Dynamic response evaluation and seismic zoning of western Osaka plain under Nankai Trough and Uemachi Fault assumed seismic motions

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ABSTRACT

Japan has had a long history of destructive earthquakes, among which the most recent were the Great Hanshin Earthquake (1995) and the Great East Japan Earthquake (2011). In these recent years there is a concern about the occurrence of another great earthquake with the Nankai Trough as its epicenter. Preparedness is becoming crucial, especially in regions with a widespread formation of soft weak subsoil such as Osaka plain. In order to prepare for an earthquake, it's important to estimate its strength of shaking. When seismic waves travel from the fault to the ground surface through layers of subsoil, the nature of the soil strongly affects how the wave will propagate. Dynamic response analysis based on detailed geological information of the ground will help estimate the shaking intensity of future earthquakes. In this study, a total of 894 soil profiles scattered around Osaka's western plane are obtained from Kansai Geo-informatics Database. And a two-dimensional seismic response analysis is performed using DYNEQ. Uemachi fault and Nankai Trough input motion were used, and a zoning map was created based on their peak ground acceleration (PGA) amplification. From the results of the map, the regional tendencies of the soil's behavior are inspected. In addition to that, the effects of local site conditions; such as soil properties and model parameters are investigated.

Keywords: Seismic response analysis, Peak ground acceleration amplification map, Geo-informatics Database

1 INTRODUCTION

Osaka plain consists of a widespread formation of soft weak subsoil in an alteration of gravel sediments (Dg) and marine clay layers (Ma) topped by sandy sediments (As) (Geo-Database Information Committee of Kansai, 2007). The alluvial soils can strongly influence the characteristics of ground shaking. They can amplify the shaking for some areas and cause a high risk on land, buildings and infrastructure. They can also de-amplify the shaking in other areas. For the purpose of disaster prevention, learning about the condition of the ground is crucial. In order to evaluate earthquake hazards based on the ground characteristics of the area, it is necessary to obtain the nonlinear response of the ground considering the dynamic deformation characteristics of the ground material.

2 METHODOLOGY OF THE ANALYSES

2.1 Analysis Model

The soil profile is shown in Figure 1. The input motion is originally defined at the base layer (Dg4). However, in order to conduct the seismic response analysis with a detailed soil profile calculation is performed in 2 steps:

Step1: To insert the earthquake wave in the lower model. The lower model is a 500m mesh with 50m thickness for each element starting from (Dg4) at the bottom to (Dg2) at the top.

Step2: To use the obtained new wave for the dynamic response of the ground surface. The upper model is a 250m mesh with an element thickness of 1m starting from (Ma12) at the bottom to (As) at the top. For each four adjacent 250m mesh points the lower model (500m mesh) and the input waves are the same.

2.2 Input motion

Osaka region is expected to be affected by the anticipated Nankai Trough earthquake. Therefore, the anticipated (TNN) wave was chosen. In addition to that, Osaka region itself has several seismically active faults among which one of the biggest is Uemachi Fault. Therefore, the anticipated (UMT) wave was chosen. Waveforms of the input motions are shown in Figure 2. It can be seen that the duration of the inland earthquake (UMT) is short, but the intensity is large. Contrary to the trench type earthquake (TNN) which has a long duration and lower intensity. It's however to be noted that each 500m mesh has its own acceleration waveform. The input waves cover a wide range of amplitudes. The acceleration ranges from 1.2 m/s^2 to 3.5 m/s^2 for (TNN) and from 2.9 m/s^2 to 13.2 m/s^2 for (UMT) (Osaka Prefectural Government, 2007). The analysis is two dimensional, both east-west (EW) and north-south (NS) components of the seismic waves are used.

2.3 Model Parameters

In order to consider the nonlinear behavior of the soil various models are used for the dynamic response analysis of the ground such as Hardin-Drnevich (HD), Ramberg-Osgood (RO) and the double hyperbolic (DHP) models (Yoshida, 1995). The results of different dynamic deformation test data in Osaka area were analyzed (Goto, 2018) and the HD model with the parameters on Table 1 was found to best fit the test data among the three models. Therefore, the HD model was adapted for this research (Yoshida, 1995).

$$h = \max\left(h_{max}\left(1-\frac{G}{G_0}\right), h_{min}\right) \qquad (1)$$

$$\frac{G}{G_{max}} = \frac{1}{1+\frac{\gamma}{\gamma_r}} \qquad (2)$$

Table 1. H-D model parameters.

