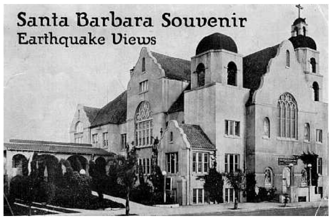

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BROADBAND STRONG GROUND MOTION PREDICTION FOR HYPOTHETICAL TONANKAI EARTHQUAKE USING STATISTICAL GREEN'S FUNCTIONS METHOD AND SUBSEQUENT BUILDING DAMAGE EVALUATION

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ABSTRACT

We used an empirical Green's function method together with the heterogeneous asperity source model to sum up broadband statistical Green's functions for a moderate size earthquake to predict strong ground motions due to the expected Tonankai earthquake. We were able to simulate seismic intensity distribution similar to past earthquakes and strong ground motion waveforms that correspond to previous studies and attenuation relations. Using these results, we predicted building damage by non-linear response analysis and found that at the regions close to the source as well as regions with relatively thick soft sediments such as the shoreline and alluvium deposits along the rivers, there is a possibility of severe or higher damage regardless of the type of buildings. Also, damage ratio for buildings built before 1981 was higher than those built after and the damage ratio was highest for steel buildings, followed by wooden buildings and then reinforced concrete buildings.

INTRODUCTION

The Tohoku Region Pacific Coast Earthquake occurred on 11 March 2011 at 2:46 pm across a broad source region in the Pacific spanning from off Sanriku coast to offshore Ibaraki. The earthquake caused over 23,000 deaths and missing persons and left devastating damage primarily around the Pacific coast in eastern Japan. It is thought that massive earthquakes such as this occur only rarely, but the probability of a general magnitude 8 class massive subduction zone mega-thrust earthquake occurring is relatively high, and it's impact spreads over a vast region. Direct damage from strong ground motion, including collapse of buildings, landslides, liquefaction, land subsidence and tsunamis, occurs in tandem with secondary damage, such as fires, damage to industrial facilities, disturbance to transportation facilities, etc., and as a result have economic impacts across the country. The source regions of these earthquakes are surrounding the Japanese archipelago, so it is imperative that each region of Japan conducts earthquake disaster damage prevention measures that are customized to suit local conditions. The probability of a Tonankai or Nankai earthquake occurring over the coming 30 years is said to be approximately 50% to 60% (The Headquarters for Earthquake Research Promotion (below abbreviated as Earthquake Headquarters), 2002), and if one does occur, it is feared that vast and immense damage will result from ground motion and tsunamis by the earthquake, primarily along the Pacific coast near the source region ranging from the Tokai region to the Kyushu region. Meanwhile, in order to make a quantitative estimate of the damage to buildings that would result from such a hypothetical earthquake that will probably occur in the future, it is clear that the associated ground motion characteristics and building response characteristics must be considered. Despite the efforts of national and local governments there still remains large numbers of buildings with low earthquake resistance and deteriorated buildings. It is extremely important that damage forecasts are made with a clear understanding of these buildings' earthquake performance. Further, despite the fact that research done since the occurrence of the Kobe Earthquake in 1995 has given rise to the capability to make quite accurate damage predictions for inland earthquakes (Matushima and Kawase, 2000; Ito and Kawase, 2001), a variety of problems continue to plague the task of predicting the strong ground motion resulting from mega-thrust earthquakes, such as the problem of how to express a seismic source process that can reproduce strong ground motion rich in long period components appropriately. Furthermore, to date there have been no real quantitative evaluation of extremely important elemental technologies such as total damage assessments using quantitative building damage prediction models, and damage mitigation measures based on them.

In this paper we use the latest strong ground motion evaluation methods to make a quantitative prediction of the strong ground motion that would occur in an independent event ofthe Tonankai earthquake, a massive mega-thrust earthquake along the Nankai Trough, which is of the utmost concern as it has the potential of 3 earthquakes occurring simultaneously. The results of this will be input into a non-linear building response analysis model (Nagato and Kawase, 2001), and prediction of the resulting damage for wooden buildings, mid-to-low-rise reinforced concrete (RC) buildings, and low-rise steel-frame buildings shall be conducted. This series of predictions will be based on the "Building Destruction Behavior Simulator", which numerically evaluates non-linear responses, and the predicted damage will be the function of building's true seismic performance, enabling a quantitative assessment of the degree to which certain improvements in the seismic performance of groups of buildings would result in reduced structural and human damage. That is to say, cost assessments of the policies necessary to counterbalance the effects of earthquake proofing measures become possible.

