

COUNTERMEASURES FOR LONG-PERIOD GROUND MOTIONS

Takaharu FUKUDA
Kajima Corporation
Tokyo, Japan

Haruyuki KITAMURA
Norihide KOSHIKA
Kobori Research Complex
Tokyo, Japan

Tokyo University of Science
Tokyo, Japan

ABSTRACT:

The Architecture Institute of Japan (AIJ) had carried out the research regarding the effects of long-period ground motions on high-rise buildings and base-isolated buildings since 2007. The result of the research was summarized as a report, and released to the public in the Public Workshop regarding the Countermeasures for Long-period Ground Motions held on March 4, 2011, just one week before the Great East Japan Earthquake.

After the Great East Japan Earthquake, AIJ immediately started a survey and research regarding the damage and effects of long-period ground motion caused by huge subduction earthquake for high-rise buildings and base-isolated buildings. The result of the survey and research was summarized as a report and released to the public in the Public Workshop Regarding the Countermeasures for Long-period Ground Motions held on March 16, 2012.

This paper briefly introduces the content of these reports.

1. Introduction

In response to the request by the Cabinet Office, the Architecture Institute of Japan (AIJ) had been carried out the research regarding the effects of long-period ground motions on high-rise buildings and base-isolated buildings since 2007. The Long-period Building Investigation WG, established in 2007 under the Structural Committee of the Architectural Institute of Japan, had extensively carried out the research regarding the feature of long-period ground motions and the damage of long-period structures such as high-rise buildings and base-isolated buildings. The WG had investigated the feature of long-period ground motions, the damage level judgment, the recover measures, the damage reduction measures, and the future problems. The result of the investigation was summarized as a report [1] and released to the public in the AIJ workshop held on March 4, 2011, one week before the Great East Japan Earthquake on March 11, 2011.

After the Great Disaster, the WG immediately started the survey and research regarding the influence induced by the unpredictable large earthquake in high-rise buildings and base-isolated buildings. The result of the investigation was summarized as a report [2] and released to the public in the AIJ workshop held on March 16, 2012.

The authors (2) and (3) were in charge of these studies, and the author (1) translated the summary of these reports. This paper briefly introduces the content of these reports to the attendants in the 14th US-Japan Workshop.

2. The First Report Summary

The following is the summary of the report; “The Public Workshop regarding the Countermeasures for Long-period Ground Motions”, published on March 4 by AIJ:

1) Huge subduction earthquakes and regions of interest

Existing high-rise buildings in Tokyo, Nagoya and Osaka area subjected to the simultaneous event of the Tokai, Tonankai and Nankai earthquakes which is the largest earthquake ever examined, are likely to be shaken for considerably longer than had expected in the initial design.

2) Shaking and damage level of high-rise buildings

There is almost no possibility of collapsing of high-rise buildings during the simultaneous event of the Tokai, Tonankai and Nankai earthquakes. Long-period ground motions have different characters depending on the areas. High-rise buildings also have different structural characters individually. As a result of that, the shaking and damage level of the buildings will exhibit a different aspect in each building. Long-period ground motions will bring a big and long time shaking in high-rise buildings with a long natural period.

Damping devices attached in high-rise buildings can significantly decrease the sway and keep the structural frames with no damage.

Seismic diagnosis should be performed for existing high-rise buildings. If some damage is expected, seismic retrofit by installing damping devices should be carried out and the damage may be dramatically reduced.

3) Damage of non-structural members, furniture and MEP equipment

The damage of non-structural members, and also the movement or falling of furniture and fixtures are very likely to occur.

On the other hand, this kind of damage can be surely prevented by fixing them appropriately.

4) Post-earthquake emergency judgment and recovery measures in the early stage

Emergency risk judgment (for evacuation) and post-earthquake damage judgment (for damage estimation and recovery work) should be performed, however, is very difficult.

It is recommended that at least one of elevators be a high seismic performance type which can be used safely after a large earthquake. It will greatly facilitate the evacuation, risk judgment, restoration and repair works.