	As	Ma13	Dg1	Ma12
γ_r	0.00286	0.00204	0.00115	0.00316
h_{max}	21.6	20.8	20.9	19.2
h_{min}	3.0	3.0	1.2	2.3

3 ANALYSIS RESULTS

PGA amplification was calculated at 894 points for (TNN) and (UMT) waves. The analysis results show that it varies between 1.0 and 4.4 for (TNN), and 0.3 and 2.7 for (UMT). There is significant difference in the response to the two waves. The soil amplifies greatly in the case of (TNN), but only slightly or even de-amplifies in the case of (UMT) (Figure 3).

Uemachi Fault earthquake deamplifies in the majority of the points. As the earthquake has a very large amplitude, it can be assumed that the soil is displaying a nonlinear behavior. In order to confirm this, (UMT) amplitude was reduced to the 10th of the original amplitude at ten random points. A sudden increase in PGA was noticed. It can be concluded that the deamplification of (UMT) is due to the nonlinear behavior of the soil.

On the other hand, it's observed that the two earthquakes show the same trend, the eastern area shows a strong amplification while the northern and western areas show a comparatively lower amplification. Therefore, to study the soil's response to both earthquakes, the study area is divided to: West, North and East

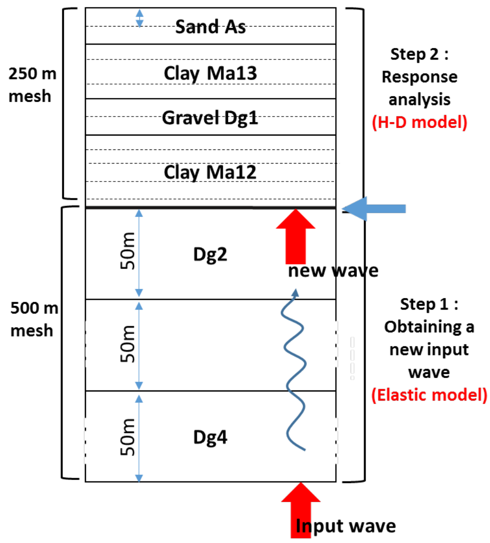

Fig. 1. Analysis model.

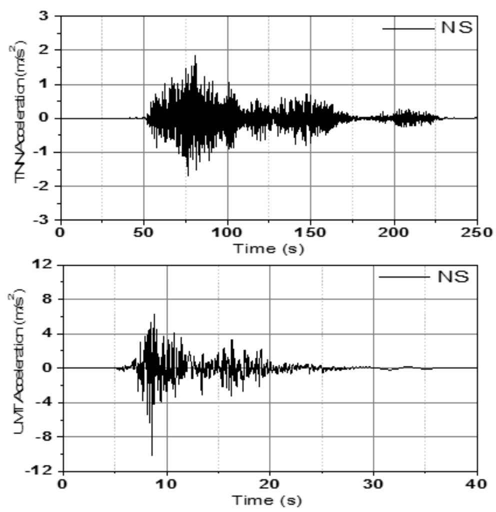

Fig. 2. (TNN) and (UMT) input motion waveforms.