THE CHARACTERISTICS OF EARTHQUAKE ACTIVITY IN THE SUBJECT REGION

It is of the utmost importance from the viewpoint of earthquake disaster planning and mitigation, to conduct earthquake research to clarify the causes of past earthquake damage. In particular, when conducting estimates of the damage that would result from these hypothetical earthquakes that may occur in the future, an understanding of the characteristics of ground motions, which occur repeatedly in the source region, becomes the most fundamental and important data for the purpose of urban disaster prevention and mitigation planning, and the seismic safety of buildings. There are several types of earthquakes that occur in the Chubu-Kinki region, which is the source region of the hypothetical Tonankai earthquake. One would be off-shore earthquakes in the Pacific that occur near the boundary of the oceanic plate that slopes from the Suruga and Nankai Troughs, toward the Eurasia plate. Another type would be shallow inland earthquakes (less than 20km below the surface), and yet another would be earthquakes that occur on the eastern margin of the Japan Sea (near offshore Niigata) (Source: Earthquake Headquarters). Figure 1 shows the magnitude and epicenter of all earthquakes that occurred after 1887 (the 20th year of the Meiji era) and caused major damage. A, B, and C indicate the source regions for the Nankai, Tonankai, and Tokai earthquakes, respectively. According to the historical earthquake data and literature of past earthquakes, magnitude 8 class Tonankai and Nankai massive mega-thrust earthquakes reoccur at intervals of approximately 100 to 150 years in the regions along the Suruga and Nankai Troughs, and cause vast and immense damage from ground motion and tsunamis primarily around the Pacific coast, which is near their source regions. Since the Meiji era major damage from ground motion, tsunamis, etc., has been caused by the occurrence of the Showa Tonankai Earthquake (M7.9, 1944) and the Showa Nankai Earthquake (M8.0, 1946). Meanwhile, in inland regions, there was the Fukui Earthquake (M7.1, 1948) that occurred directly under an urban area, the Kobe Earthquake (M7.3, 1995), the relatively large-magnitude, shallow Nobi Earthquake (M8.0, 1891), etc., in which urban areas were devastated. Comparing the death toll of post-Meiji earthquakes, there was the Great Kanto Earthquake of Showa (M7.9, 1923), the Tohoku Region Off Pacific Coast Earthquake (M9.0, 2011), and the Meiji Sanriku Earthquake (M8.2 - 8.5, 1896), after which come the Nobi Earthquake, the Kobe Earthquake, the Fukui Earthquake, etc., which also occurred in this area. The death toll from each of these earthquakes stand at over 5,000, making them immensely damaging earthquakes. In the figure, the Niigata Earthquake (M7.5, 1964) is included as an earthquake that occurred in the eastern margin of the Japan Sea.

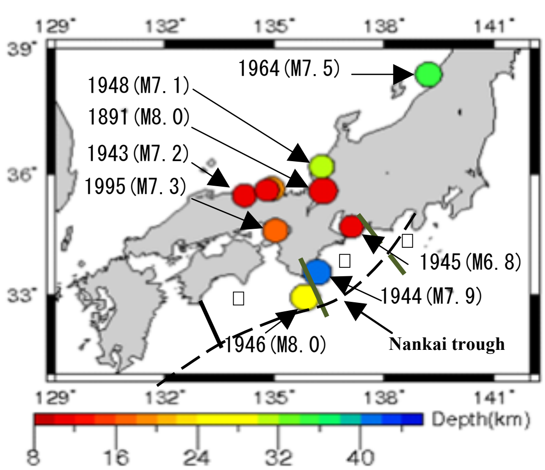


Fig. 1. Epicenter of earthquakes that caused extensive damage in Kinki to Chubu areas since the Meiji era.

From the above it can be seen that, there has been a relatively large number of large-magnitude, shallow inland earthquakes in the region spanning from the Chubu region to the Kinki region in the Japanese archipelago.

It seems that every few decades before and after the occurrence of a massive mega-thrust earthquake along the Nankai Trough, inland earthquake activity increases (Kawase, 2005), and it is said that this began with the Kobe Earthquake in 1995. The earthquake activity in this region is thought to be largely related to the subduction of the Philippine Sea Plate.

PREDICTING GROUND MOTION WITH THE STATISTICAL GREEN'S FUNCTION

Settings of the Source Model for the Hypothetical Tonankai Earthquake and Analysis Points

Until now we have used the settings based on the provisional model built by Kamae (2004) which is modeled according to the standard settings and methods of outer and inner source characteristics released by Earthquake Headquarters and predicted strong ground motion for a hypothetical Tonankai earthquake (Baoyintu *et al*., 2010, hereafter abbreviated as "the previous study"). We have also input the predicted strong ground motion into a non-linear response analysis model, and estimated the average damage ratio of buildings by type of structure and number of story in the hypothetical source region. In recent research, by introducing an attribute for the heterogeneity in the asperities of major source faults such as massive mega-thrust earthquakes and introducing a property whereby the strength of ground motion saturates in the vicinity of the source fault, strong ground motion evaluation results are said to have improved dramatically (Ho and Kawase, 2006, 2008). In this paper we attempt a more accurate method of strong ground motion prediction by considering the heterogeneous attribute of similar source faults. We also introduce the characteristic of the strength of ground motions reaching saturation in the vicinity of source faults.

