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# GROUND MOTION PREDICTION IN OSAKA BASIN, CENTRAL JAPAN, BASED ON GEOLOGICAL, GEOPHYSICAL AND PALEOSEISMOLOGICAL DATA AND NUMERICAL SIMULATIONS OF EARTHQUAKE RUPTURE AND GROUND MOTION

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## SUMMARY

Active Fault Research Center, GSJ/AIST conducts a project of ground motion prediction in the Osaka sedimentary basin, southwest Japan from future large earthquakes that have high potential to cause considerable damage there. Our goal is to make a high quality prediction by incorporating geological, geographical and geophysical survey data.

Our ground motion prediction work is characterized by a detailed 3D structure model of the Osaka sedimentary basin and rupture scenarios generated by dynamic rupture simulations under constraints of geological data about active faults.

For a reverse fault in the study area, the Uemach fault system, we compiled paleoseismological data and constructed a model of coseismic stress drop distribution. The stress drop distribution model was incorporated into the dynamic rupture simulation to obtain spontaneously propagating earthquake rupture scenarios. Ground motions generated by the rupture scenarios, up to 1 Hz, were calculated with the 3D finite difference method in the 3D Osaka basin structure model. We found that the heterogeneous initial stress drop controls rupture process and the effect is directly reflected in the ground motion distribution.

## INTRODUCTION

### Our focus in ground motion prediction

Taking advantage of abundant data on active faults that we have accumulated through our active faults studies, we develop methods for high quality ground motion prediction by including as much geological data on active faults as possible. Therefore, we construct a detailed 3D subsurface structure model

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compiling the latest geophysical survey data. For rupture scenarios we perform dynamic rupture simulations under constraints of geological data about active faults.

**Study area**

The study area of ground motion prediction is 90 km in EW direction and 85 km in NS direction. It contains, at its center, an elliptically shaped Osaka sedimentary basin which is surrounded by Ikoma, Rokko, Izumi Mountains and Awaji Island. The basin is filled with sediments of Osaka Group, terrace deposits and alluvium layers; the thickness of the sediments ranges around 1000 to 3000 m at the center. The basin is bordered by active faults on its eastern, western and northern margins. Several active faults also exist inside the basin under the thick sediments.

**Historical disastrous earthquakes**

The possible sources of disastrous earthquakes for the study area are active faults bordering or lying inside the basin, the plate boundary about 200 km to the south of the basin (the Nankai trough) and inside the subducting Philippine Sea Plate. Looking back the past, the 1995 Hyogo-ken Nanbu, or Kobe, earthquake (M7.2) occurred on the Rokko fault system hemming the northwestern margin of the basin, generated ground motion of up to 7 on the JMA scale along the northwestern margin of the basin. The 1707 Hoei-Nankai earthquake (M8.4), the historically recorded largest earthquake on the Nankai trough, is estimated to have brought ground motion of about JMA intensity 6 in the Osaka basin and even intensity 7 along the eastern edge of the basin. The 1952 Yoshino earthquake (M6.8) occurred at about 10 km to the east of the study area, 60 km depth inside the subducting plate, and caused 2 deaths and 9 complete collapses of buildings in Osaka prefecture.

In this paper, we show our Osaka basin structure model, our unique method of rupture scenario modeling, and prediction of rupture scenarios and ground motion for the Uemachi fault system which lies inside the basin.

## VELOCITY STRUCTURE MODELING

**3D Osaka basin structure model**

A 3D structure model of the Osaka basin was constructed based on geological and geophysical data obtained by reflection surveys, borings, gravity measurements. The model consists of mesh data of 100 m and 50 m intervals in horizontal and vertical directions, respectively (Horikawa et al., 2003 [1]). The model is 90 km in EW direction, 85 km in NS direction and down to 3 km depth. The area was divided into several geological blocks separated by major faults. Depth variation of key sedimentary layers and basement floor were modeled inside each block, and discontinuities of those layers and basement floor were allowed at the block boundaries. Therefore, shapes of those layers, including overhang at reverse faults, are realistically expressed. Fig. 1 illustrates the depth to the top of the basement. Medium constants such as P- and S-wave velocities and density were given to each grid point based on empirical relations among P- and S-wave velocities, density, depositional age and depth. For a calibration of the model, we compared the observed and simulated waveforms from a small (M~4) earthquake in the frequency range up to 0.3 Hz (Fig.2, Horikawa et al., 2003 [1]). The ground motions recorded by CEORKA (The Committee of Earthquake Observation and Research in the Kanasai Area) and F-net (National Research Institute for Earth Science and Disaster Prevention) were used in the comparison. The amplification and duration of direct waves, overall features of later phases (basin induced surface waves) are well reproduced at many stations.