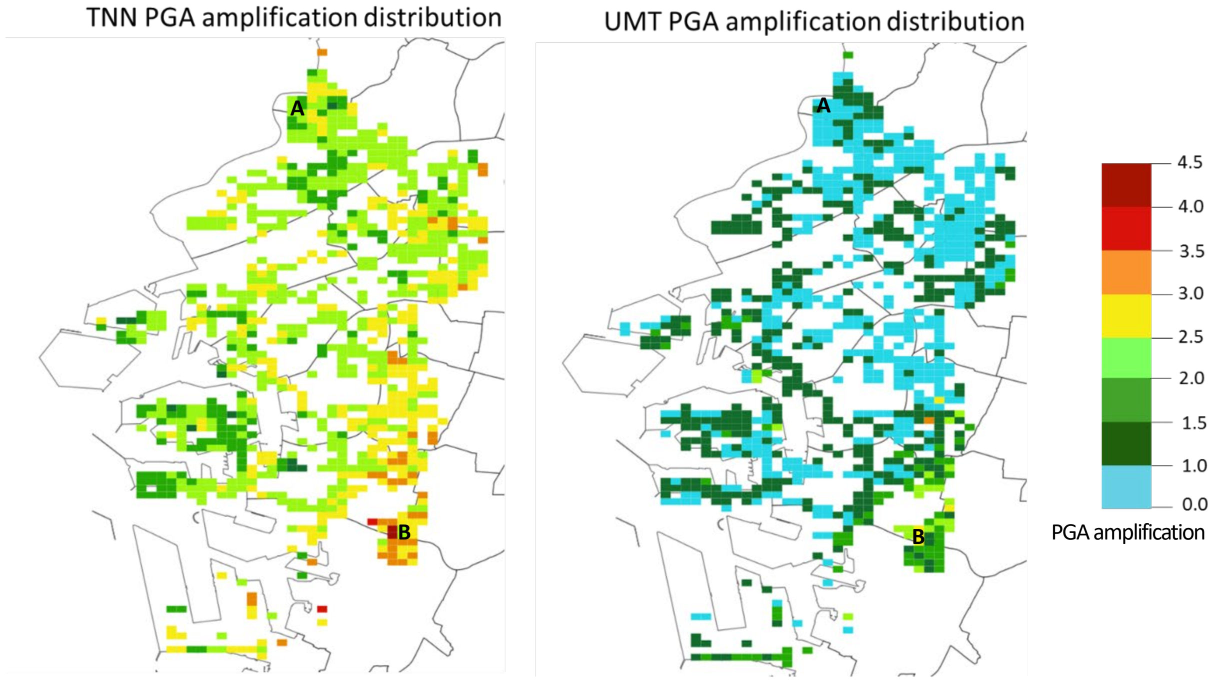

Fig. 3. Nankai Trough and Uemachi Fault earthquakes PGA amplification zoning maps

4. DISCUSSION

4.1 Resonance investigation

During earthquakes, the largest amplification occurs when the soil's natural period T_S coincides with the wave's predominant period T_W and that is called resonance. Representative points are chosen in each region, and resonance behavior is investigated.

Table 2. Period characteristics of the western area (TNN).

West	H (m)	PGA	T_W (s)	T_S (s)
1	63	1.5	0.6	1.3
2	64	1.6	0.6	1.3
3	64	2.0	0.7	1.3

Table 3. Period characteristics of the northern area (TNN).

North	H (m)	PGA	T_W (s)	T_S (s)
4	25	1.8	1.1	0.7
5	24	1.7	1.1	0.6
6	30	2.0	1.1	0.6

Table 4. Period characteristics of the eastern area (TNN).

North	H (m)	PGA	T_W (s)	T_S (s)
7	24	2.7	0.3	0.4
8	22	3.5	0.3	0.4
9	21	3.0	0.4	0.5

The western area (Table 2) located by the bayside has thick sedimental deposits resulting in a long natural period of the soil, on the other hand the wave's strongest component has a short period. The soil's natural period and the wave's predominant period don't match, which may explain the low amplification. The same thing can be said about the northern area (Table 3) which has a short natural period of the soil and a long predominant period of the wave.

The eastern area (Table 4) adjacent to the mountains has thin sedimental deposits resulting in a short natural period of the soil, on the other hand the wave's strongest component has a short period as well. The soil's natural period and the wave's predominant period match causing resonance within the soil. This may explain the exceptionally strong amplification.

The same as previously, the two periods are compared for Uemachi Fault earthquake in selective points around the different regions. Resonance behavior was observed in the eastern part of the study area.

4.2 Effect of soil properties and model parameters

Layer properties and model parameters were found to have an important influence on the soil's response. Layer properties imply the layer's stiffness or shear modulus G_0. Regarding the ranking of the soil types, generally alluvial gravel (Dg1) has the highest stiffness, followed by diluvial marine clay (Ma12) and then alluvial sand (As) and alluvial marine clay (Ma13).

The second most important parameter is the referential shear strain γ_r. It's one of the HD model parameters. A low referential shear strain means that the soil will behave nonlinearly under high shear stresses. Marine clay (Ma12) has the highest γ_r, followed by sand (As), marine clay (Ma13) and then gravel (Dg1). In this part, representative 500m meshes where the soil behaves differently are chosen (Fig.3). The properties of the soil are investigated within each point of the mesh to find their influence on the soil's behavior.