As the source model for the hypothetical Tonankai earthquake, we set up a heterogeneous source model that, like the source model in the previous study, is composed of three large asperities and background region. In the predictions of the previous study, we arranged two stages of element earthquake sizes, but for this study one size of element earthquake is introduced for heterogeneous attribute to the asperities in the source fault. That is to say, we considered asperities that have large slips even have heterogeneity, and assumed that in 22% of the asperity, the slip is 1.5 times higher than average of the asperity (those marked with a small black square), while in the remaining 78%, of the asperity the slip is less than average (without changing the seismic moment). The points to be analyzed are K-NET, KiK-net and JMA observation stations within 400km from the center of the hypothetical Tonankai earthquake's asperities and the background region. The target region was focused on the Kinki-Chubu region. Figure 2 shows the location of the asperities, the center point of the asperities (red mark), and the center points of the background region (black mark) and the rupture starting point (blue star) of the source fault of the hypothetical Tonankai earthquake. Further, points subject to analysis are also marked with a ⊗. Table 1 shows the hypothetical Tonankai earthquake's fault parameters.

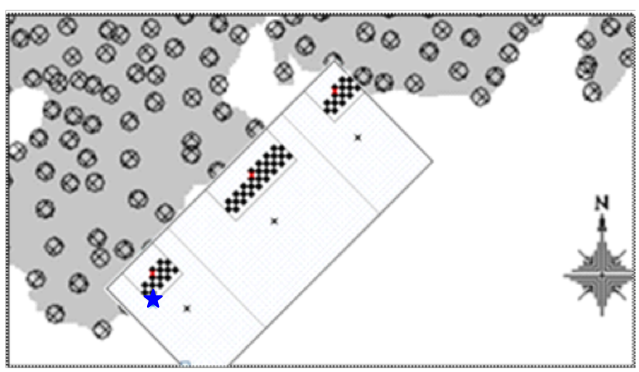


Fig. 2 Location of asperities on the assumed source fault, rupture initiation point and points being analyzed in this study.

The Statistical Green's Function Method

In this paper, the strong ground motion of the hypothetical Tonankai earthquake is predicted using the statistical Green's function, which was made by Ho and Kawase (2007), and which is effective even for long-period components. They made use of Kawase and

Matsuo (2002) to develop a method for preparing the statistical Green's function. They did this in the following way. Starting with the group of all 110 earthquakes that occurred on land or near oceanic trenches in Japan during the period of August 1996 to March 2005, then selected data that matched the following conditions: Mj ≥ 5.5, hypo-central distance ≤ 400km, focal depth ≤ 60km, PGA ≤ 200Gal, and triggered at 3 or more sites. They expanded the frequency to between 0.1 and 20 Hz and conducted analysis using observed data after the onset of S-waves. The statistical spectrum characteristics were seperated into source, path and site characteristics, and statistical time properties were regressed against magnitude (M) and hypo-central distance (X). They also made a strong ground motion prediction in the hypothetical Nankai earthquake using this statistical Green's function, conducted non-linear response analysis and estimated the building damage in western Japan from a hypothetical Nankai earthquake. This time we considered an independent hypothetical Tonankai earthquake but used the same strong ground motion prediction method. We believe that suggesting countermeasures for the predicted strong ground motion building damage for a massive mega-thrust earthquake of the Philippine Sea Plate, including simultaneous Tokai, Tonankai and Nankai earthquakes, will contribute substantially to damage prevention measures for future earthquakes in the Nankai Trough.

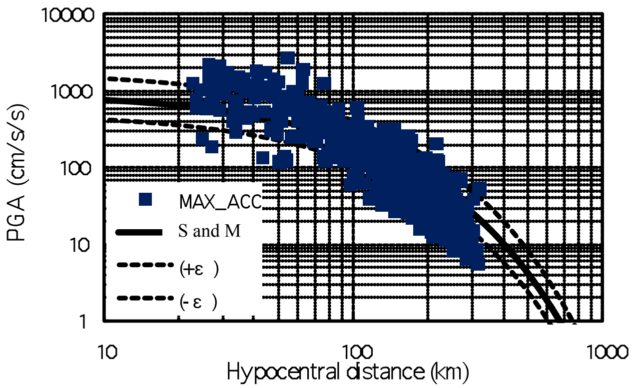
Table 1 The assumed fault parameters of the expected hypothetical Tonankai Earthquake

Name	**Mj**	**Mo (N・m)**	**Δσ(bar)**
Hypothetical Tonankai Earthquake	8.1	2.12E+21	30
Small Event	5.7	1.70E+17	98
Asperity	**No.1**	**No.2**	**No.3**
Size (km²)	24*24	24*48	24*24
Small Event Size (km*km)	3*3	3*3	3*3
Strike θ(degree)	250.7	250.7	250.7
Dip Angle δ(degree)	14.0	14.0	14.0
Slip Angle γ(degree)	122.7	122.7	122.7
Seismic Moment (N・m)	1.42E+20	4.00E+20	1.42E+20
Stress Drop (MPa)	20.1	20.1	20.1
Similarity ratio N	8	16	8
Rise Time (sec)	1.8	2.5	1.8
Background Domain	**No.1**	**No.2**	**No.3**
Seismic Moment (N・m)	3.87E+20	7.18E+20	3.30E+20
Area (km²)	3168	5868	2700
Stress Drop (MPa)	2.7	2.7	2.7
Similarity ratio N	20	20	20
Rise Time (sec)	0.5	0.5	0.5
Shear Rgidity (N/m²)	4.09E+10		
Rupture Velocity (km/s)	2.7		
S wave speed of Source Region (km/s)	3.0		
Rupture Type	Radial		

