month after the main shock. The intensity was totally same with the main shock in Sendai city. This aftershock destroyed some buildings in Sendai city which were safe in the main shock. Fortunately our 8F steel building was safe in this aftershock but there are some very strange things (responses) we found.

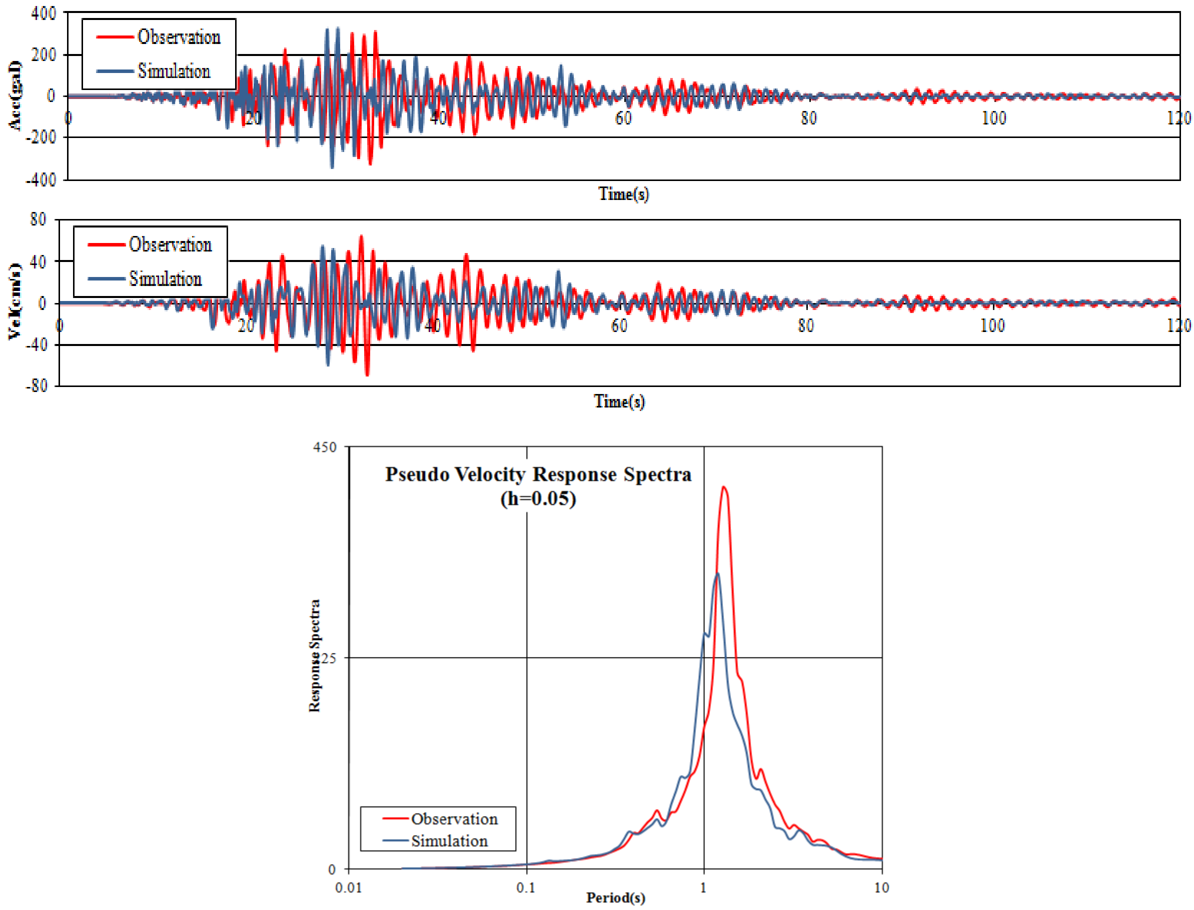


Figure 8. Comparison of the observation and simulation (2011/04/07)

Figure 8 shows the waves recorded and simulated in time domain and frequency domain, and Figure 9 is the transfer function. It is clear that the maximum magnification of observation is larger than the maximum magnification of simulation. It can be seen that some properties of our steel building maybe changed during the 2011 Great East Japan Earthquake.