It is necessary to prepare the latest design documents and the analytical model for the seismic response analysis which is carried out immediately after the earthquake.

The design documents are essential for the emergency risk judgment and the post-earthquake damage judgment.

It is recommended to permanently equip the devices to measure building behavior during earthquake.

Damage diagnosis performed in combination with simulation studies using an analytical model and an observation record of the earthquake are very effective for the determination of the risk and damage level, and the identification of the damage position.

5) Damage scenario and preparation

The feature of possible damage in high-rise buildings subjected to a long-period ground motion has yet not been experienced. In order to improve the situation, it is important to draw a scenario, identify the current issues, and also develop strategies in advance.

6) Education for society

Owners, users and residents of high-rise buildings should consider seriously about the countermeasures against the long-period ground motions. We have to emphasize the necessity.

They can understand the need of adopting the countermeasures through the pseudo shaking experience of the building subjected to long-period ground motions.

The day-to-day efforts such as developing an action manual during an earthquake, regularly conducting emergency drills are also required.

A prior agreement among the building owners, in particular condominium owners usually consisting of a wide range of people, is required for the implementation of seismic diagnosis, seismic retrofitting, and emergency repair.

3. The Second Report Summary

The following is the summary of the report, “The Public Workshop Regarding the Countermeasures for Long-period Ground Motions”, released on March 16, 2012 by AIJ:

3.1 What happened in the Great East Japan Earthquake?

1) The ground motion caused by the Tohoku off-Pacific Ocean Earthquake in Sendai area continued to shake for 5 minutes and was approximately equivalent to the code specified time-history wave, so called the Notice Wave, which is used in the structural design of high-rise buildings. The ground motion in Tokyo area continued to shake for 10 minutes and was approximately a half of the Notice Wave.

The damage on the high-rise buildings was limited and less than the level requiring repair works.

2) The acceleration level of buildings in Miyagi Prefecture was 200-300cm/s² at first floor, and was 450-600cm/s² in steel buildings and 300-450cm/s² in reinforced concrete buildings at the top floor, respectively. The difference of amplification feature among the buildings was small.

3) According to the observation result of building response in Tokyo metropolitan area, the maximum sway (half amplitude) and the maximum drift angle at the top floor were about 50cm and 1/200rad. in reinforced concrete high-rise buildings (housing use) and about 90cm and 1/250rad. in steel high-rise buildings (office use), respectively.

4) As the result of long-period ground motions of the Tohoku-Pacific Ocean Earthquake, the sway of high-rise buildings located along the coast of Tokyo Bay from Yokohama to Chiba was at most two times as large as the sway of high-rise buildings in Otemachi and Shinjuku.

5) The damage of non-structural members and mechanical equipment, such as ceiling materials, finishing materials and plumbing equipment has been observed widely in high-rise buildings located from Sendai to the Tokyo metropolitan area. Similar damage was also observed in some high-rise building in Osaka.

6) A large number of elevators in the Tokyo metropolitan area had stopped in emergency mode. The recovery measure in order to make elevators available had been taken immediately after the earthquake. At least one elevator became operational in most buildings on Monday, three days after the earthquake.

7) According to the survey for the total number of 370 000 units of elevators by the Japan Elevator Association, about 9,000 units of elevators were suffered some damage. The typical damage was the catch of main and other cables with elevator equipment, accounted for 24% of the total damage. Falling off of counterweight had occurred in 49 units of elevators made before 1998. The retrofit of old elevators will be required.

8) There was some damage like slipping, falling and overturning in furniture and fixtures at the top floor of high-rise buildings in the Tokyo metropolitan area, in comparison with relatively small damage in the lower floors.

The damage in high-rise office buildings was less than that in high-rise housing buildings. It seems to be because the tall cabinets in offices are usually fixed.

The overturning of unfixed shelves and the lateral movements of equipment with casters were observed in some offices.

