2011 TOHOKU (JAPAN) EARTHQUAKE AND ITS IMPACT ON DESIGN OF SUPER HIGH-RISE BUILDINGS

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Summary On March 11, 2011, the eastern Japan was severely shaken by the 2011 off the Pacific coast of Tohoku earthquake (the Great East Japan earthquake). Nearly 20,000 people were killed or are still missing due mainly to the ensuing monster tsunami. This paper reports an aspect of this devastating earthquake which hit an advanced country in seismic resistant design. It has been reported that long-period ground motions were induced in Tokyo, Nagoya and Osaka. The properties of these long-period ground motions are discussed from the viewpoint of critical excitation and the seismic behavior of two assumed steel buildings of 40 and 60 stories subjected to the long-period ground motion simulated or recorded in mega cities is investigated. This paper also reports the effectiveness of visco-elastic dampers in the reduction of responses of super high-rise buildings subjected to such long-period ground motions.

INTRODUCTION

The most devastating earthquake in Japan after the 1923 Great Kanto earthquake hit the eastern Japan on March 11, 2011 [1, 2]. The moment magnitude 9.0 earthquake is one of the five most powerful earthquakes in the world since modern record-keeping began in 1900. Nearly 20,000 people were killed or are still missing due mainly to the ensuing monster tsunami. This paper reports an aspect of this devastating earthquake which hit an advanced country in seismic resistant design. It has been reported that long-period ground motions were induced in Tokyo, Nagoya and Osaka. The properties of these long-period ground motions are discussed from the viewpoint of critical excitation and the seismic behavior of two assumed steel buildings is investigated of 40 and 60 stories with and without high-hardness rubber dampers [3] subjected to the long-period ground motion simulated or recorded in mega cities.

MEASURE OF CRITICALITY IN LONG-PERIOD GROUND MOTIONS

Fig.1(a) presents the comparison of the actual input energies (5% damping), the credible bounds [4, 5] for acceleration constraints [4, 5] and the credible bounds for velocity constraints [4, 5] for the ground motions recorded at K-NET, Shinjuku station (TKY007) [1]. The intersection point implies the predominant period from the viewpoint of input energy. The periods of 4 and 6.5 seconds are such predominant periods of the ground motions and this implies that this ground motion actually included fairly large long-period wave components. For comparison, Fig.1(b) shows the corresponding figures for the ground motion in Osaka bay area. It may be concluded that the credible bound for the velocity constraint can control the bound of input energy from the long-period ground motion and this bound plays a role for overcoming the difficulties caused by uncertainties [5, 6] of long-period ground motions (predominant period and intensity level).

SEISMIC RESPONSE SIMULATION OF SUPER HIGH-RISE BUILDINGS

Fig.2 illustrates the comparison of time histories of top-story displacements of the assumed 40-story building of the fundamental natural period T_1=3.6s to a simulated long-period ground motion (frame response: elastic, without or with high-hardness rubber dampers [3]). It can be understood that the high-hardness rubber dampers [3] can damp the building vibration in an extremely short duration. Fig.3 shows the distributions of (a) the maximum story displacements and (b) the maximum interstory drifts of another assumed 60-story building of T_1=5.92s to the ground motions at K-NET, Shinjuku station (TKY007) (frame response: elastic-plastic, without or with high-hardness rubber dampers).

SEISMIC RESPONSE OBSERVATION IN TOKYO AND OSAKA

It has been reported [1, 2] that a 54-story building (height=223m: T_1=6.2s (short-span direction), 5.2s (long-span direction)) retrofitted with passive oil dampers including the supporting bracing system at Shinjuku, Tokyo experienced a top displacement of 0.54(m) during this earthquake. The vibration duration has been reported to be over 13 minutes. It has also been found that the building would have attained a top displacement of 0.7(m) if the passive dampers had not been installed. This fact corresponds well to the result explained above.

There is another report that a 55-story super high-rise building in Osaka (height=256m: T_1=5.8s (long-span direction), 5.3s (short-span direction)) was shaken severely regardless of the fact that Osaka is located far from the

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epicenter (about 800km) and the JMA instrumental intensity was 3 in Osaka. It should be pointed out that the level of velocity response spectra of ground motions observed here (first floor) is almost the same as that at the Shinjuku station (K-NET) in Tokyo and the top-story displacement are about 1.4m (short-span direction) and 0.9m (long-span direction). This implies the need of consideration of long-period ground motions in the seismic resistant design of super high-rise buildings in mega cities even though the site is far from the epicenter. Fig.4 shows the resonant behavior. It can be observed that the resonant response corresponds well to the large amplitude of ground velocity, not the acceleration. It should also be noted that, while the reduction of damping ratio is not influential in the random response, the reduction of damping ratio (usually small in super high-rise buildings) is critical in the resonant state (Fig.5).