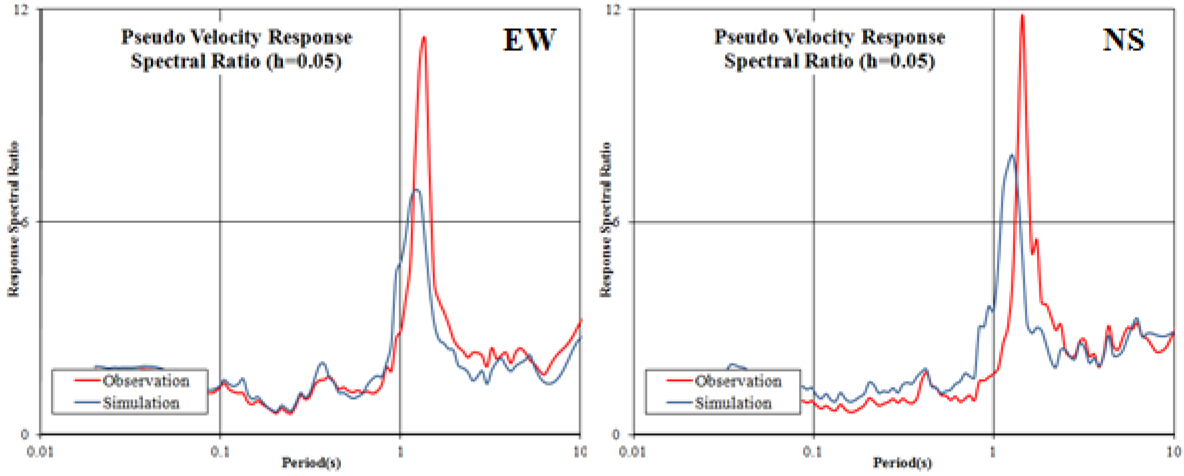


Figure 9. Comparison of the transfer function (8F/1F) (2011/04/07)

4.3. Damper damage in the main shock

The acceleration and velocity waves simulated for the main shock are shown in Figure 10 in time domain and frequency domain respectively and Figure 11 is the transfer function.

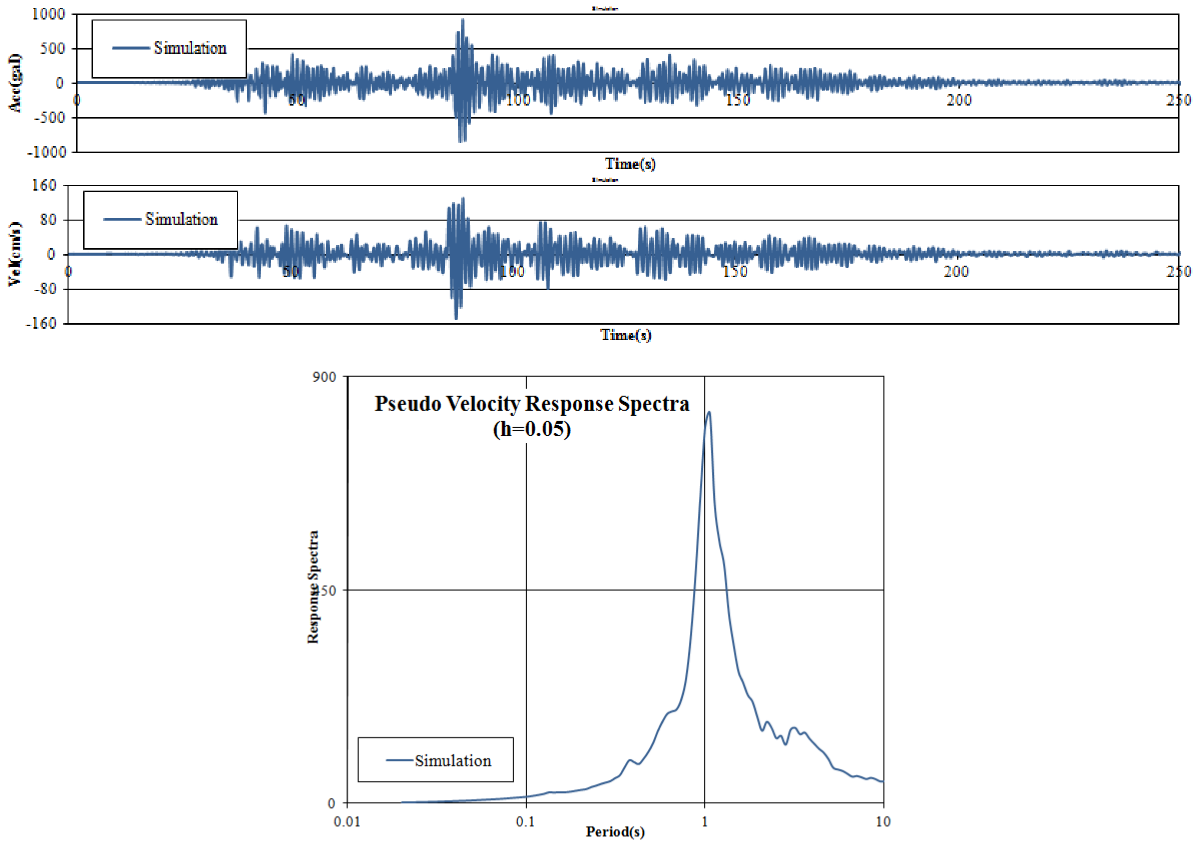


Figure 10. The simulation data (2011/03/11)