**Alluvium layer structure model**

Shallow borehole data in Osaka prefecture are compiled and organized into a subsurface structure model (Yamamoto, personal communication). Alluvium layer structure (stratigraphic classification, layer thickness and N-value) is modeled at 500m interval mesh points. P- and S-wave velocities and densities are evaluated using empirical relationships among these values and N-value for this region.

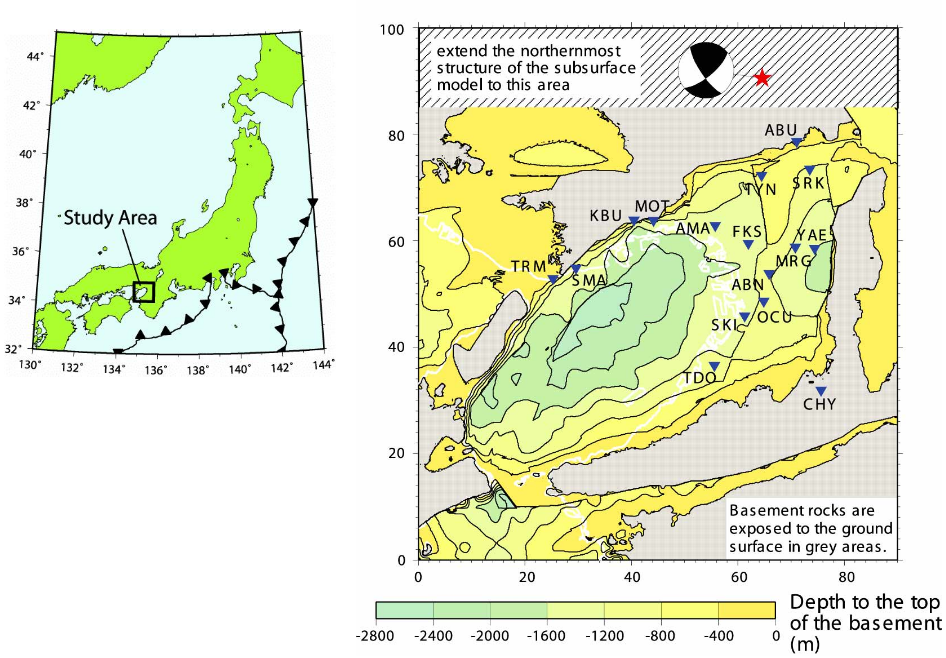


**Fig. 1 Depth to the top of the basement. The star shows the epicenter of a M~4 event whose records are shown in Fig. 2. The inverted triangles indicate the observation stations of CEORKA and F-net (ABU) (after Horikawa et al., 2003 [1]).**

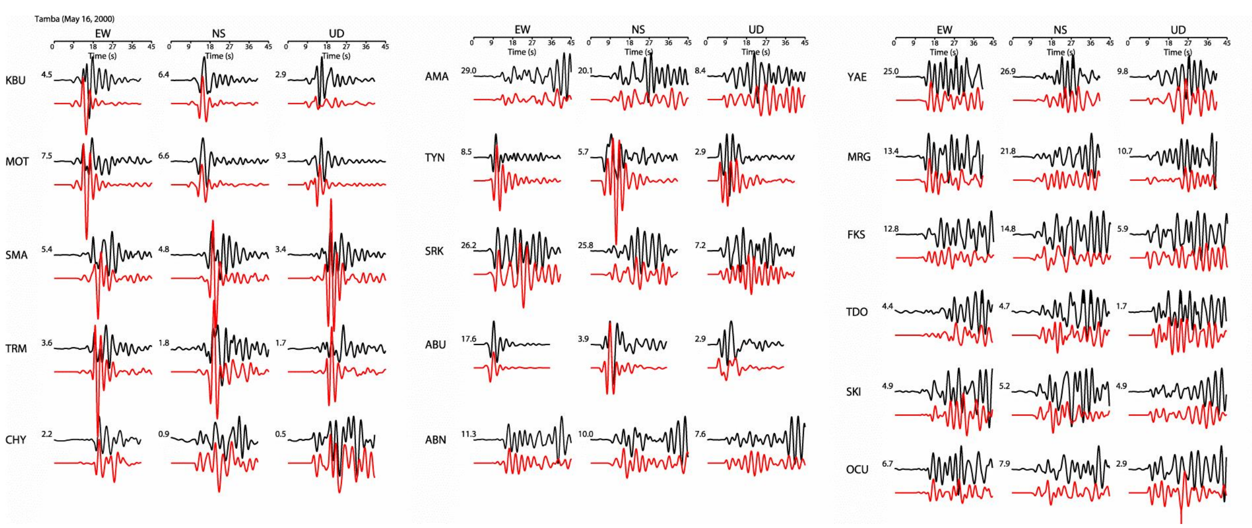


**Fig. 2 Comparison of observed (black) and sythetic (red) waveforms for the M~4 event shown in Fig. 1 (after Horikawa et al., 2003 [1]).**