CONCLUSIONS

The 2011 off the Pacific coast of Tohoku earthquake is the most devastating earthquake in Japan after the 1923 Great Kanto earthquake in terms of the damaged area and loss cost. The critical excitation method is reliable to overcome the difficulty under uncertain circumstances [5, 6] induced by long-period ground motion.

References

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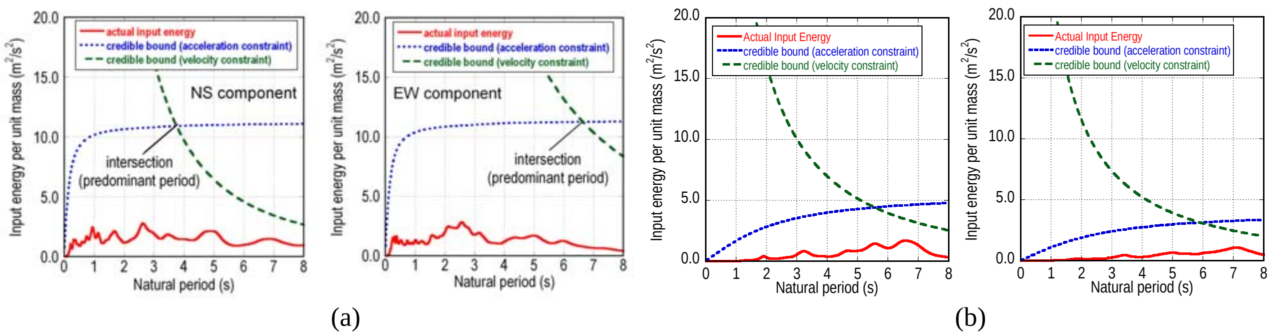

Fig.1Actual input energy, credible bound for acceleration constraint and credible bound for velocity constraint

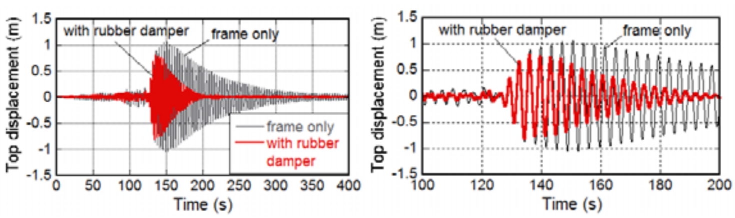

Fig.2 Time histories of top-story displacement

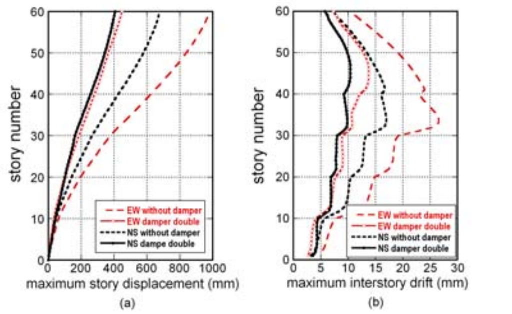

Fig.3 Maximum displacement and interstory drift

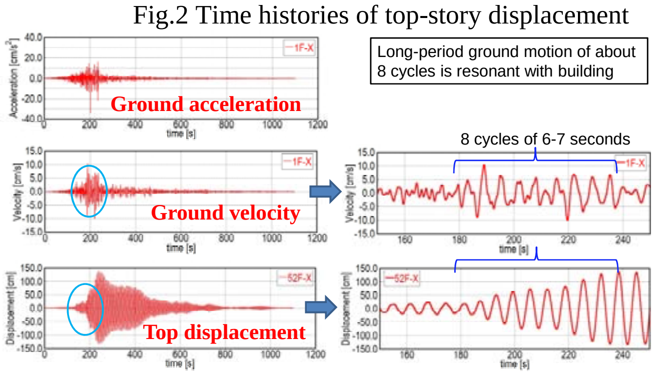

Fig.4 Resonant response of a building in Osaka

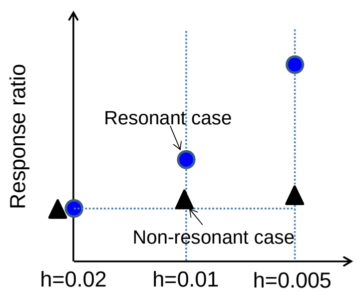

Fig.5 Response amplification in resonant and random cases