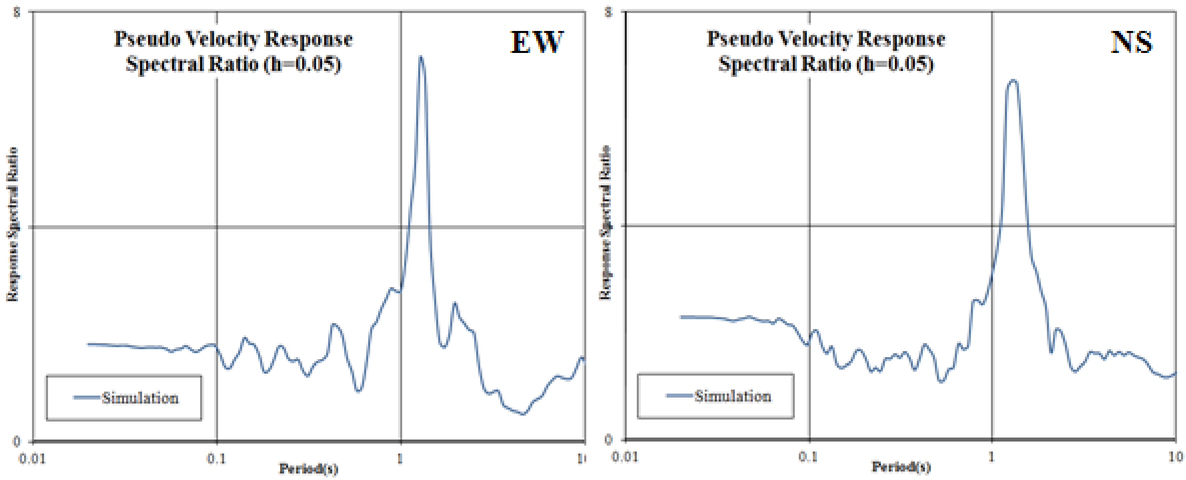


Figure 11. The transfer function (8F/1F) (2011/03/11)

The transfer functions from 1F to 8F are shown in Figure 12 for three earthquakes, where the foreshock is recorded in 20110309, main shock is the simulated one and the aftershock is recorded in 20110407. It is clear that the period of aftershock is larger than the other two because of the absence of the dampers in 1st floor. Maximum magnification of the aftershock is obviously takes a big value compared with others. Such fact clearly reveals the effectiveness and the importance of the dampers.

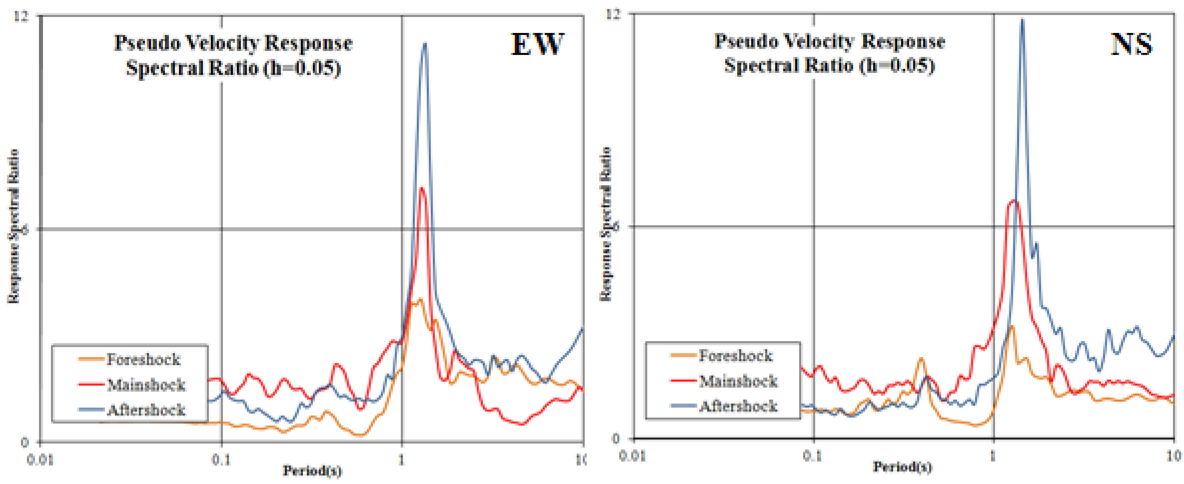


Figure 12. Comparison of the transfer function (8F/1F) Foreshock, aftershock recorded, main shock simulated