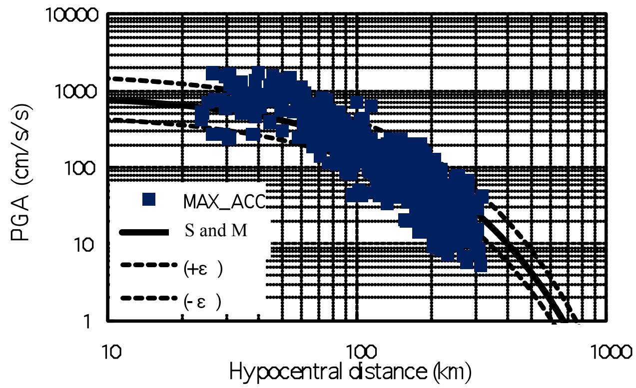
Consideration of Hypothetical Ground Motion Waveforms

We synthesized a waveform using Irikura's (1986) empirical Green’s function method, utilizing the heterogeneous source model for the hypothetical Tonankai earthquake set up above and the statistical Green's function (Ho and Kawase, 2007) which is effective for long-period components. We also incorporated the characteristic of strong ground motion saturation at target points, by enforcing a lower limit to the hypo-central distances so that even the target points close to the source fault are not closer than a certain distance (the radius of a circle equal to the area of the element earthquake).

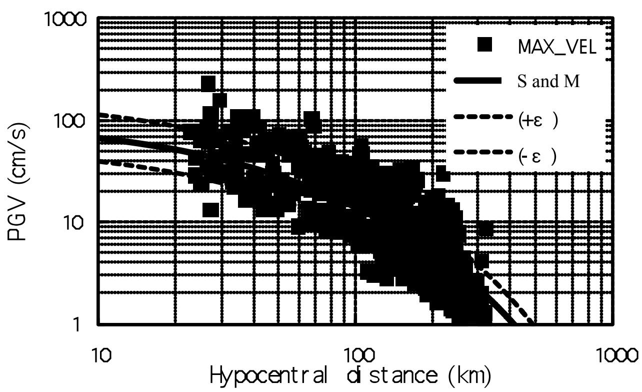
Figure 3 shows PGA and PGV of the synthesized waveform obtained in the previous study and this study in comparison with the attenuation relation by Si and Midorikawa (1999). The top two are figures of PGA, and the bottom two are of PGV, and in each case the figure on the left shows the results of the previous study, while the right ones show the results of the current study. In the current study the PGA were not as varied for short hypo-central distances, and on average matched the attenuation relation well. The PGA at observation points with hypo-central distances above 100km were slightly smaller than those in the previous study, but overall they matched the attenuation relation well. In the previous study the PGV of some points for short hypo-central distance were separated substantially from the attenuation relation, but in this study the PGV estimates calculated were comparatively well-matched with attenuation.