Mesh A

This mesh shows the most discrepant behavior in the study area. For both earthquakes points ① and ③ show a much higher amplification than points ② and ④. Figure 3 shows the example of (TNN). The highly amplified points contain only (As, Ma12) layers. We also can see from the acceleration distribution that when the wave reaches the lower border of the sandy layer (As), the acceleration increases sharply in points ① and ③. Looking at the stiffness diagrams, that sharp acceleration is found to be due to the lower stiffness of (As) at those points. What can be concluded is that due to their high referential strain, the waves amplify with greatly in the clayey layer (Ma12) and sandy layer (As) comparing to the gravel layer (Dg1), especially when these layers are soft.

Mesh B

In mesh B (Figure 4) we notice a slight amplification at points ① and ②, while point ③ deamplifies. The deamplification in point ③ is due to the nonlinear behavior in the clayey layer (Ma13). When (Ma13) layer is present it attenuates the earthquake motion resulting in a low amplification of the (TNN) wave and a total deamplification of the (UMT) wave.

4.3 Geological explanation

There are two geological explanations as to why the motion amplifies greatly in the southern area.

1) The predominance of (Ma12) and absence of (Ma13):

The south eastern area happens to be adjacent to the Uemachi plateau, it's an elevated land where the marine tides didn't reach and the marine clay (Ma13) was not deposited. As seen before (Ma13) layer attenuates the motion, its absence in the south eastern area is part of why the amplification is high.

2) The thinness of deposits:

The area is right above Uemachi fault where the Uemachi plate is being lifted causing the (Dg2) layer to be at a shallow depth. The wave being input at a shallow depth where the deposits are thin (20m) has no chance to attenuate. These two geological processes make the eastern area the most prone to motion amplification within the study area.

5. CONCLUSION

Dynamic deformation analysis is performed for 894 points through western Osaka area for two waves. (UMT) wave shows less amplification than (TNN) wave due to the soil's nonlinear behavior. The eastern area shows a large amplification response to both waves. It is found to be due to the resonance behavior and also the geological formation of the area. The eastern area has an absence of marine clay (Ma13) which attenuates the motion and a predominance of marine clay (Ma12) which amplifies the motion making it the area most prone to motion amplification in western Osaka plain.

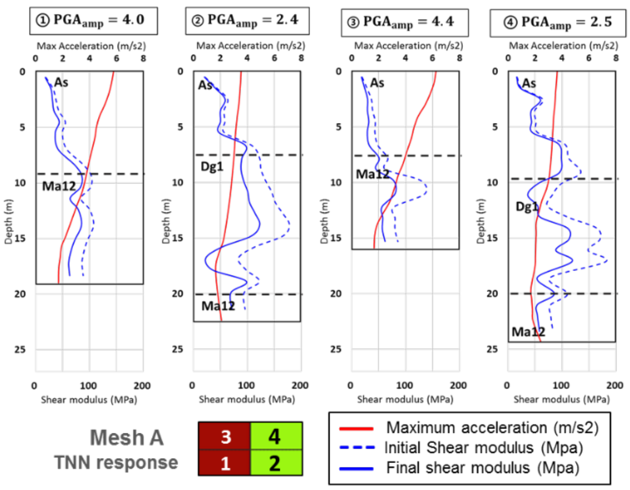

Fig.3. Mesh A max acceleration and shear modulus distribution (TNN).

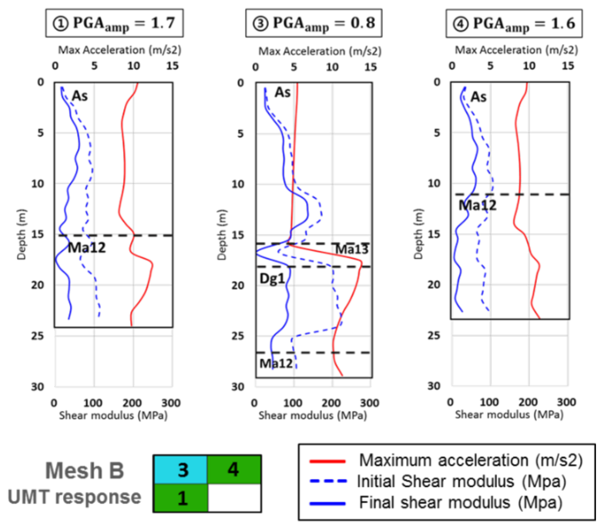

Fig.4. Mesh B max acceleration and shear modulus distribution (UMT).

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