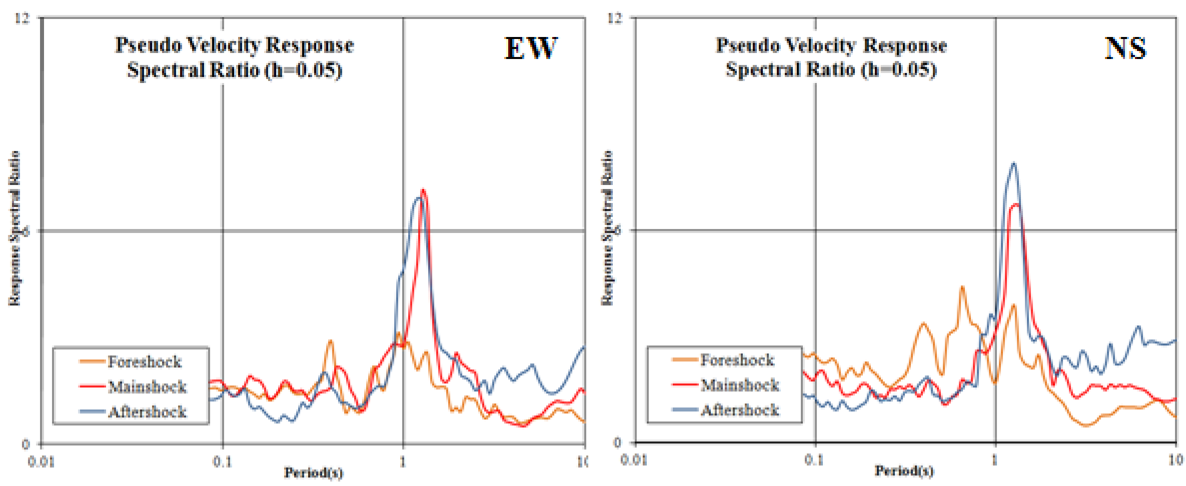


Figure 13. Transfer functions (8F/1F) of simulated Foreshock, main shock and aftershock

Figure 13 is the simulated results for transfer functions (8F/1F) of foreshock, main shock and aftershock. Comparison of Figure 12 to Figure 13, it is found that the simulated aftershock one do not identify with the foreshock one, which means that after the 311 earthquake the characteristics of the building may changed.

Figure 14 shows the simulated displacement of dampers on 1st, 3rd and 8th floor in EW direction in the 311 earthquake. During the earthquake the dampers on 1st floor had been destroyed and the oil leaked out, the dampers on 3rd floor kept undestroyed but leaked the oil out. Following the design book, the designed limit displacement of the damper for 1st floor is 16mm (pink line) and for others is 8mm. In addition to protect the damper, a cushion has also been designed as 8mm (red line) for 1st floor and 5mm for others. Considering the limit situation of the dampers of 3rd floor with oil leaded but itself safe, it is reasonable to assume damper destroy limit displacement in such situation, that is if this limit is being exceeded the dampers can be thought to be damaged. Because of different sizes of the dampers, the ratio of maximum displacement to the limit displacement for 3rd floor should be confirmed and be used as a standard damage value to also apply to the dampers in the 1st floor.