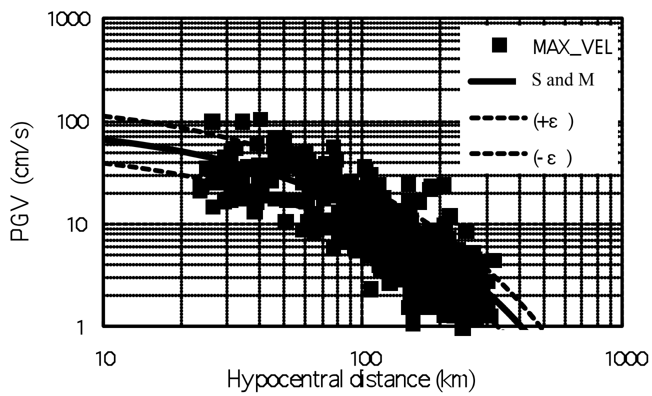
(a) previous result tor PGA



(b) present result tor PGA



(c) current result tor PGV

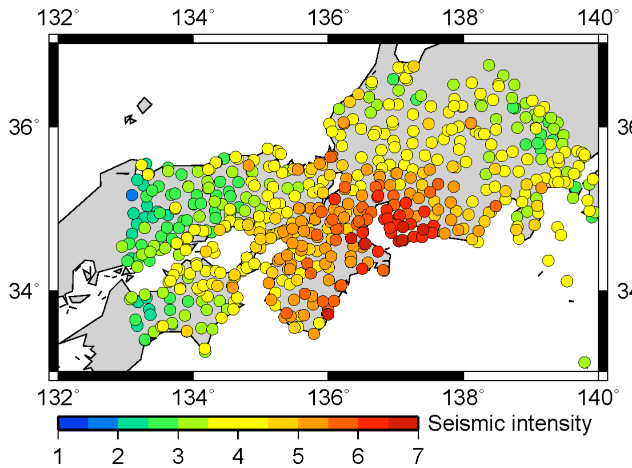


(d) current result tor PGV

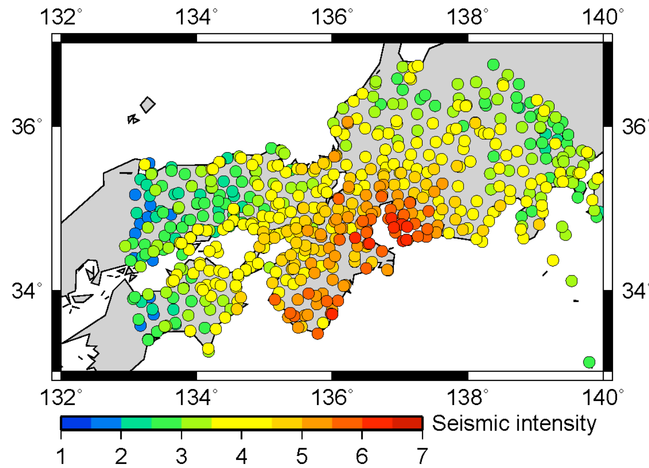
Fig. 3 Comparison of estimated PGA and PGV with the attenuation curves by Si and Midorikawa (1999).
(a) previous result tor PGA. (b) current result tor PGA. (c) previous result tor PGV. (d) current result tor PGV.

However, these are the values for the case where the average S-wave velocity up to 30m underground is 600 m/s for the attenuation relation for PGV by Si and Midorikawa (1999), and if the influence of further site amplification is considered, the PGV obtained in this study appear a little low. The cause of the large variations in the previous study's calculations is thought to be the use of a two-stage element earthquake synthesizing method, rather than heterogeneity of asperities. Further, in the investigation of the Nankai earthquake, Ho and Kawase (2008) set up heterogeneity in the large asperities as used in this study, and made the PGV conform to the attenuation curve of Si and Midorikawa (1999).

We compared the instrumental seismic intensity in the previous study (see Fig. 4a) and the current study (see Fig. 4b), which were derived from calculated seismic intensity of computed synthesized waveforms, with a comparison of the results of trial calculations of seismic intensity in prefectural capitals, etc., for a hypothetical Tonankai earthquake derived from Earthquake Headquarters' public data (2001), with the estimated seismic intensity distribution for the Showa Tonankai Earthquake (see Fig. 4c). In the instrumental seismic intensity obtained in this study, there were fewer observation points estimated to be above the equivalent of a seismic intensity of 6+, and particularly in the coastal region spanning from Nara Prefecture, Shiga Prefecture, and Ise Bay to Mikawa Bay the instrumental seismic intensity has a decreasing trend compared to the previous study. The seismic intensity rank of 6- and 6+ of this study is equivalent to the Earthquake Headquarters' maximum class of 6 and above, and the rest are expressed as almost the same rank. In the coastal region of southern Wakayama Prefecture the figures were slightly higher than the Earthquake Headquarters' estimated seismic intensity distribution, but overall they match well with the results of this study.



(a) previous result



(b) current result

(c) estimated JMA seismic intensity class for Showa Tonankai earthquake

Fig. 4 Comparison of simulated seismic intensity for (a) previous result and (b) current result, and (c) estimated JMA seismic intensity claee for Showa Tonankai earthquake by Headquaters of Earthquake Research Promotion (2002).

PREDICTION OF BUILDING DAMAGE RESULTING FROM THE HYPOTHETICAL GROUND MOTIONS

We input the hypothetical strong ground motion values from the Tonankai earthquake hypothesized in this study into the non-linear response analysis model of Nagato and Kawase, and estimated the damage to wooden, mid-to-low-rise RC, and low-rise steel-frame buildings. From the results of analyses of the many real earthquakes that have occurred in the past, damage rated as 'heavy' does not arise with input of less than 200 Gal, so in this study we selected 136 waveforms with PGA larger than 200 Gal from among the hypothetical strong ground motions and used them to conduct non-linear response analysis.

Nagato and Kawase (2001) conducted a non-linear earthquake response analysis based reproduced strong ground motion of Kobe Earthquake by Matsushima and Kawase (2000), and built a total of 15 non-linear response analysis models including a wooden building model (2F) which is able to reproduce actual damage rates without specification of age, RC building models (3F, 6F, 9F, 12F) and steel-frame building models (3F, 4F, 5F) that distinguish between buildings with new and old earthquake-resistance.