## HOW TO CONSTRUCT RUPTURE SCENARIOS ON ACTIVE FAULTS

**Strategy**

We have proposed a method to estimate heterogeneous rupture models for scenario earthquakes from displacement distributions of past earthquakes measured along active faults (Sekiguchi et al., 2003 [2], Kase et al., 2003 [3]). This is based on an assumption that rough features of slip distribution of earthquakes repeatedly occurring on an active fault are similar if regional stress field is temprallily constant. In other words, we expect that long-wavelength components of heterogeneity in rupture process is stable over geological (10e+6 yrs) time scale and must have been reflected in slip distribution of past earthquakes. Lindvall et al. (1989) [4] and Sieh and Jahns (1984) [5] have shown that displacement distributions on surface ruptures are always similar, which supports our assumption. From comparison of measured surface ruptures and inverted slip models for recent large earthquakes we infer that a slip distribution at a shallow portion on a causative fault is reflected in the displacement distribution along its earthquake surface rupture (Figs.3 and 4).

**Method of construction**

First, we construct a slip distribution model. We assume that static slip varies along fault strike in a similar way to coseismic displacement on surface traces. Along the downdip direction, we assume a distribution similar to those of recent, well-analyzed earthquakes. The slip gradually converges to zero at the bottom of the seismogenic zone. The slip distribution is then converted to static stress drop distribution with the formulation of Okada (1992) [6].

The static stress drop distribution and a rupture initiation point somewhere on the fault plane are incorporated into the dynamic rupture simulation. Spontaneous rupture propagation on the fault plane is simulated by the finite difference method (Kase et al., 2002 [7]) assuming slip-weakening friction law on the fault plane.

**Application to Uemachi fault system**

The Uemachi fault system, a 45 km long, reverse-type active fault system lies beneath the Osaka basin. Only one measurement about coseismic displacement of past earthquakes is available, but average uplift rate was estimated at several points along this fault system from cumulative displacements (e.g., Osaka City, 1997 [8]; Sugiyama 1997 [9]; Osaka Prefecture 1999 [10]; Mitamura and Yoshikawa, 1999 [11]; Uchiyama et al., 2001 [12] etc.). Therefore, we derived a relative variation of a slip distribution from the distribution of average uplift rate and estimated the absolute values of slip from the coseismic displacement data (Fig. 4). When we assume a constant earthquake recurrence time along the fault strike, we obtain two peaks in thec slip distribution, which indicate asperities. We assume slip spreading over the whole depth range.

Several rupture scenarios were computed from the static stress drop model (Kase et al., 2003 [3]) by the 3D finite difference method (Kase et al., 2002 [7]) which deals with inclined fault planes. Rupture initiation points were assumed at peaks of the static stress drop distribution. Details of the rupture scenarios are given in the next chapter with the resultant ground motion.

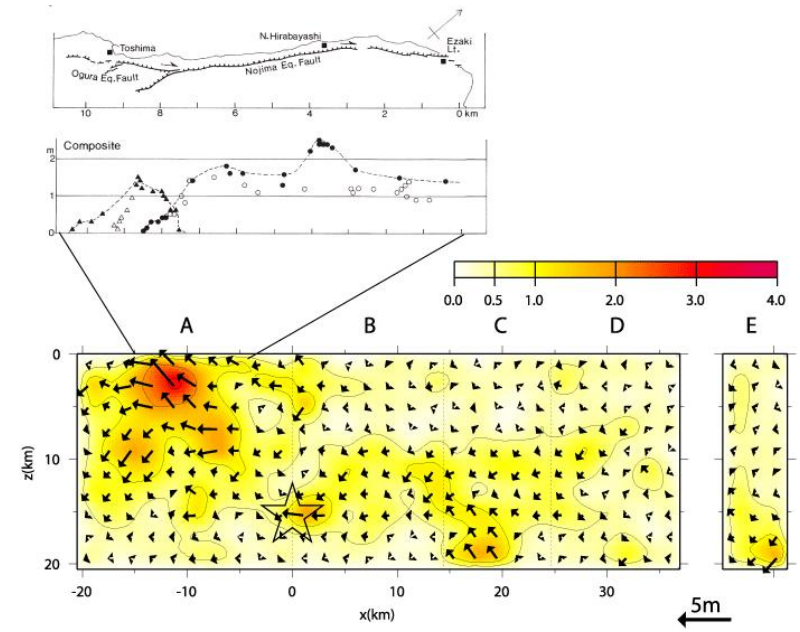


**Fig. 3 Displacement distribution on surface rupture (Awata et al., 1996 [13]) and slip distribution over the fault plane inferred from strong motion records (Sekiguchi et al., 2002 [14]).**