9) According to the survey, more than 80% of the people who stayed in the upper floors of high-rise buildings in the metropolitan area felt large shaking and some sort of trouble for moving or walking by themselves.

They were able to behave normally if the floor velocity response was less than 20cm/s. They also felt the difficulty for standing if it was about 40cm/s. They finally could not act anything if it was more than 70cm/s.

10) More than 80% of the people who stayed in lower floors as well as in upper floors of high-rise buildings felt the intense fear during the earthquake. There were a variety of feelings; someone felt like seasickness, and someone felt shaking after the earthquake, as well as someone felt nausea and dizziness.

3.2 Lessons from the Great East Japan Earthquake

1) The review of the earthquake fault models for the three linkage of Tokai, Tonankai and Nankai earthquake has been made after the Tohoku-Pacific Ocean Earthquake. In accordance with the review, it becomes necessary to re-examine the prediction of long-period ground motions.

Assuming the waves of the three linkage of Tonankai Tokai and Nankai earthquake which was studied last year, the shaking level of high-rise buildings (with natural period 2-6 seconds) located in Tokyo will be more than two times of that experienced in Tohoku-Pacific Ocean Earthquake. Also the shaking time will be longer than expected, continuing for more than 10 minutes. The shaking level of high-rise buildings located in Nagoya and Osaka will possibly reach to about 2 times of that experienced in Sendai.

2) If the seismic performance of high-rise buildings against the predicted long-period ground motions can be diagnosed in advance, the building damage can be determined at an early stage using the observed wave of the building or the recorded wave by the K-net nearby. The shaking duration and level of high-rise buildings which had carried out the seismic retrofit using response control devices were reduced significantly. Also, a significant response reduction effect was confirmed in many base isolated buildings.

3) At the time of the periodical maintenance and retrofit of non-structural members and mechanical equipment, it is recommended to adopt a seismically effective method learned from this lesson.

4) Elevator is an indispensable transportation tool in all high-rise buildings. The recovery speed of the building immediately after a earthquake will be greatly improved by updating at least one unit of elevator to the one having high seismic performance.

5) The shaking duration of high-rise buildings in the metropolitan area which carried out the seismic retrofit using response control devices had been reduced significantly in addition to the reduction of the shaking level.

The Implementation of the seismic diagnosis and seismic retrofitting, in conjunction with large-scale functional renewal (update of MEP equipment and renewal of the interior and exterior material) that is required on a regular basis (every 25-30 years) in order to maintain a building, is very effective way for saving construction cost and reducing the delivery time as well as improving the seismic performance. In general, the costs required for functional renewal work is about 30-50% of the initial investment cost. On the other hand, the cost required for seismic retrofitting during the functional renewal work will be only a few percent of the total renewal cost.

6) There was some damage like slipping, falling and overturning of furniture and fixtures as well as movement and scattering of small products and documents, jumping out of received material at the top floor of high-rise buildings in the Tokyo metropolitan area. More than 80% of the people felt a large shaking and some sort of trouble for moving or walking by themselves. Judging from these facts, moving to a safe place and protecting the personal safety is the top priority matter.

7) In particular, the action of building users and occupants during an earthquake and the role of administrator in office buildings should be clarified through the periodical anti-disaster drills.

It was verified that by taking advantage of the emergency earthquake information system and the damage judgment system based on the earthquake observations, the building management can ensure the safety and security of users and residents of the buildings during the earthquake.

8) We should investigate the experience of the Great East Japan Earthquake as a lesson against the next great earthquake, and clarify the current problems, and also develop the countermeasures in advance.