The criteria for the wooden building model is the same regardless of year of production, and maximum inter-story drift angles of 1/10 rad or more were assumed to receive damage of 'heavy' damage or greater. For RC and steel-frame buildings, the criteria is the same regardless of whether the building was built with the new or old earthquake-resistance, and if the inter-story drift of any story exceeds 1/30 rad, are assumed to receive damage of 'heavy' damage or greater. Further, each model includes 12 models considering the balance of strength of existing buildings by including models with low, standard (mode model), and high strength in a lognormal distribution, and calculated the damage ratio from the presence of damage in these models.

Firstly, we estimated the damage to buildings by inputing the acceleration waveform of the hypothetical Tonankai earthquake into Nagato and Kawase's (2001) wooden, RC, and steel-frame models.

Figure 5 shows the number of damaged buildings in the hypothetical Tonankai earthquake reported by the Central Disaster Management Council's "Expert Panel on Tonankai and Nankai Earthquakes, etc." (Central Disaster Management Council, 2003). Figures 6 and 7 show the damage ratio distributions for 3-story, steel-frame buildings with new and old earthquake resistance, and the damage ratio distribution for 2-story wooden buildings and the damage ratio for 9-story RC buildings with new and old earthquake resistance, derived from the Nagato and Kawase model for the hypothetical Tonankai earthquake. The calculated damage ratios this study were high in places like Ise Bay, Kumanonada and Enshunada, where the Central Disaster Management Council estimated a large number of buildings would be damaged by a hypothetical Tonankai earthquake, and building damage distributions were, on the whole, corresponding. Further, it can be seen that in places with comparatively soft ground such as the coastal areas, and alluvial soil areas along rivers in Aichi, Shiga, Mie, and Wakayama Prefectures, the possibility of 'heavy' damage or greater exists regardless of the type of building. In the building damage prediction in this study we have used a set of models designed to match the actual damage ratios for heavily damaged buildings in the Kobe Earthquake. Attention should be paid to the fact that the estimated damage ratios apply to cases where buildings with roughly the same strength as those in these models have been built in the vicinity of the target observation points. This estimated building damage ratio is a damage ratio for points subject to analysis in the hypothetical Tonankai earthquake, and we estimate that the strength of the ground motions in the vicinity will differ depending on the area. It is therefore difficult to compare on equal ground the precise predicted damage ratios of this study and the outcomes predicted by the Central Disaster Management Council.

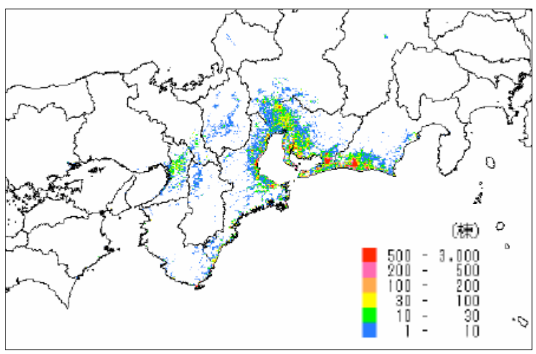
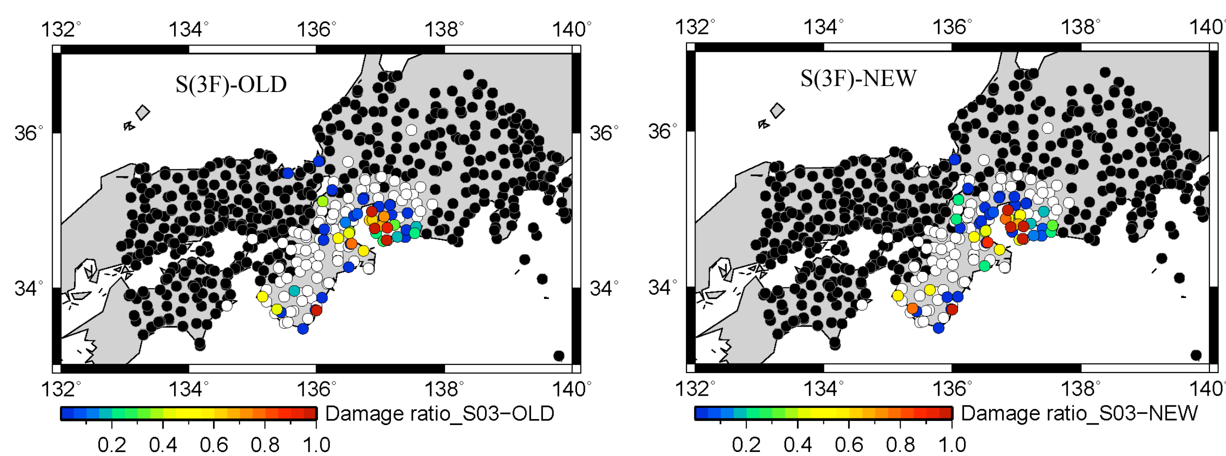


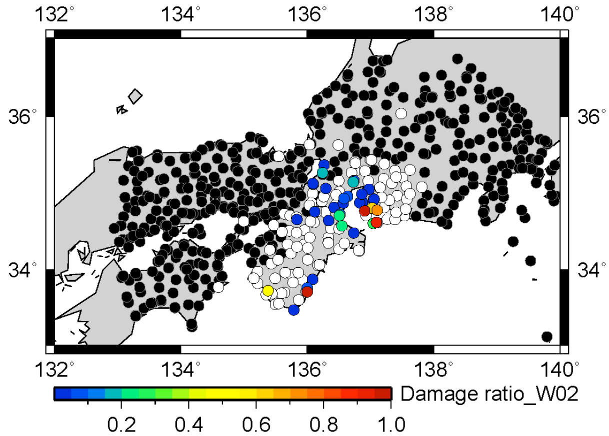
Fig. 5 Distribution of damaged buildings for the expected Tonankai earthquake (Central Disaster Management Council).