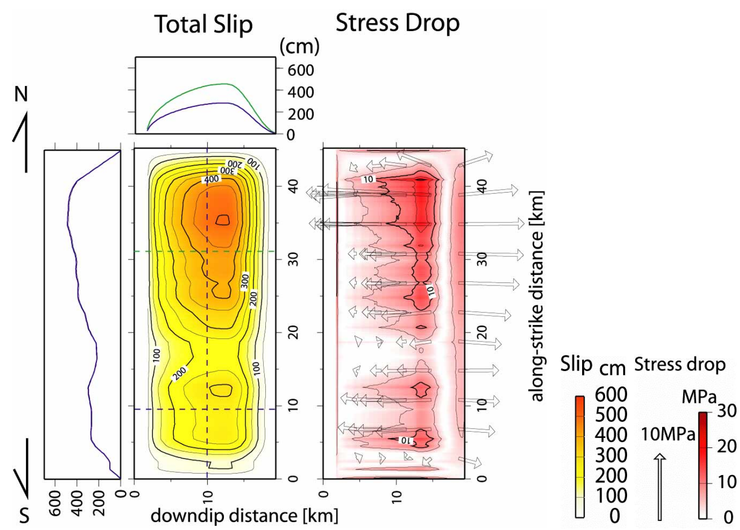


**Fig. 4 Static slip model and static stress drop model for the Uemachi fault system.**

## GROUND MOTION PREDICTION

Ground motion in the 3D Osaka basin was computed by the 3D finite difference method (Pitarka, 1999 [15]). Slip histories on the fault plane obtained by the dynamic rupture simulation are represented in terms of stress histories at grid points in the source region. Ground motion on engineering basement up to 1 Hz was computed considering media with S-wave larger than 0.55 km/s.

Effect of the shallow alluvium layers is calculated by 1D multi-reflection theory using a computer code DYNEQ (Yoshida and Suetomi, 1996 [16]). This code can evaluate nonlinear response of the ground, but here we consider linear response only.

**Predicted rupture scenarios and ground motion distributions for the Uemachi fault system**

When a rupture initiation point is assumed at a peak of the static stress drop near the northern margin of the fault plane, the rupture goes through a barrier of low stress drop part near the center and reached the southern margin. Strong ground motion area expands over the whole length of the fault system (Fig. 5). The largest ground motions appear near the southern end of the north asperity owing to the mixed effect of rupture propagation directivity, heterogeneous slip distribution, and amplification in sediment layers. When a rupture initiation point is assumed at a peak near the southern margin of the fault plane, the rupture does not go through the barrier. In this case, the strong motion area is limited near the southern part of the fault system (Fig. 6).

Comparing the distributions of peak ground velocity on engineering basement and above alluvium layers, we find that the superficial alluvium layers amplify the peak ground velocity by a factor of two or three (Fig. 7). But this ground motion may be overestimated because this calculation does not consider nonlinear response of the ground.

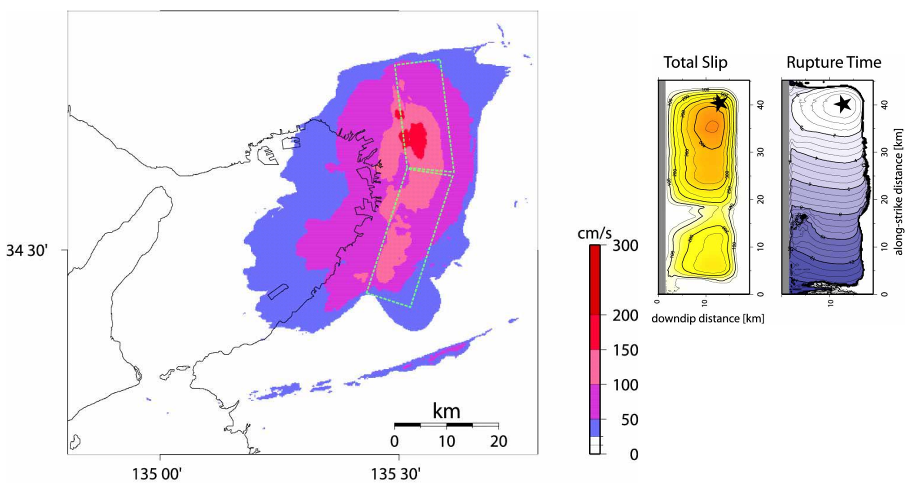


**Fig. 5 Right: Final slip and rupture time distributions of a rupture scenario for the Uemach fault system when a rupture initiation point (star) is assumed near the north margin of the fault system. Left: The peak ground velocity (vector summation of three components) distribution.**