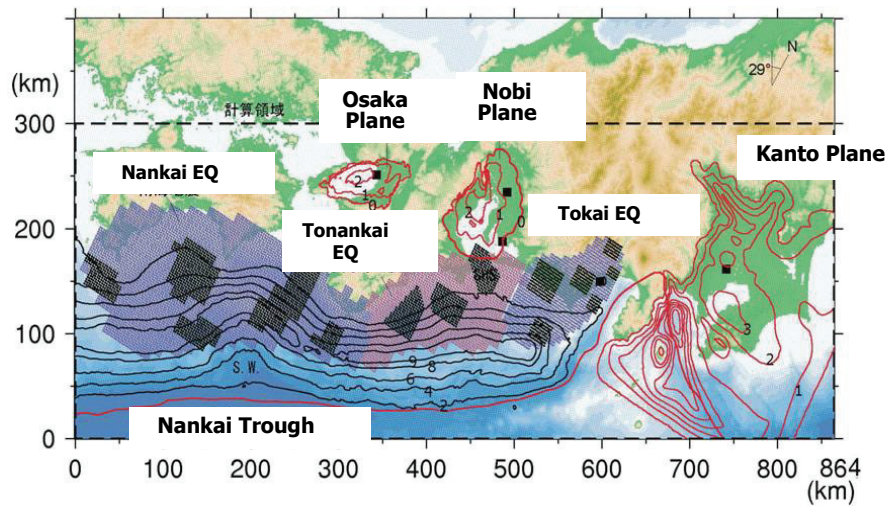


Figure 1. Earthquake Source Model for Expected Three Linkage of Tokai, Tonankai and Nankai Earthquakes

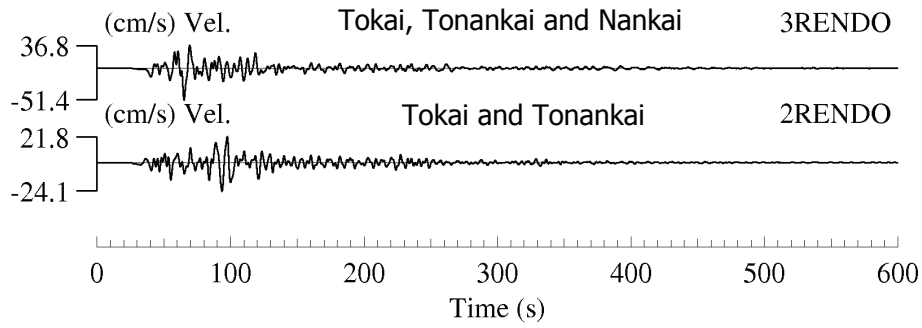


Figure 2. Calculated Seismic Wave in Osaka

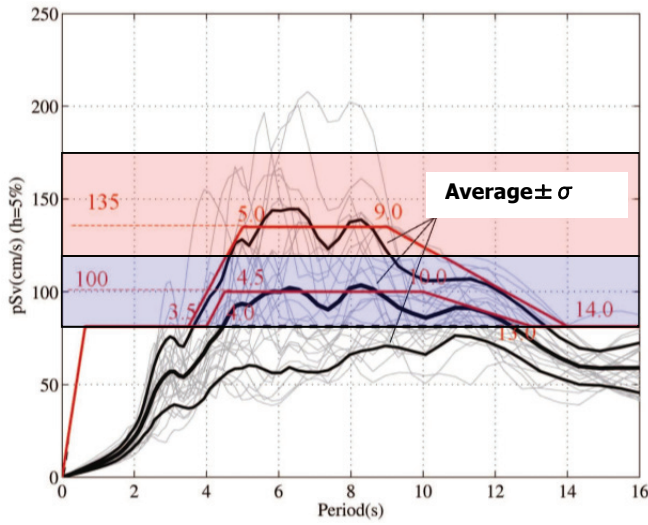


Figure 3. Velocity Spectrum in Osaka ($h=5\%$)