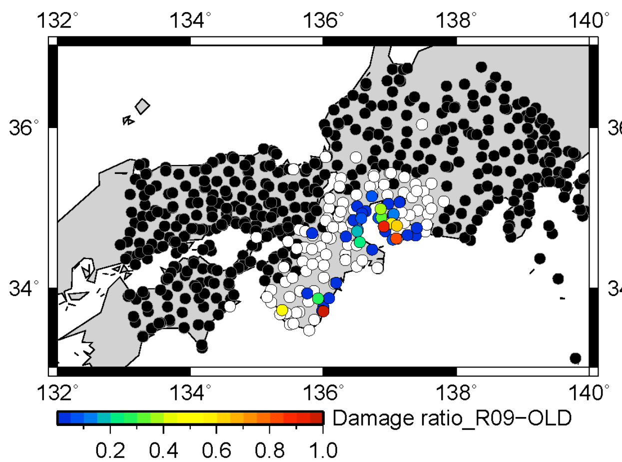
(a) buildings built before 1981

(b) buildings built after 1981

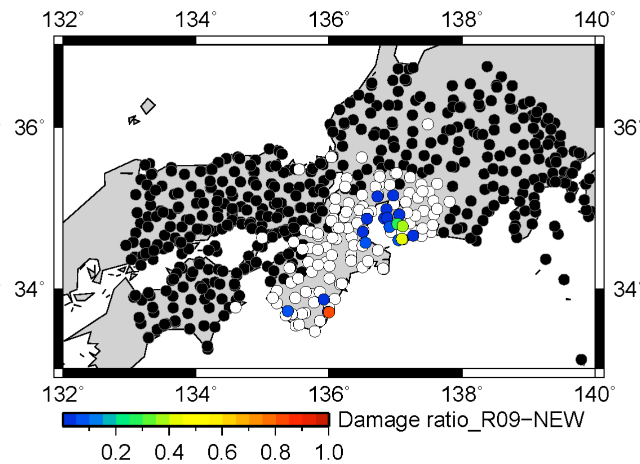
Fig. 6 Damage ratio distribution of steel-frame buildings (3F) of (a) buildings built before 1981 and (b) buildings built after 1981.



(a)wooden (2F)



(b) RC buildings (9F) built before 1981



(c) RC buildings (9F) built after 1981

Fig. 7 Damage ratio distribution of (a) wooden (2F), (b) RC buildings (9F) built before 1981, (c) RC buildings (9F) built after 1981.

Meanwhile, we understand that by using the Nagato and Kawase model, the predicted damage ratio overestimates actual damage ratios for the Niigata Prefecture Chuetsu Earthquake and the 2005 Fukuoka Earthquake. The accuracy of damage prediction models for major mega-thrust earthquakes needs to be improved by clarifying the building damage ratio distribution in the Tohoku Region Off Pacific Coast Earthquake by means of earthquake damage surveys. Further, when comparing the overall damage ratio distribution conditions with the Central Disaster Management Council's reported distribution of damaged buildings (Which includes buildings damaged by liquefaction), the damage ratios in the Osaka Plain and the coastal region of the southern half of Enshunada are smaller. This is because building damage due to liquefaction is relatively common in the predictions of the Central Disaster Management Council, and even if 'heavy' damage or greater due to shaking is minimal, the total damage may be large.

Figure 8 shows a comparison of the average damage ratio distributions from response analysis for old and new earthquake-resistance, by structure type, and by number of stories. The vertical axis is the average damage ratio, or the sum of the damage ratio divided by the number of calculated target points. As a result, we found that the damage ratio was higher for buildings with old earthquake-resistance than it was for buildings with new earthquake-resistance, and for steel-frame buildings, the smaller the number of stories, the higher the damage ratio was, and for RC buildings, the damage ratio was highest for 9 story buildings. Looking by structure type, we found that steel-frame buildings had the highest damage ratios, followed by wooden buildings, and finally RC buildings, but the damage ratio for buildings with old earthquake-resistance and new earthquake-resistance was reversed for 3-story steel-frame buildings and 12-story RC buildings. This matches the observed damage ratios when the model is designed to match the observed damage ratios of the Kobe Earthquake. The reason is because there were fewer of the concerned buildings so that the damage ratio was not as expected.