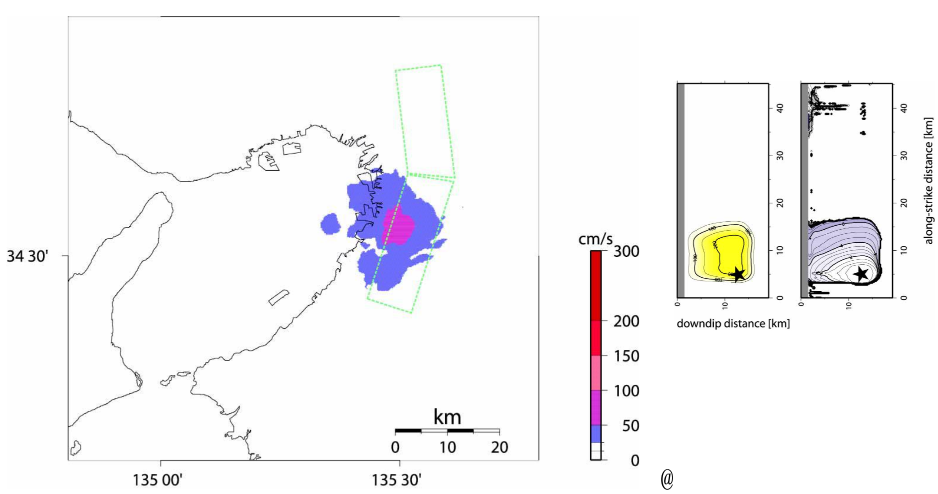


**Fig. 6 Same as Fig. 5 except that a hypocenter is assumed near the south margin of the fault system.**

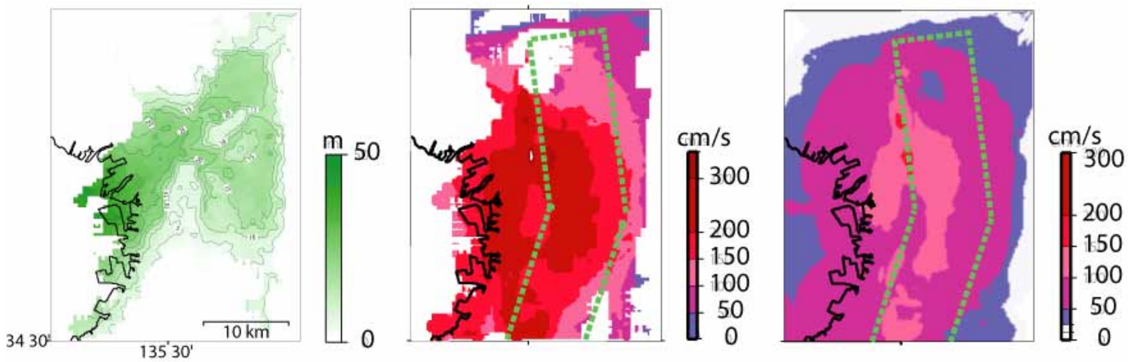


**Fig. 7 Left: Alluvium layer thickness by Yamamoto (personal communication) in the central part of Osaka. Center: Peak ground motion distribution of the vector summation of two horizontal components when the response of alluvium layers are included. Nonlinear response is not considered and therefore the values may be highly overestimated. Right: Same as the case of Fig. 5, but the vector summation of horizontal two components are shown here.**

## CONCLUSION

In our ground motion prediction, we construct a subsurface structure model that precisely reflect the results of geophysical surveys. Rupture scenarios are constructed by dynamic rupture simulation by directly incorporating geological information in order to realize fault-specific features of source process. In the prediction of rupture scenarios and ground motion for the Uemachi fault system, we found that the heterogeneous initial stress drop controls rupture process and the effect is directly reflected to the ground motion distribution. Therefore, it is important in ground motion prediction to model heterogeneity of slip or stress distribution. Paleoseismological information of active faults may help us deterministically constrain long-wavelength (>~10km) heterogeneity of coseismic slip distribution. However, shorter wavelength heterogeneity needs to be modeled stochastically.

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