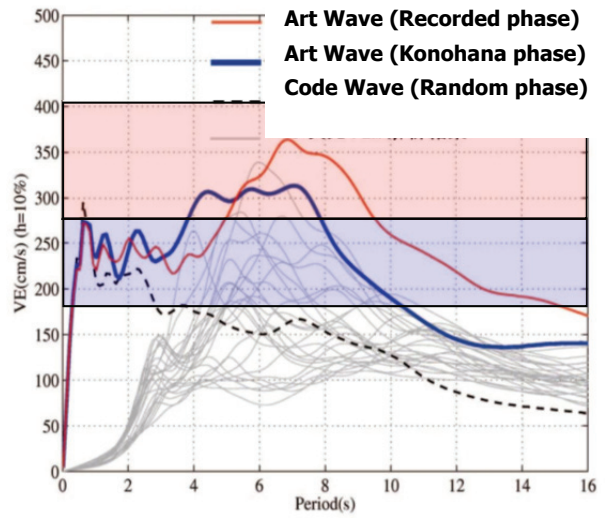


Figure 4. Energy Spectrum in Osaka ($h=10\%$) ($Average + 1\sigma$)

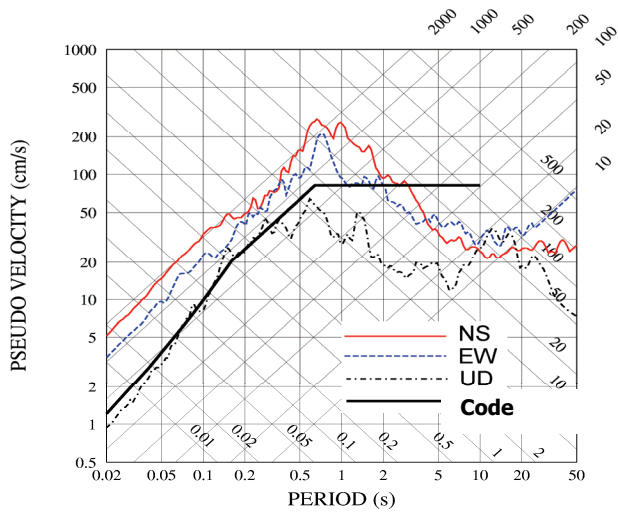


Figure 5. K-NET Sendai

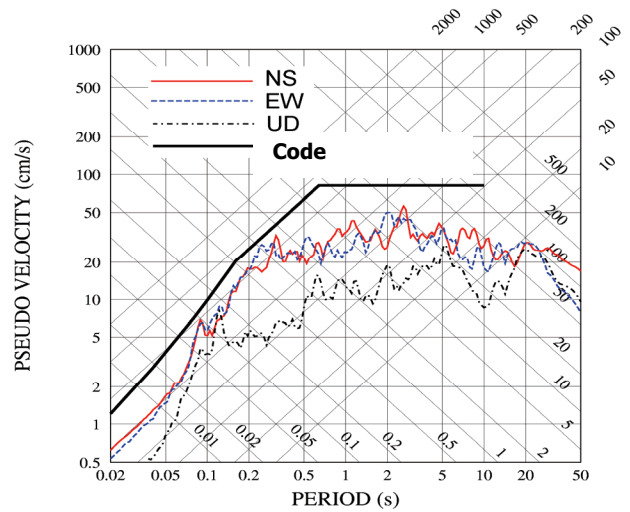


Figure 6. K-NET Shinjuku, TOKYO

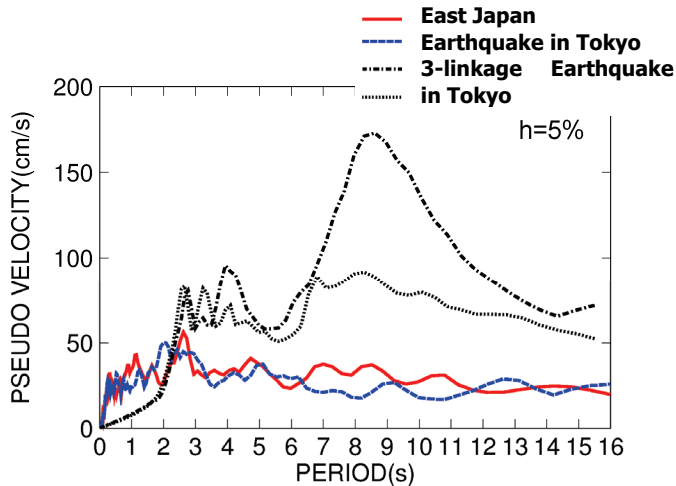


Figure 7. Comparison at Tokyo

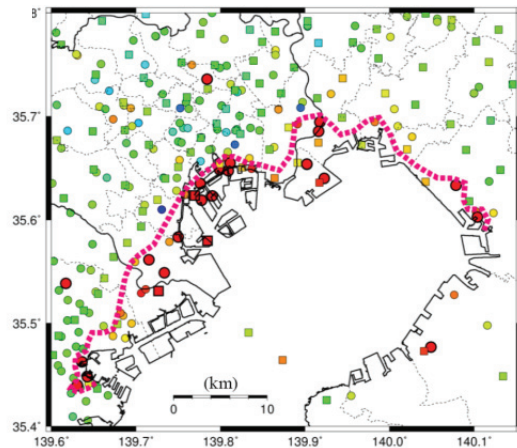


Figure 8. Large shaking Area along Tokyo bay

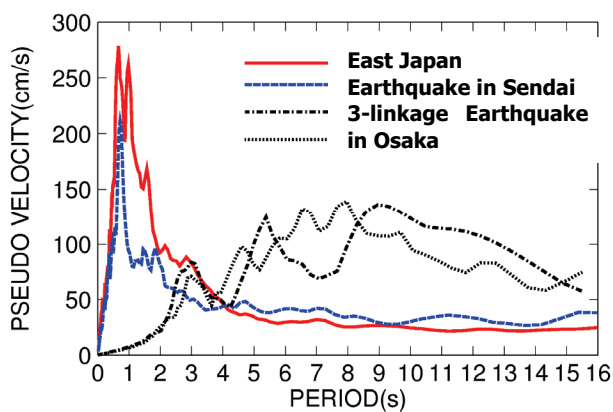


Figure 9. Comparison at Osaka

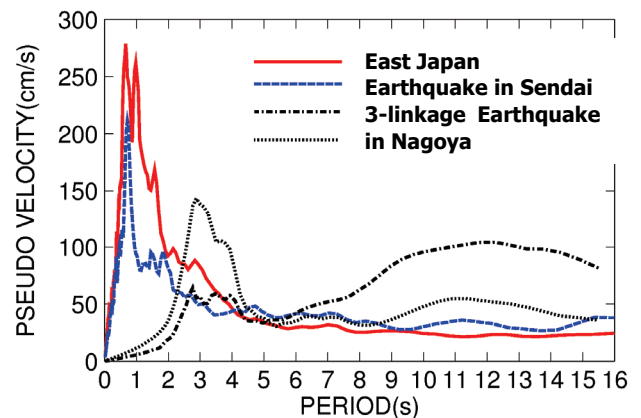


Figure 10. Comparison at Nagoya

ACKNOWLEDGEMENT

This paper is a translation of the summary of the report [1] and [2]. Gratitude is respectfully expressed to all the members of the Response Measures for Long-Period Building Structures Subjected to Earthquakes Sub Committee of AIJ (chairperson: Professor Haruyuki Kitamura of Tokyo University of Science, chief: Professor Kazuo Tamura of Chiba Institute of Technology, Yuichi Kimura of Taisei Corporation, Norihide Koshika of Kobori Research Complex) and all the members of Working Groups under the sub committee.

REFERENCES

- [1] The Long-period Buildings Investigation WG of AIJ, “The Public Workshop Regarding the Countermeasures for Long-period Ground Motions”, March 4, 2011
- [2] The Long-period Buildings Investigation WG of AIJ, “The Public Workshop Regarding the Countermeasures for Long-period Ground Motions”, March 16, 2012