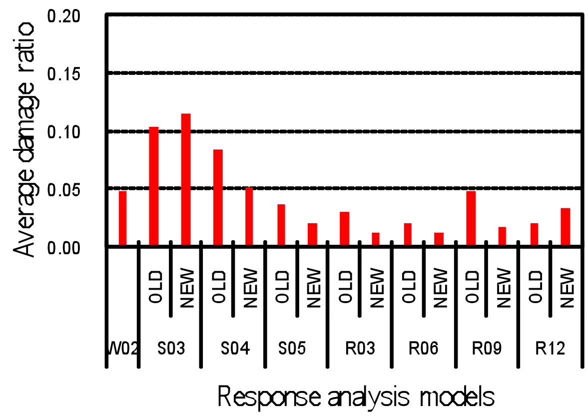


Fig. 8 Comparison of average damage ratio between building models.

For each response analysis model, Fig. 9 compares changes in the rate of analysis points within given damage ratio ranges, from sites with low damage ratios, to sites with high damage ratios. The vertical axis is the response analysis model, and the horizontal axis shows the rate of analysis points made up by sites with calculated damage ratios from 0-10%, 10-20%, 20-30%, and above 30%. Buildings with old earthquake-resistance have higher possibility for the damage ratio to exceed 30%, as was the case for the average damage ratios. Steel-frame buildings had the highest values, followed by wooden and then RC buildings.

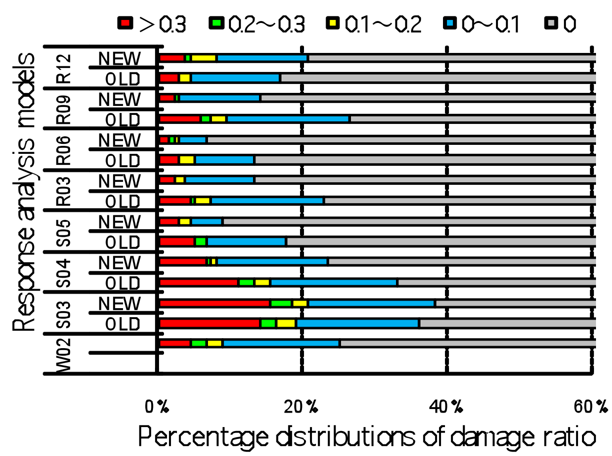


Fig. 9 Comparison of percentage distributions of damage ratios.

DISCUSSION AND CONCLUSION

In this paper, we applied the statistical Green's function, which is effective for long-period waves, and a source fault model with heterogeneous rupture to calculate strong ground motion from a hypothetical Tonankai earthquake in the Kinki-Chubu region. As a result, the predicted distribution of seismic intensity scales from strong ground motion waveforms was almost identical to research results in the past and estimated strong ground motion of destructive earthquakes. On comparing the obtained PGA and PGV with an empirical attenuation relation, variation was small and on average they matched well, and overall we obtained results that were an improvement on the previous study. A major factor in this was the fact that we considered further heterogeneity in the hypothesized asperities in the mega-thrust earthquake fault model.

Next we input the strong ground motion from this hypothetical Tonankai earthquake into a non-linear response analysis model, and conducted a building damage prediction for wooden, low-rise steel-frame, and mid-to-low-rise RC buildings in the Kinki-Chubu region. As a result, we found that in places with comparatively soft ground such as the coastal areas and alluvial soil areas along rivers in Aichi, Shiga, Mie, and Wakayama Prefectures, there is some possibility of 'heavy' damage regardless of the type of building. Further, our calculated damage ratios were high in places where the Central Disaster Management Council (2003) estimated a large number of buildings would be damaged by a hypothetical Tonankai earthquake, and our building damage distribution was corresponding. On using response analysis to compare the damage ratio distributions for buildings with old and new earthquake-resistance, and by structure type, we found that old earthquake-resistance buildings were associated with higher damage ratios than new earthquake-resistance, and steel-frame buildings had the highest values, followed by wooden buildings and finally RC buildings. Even among the group of target analysis sites with damage ratios over 30%, damage ratios were higher for old earthquake-resistance than for new earthquake-resistance, and steel-frame buildings had the highest values, followed by wooden and finally RC buildings. At the very least, these results indicate that in preparing damage mitigation measures such as seismic reinforcement for a Tonankai earthquake, areas that are either close to the seismic source or that have soft ground should be prioritized.

In future, we will use output level and building stock statistics based on building damage predictions shown here to assess the environmental load caused by earthquake damage from a hypothetical Tonankai earthquake. Further, from the total building damage in the seismic source region, we will predict the number of fatalities, casualties and people left homeless, the societal impacts, etc. In the environmental load predictions we will calculate the amount of building waste and destroyed household products, and the resources and energy required for environmental restoration, as well as the CO_2 emissions. In this damage prediction, the damage ratio is a function of real seismic performance of buildings, enabling a quantitative assessment of the degree to which the above-mentioned building damage, human damage, and societal damage could be reduced given certain improvements in the seismic performance of buildings in the region.

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