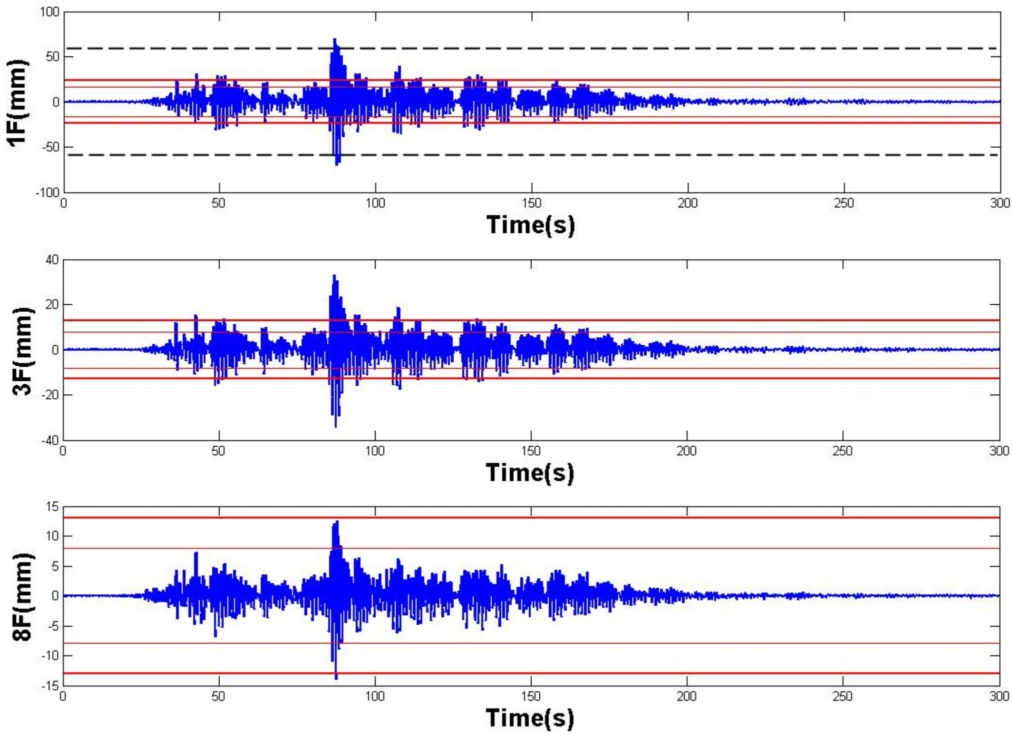


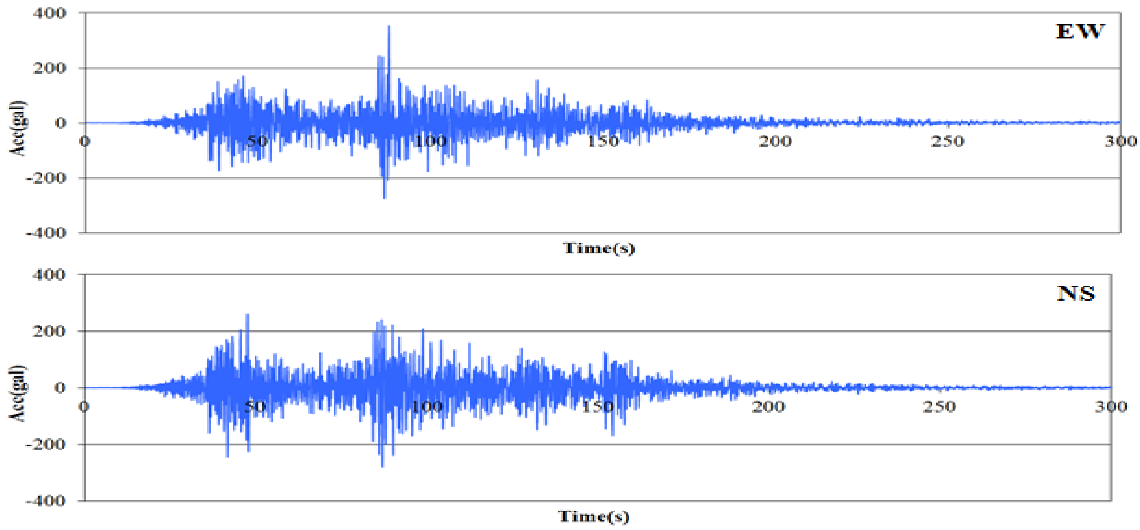
Figure 14. Displacement of dampers

The ratio of maximum displacement to the limit displacement for 3rd floor is 2.6. Applying this standard ratio to 1st floor, maximum value 62mm is obtained which is shown as broken black line in Figure 14. While this value is exceeded the dampers are suggested to be destroyed. Certainly the 1st floor dampers had been destroyed at about 85 second. Such simulation agreed with the fact.

5. CONCLUSION

In this paper, we made a FEM model to simulate the performance of our steel building in serial earthquakes, the 2011 Great East Japan Earthquake, its foreshock and its aftershock. From the results of simulation, a change of the prominent period for this building before and after the 2011 Great East Japan Earthquake is observed. Also the performance of the damper is simulated and the result is agreed with the fact. In the further research, we will focus to the detail characteristic of the damper.

SUPPLEMENTS



The Input wave: the recorded ground motion during 311 Earthquake in Tohoku Institute of Technology, 50m far away from the building.

The Destroyed damper: Damper Destroyed in the earthquake

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