EFFECT OF THE GEOLOGICAL IRREGULARITIES ON THE INPUT MOTION AND SEISMIC RESPONSE OF AN 8 STOREYS STEEL REINFORCED CONCRETE BUILDING CONSIDERING SOIL-STRUCTURE INTERACTION

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ABSTRACT

This study investigates the effects of the geological irregularities on the input motion and seismic response of an 8-storey steel reinforced concrete building considering the soil structure interaction. The motivation regard on the seismic response characteristics observed in the North and South sites of the Iwaki City Hall in a distance of just 130 m during the aftershock of the March 11th, 2011 Great East Japan Earthquake. 2D Finite Element Models (FEM) were used to simulate soil and structural responses considering inclined engineering bedrock beneath the building. The 2D FEM represent the seismic response in good agreement with the observed records of the aftershocks. The dynamic characteristics of the soil responses at the North and South site are different mainly due to the soil condition beneath each site, though, the parametric study revealed that the effect of the inclined interface of the engineering bedrock has a minor influence on the seismic soil response. Moreover, it was found and equivalency between the inclined engineering bedrock model and other model considering flat-soil layers, and the input motion and seismic response of the structure were similar.

Keywords: Geological Irregularities, Inclined Engineering Bedrock, Soil-Structure Interaction, Piles.

1. INTRODUCTION

It has been recognized that the dynamic behavior of a building structure during an earthquake is considerably affected by the geological formation and the properties of the soil medium. In particular, the geological and topographical irregularities in the soil structure seem to have effect on the characteristics of the earthquake ground motion and also on the associated structural damage of buildings.

In this sense, in the seismic analysis of a structure founded on rock, the motion experienced by the foundation is basically identical to that occurred in the same point before the structure was built. However, for soft soil sites the incident waves produce two important modifications, the former, the free-field motion at the site without structure is strongly affected; the latter, the presence of the structure modifies the entire scenario of the seismic response. The structure will interact with the surrounding soils which lead to a further change of the seismic motion at the base. This scenario becomes interesting if the geological conditions change drastically as this study presents.

2. IWAKI GOVERNMENT BUILDING SITE OUTLINE AND STRONG MOTION OBSERVATION

2.1. Strong Ground Motion Characteristics of the Target Site

With regards to the motivation of this study, it came from the observation of the strong ground motion records of the aftershocks from the March 11th, 2011 Great East Japan Earthquake obtained in the Iwaki Government Building site. Example of the response spectra observed is show in Figure 1. At the

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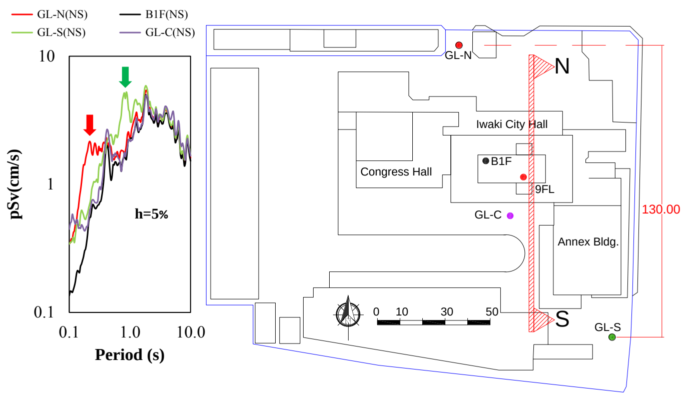

Figure 1. Response Spectrum of the North-South Direction in the Iwaki Government Building Site due to the 2011/07/10 Aftershock in Off Sanriku

North site the predominant period occurs in the short period range (0.2s), while at the South site the predominant peak is around 0.9s; this phenomena happens in a distance of just 130 meters.

2.2. Outline of the Target Building and Aftershock Observation

Figure 2 presents the location of the Iwaki Government Building; this construction is located in Iwaki city, Fukushima prefecture, Japan. It consists of three buildings: the congress hall, the city hall and its annex. The target building (the city hall) consists of 8 storeys, 1 basement and 2 penthouses. The foundations are made of steel-concrete piles resting on an irregular shape of engineering bedrock.

3. ANALYSIS OF THE SEISMIC RESPONSE OF THE IWAKI CITY HALL CONSIDERING SOIL-STRUCTURE INTERACTION MODELS

3.1. 2D Finite Element Model Process

The scope of this thesis is based on the 2D Finite Element Model of the soil and building structure. The commercial software named Finite Element Modeling and Postprocessing (FEMAP) version 10.0.2 was used, as well as several non-commercial programs developed by the supervisor of this thesis Dr. Masayuki Nagano.

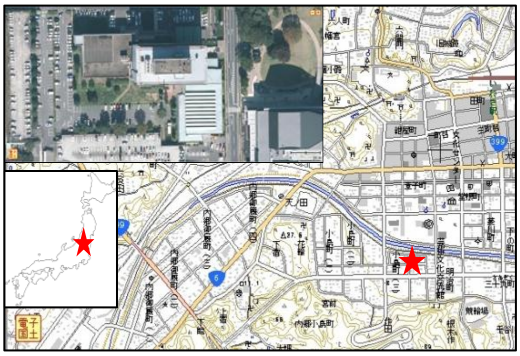

Figure 2. Location of the Iwaki Government Building

In order to create the model, it was necessary to have the geological data and the drawing plans, and furthermore, the geological data used in the models was not only from the Iwaki Government Building site but also from the annex construction.

Figure 3 shows the depth and the contour curves of the engineering bedrock assumed in the modeling process; the 8 red points represent the site where the Standard Penetration Test (SPT) was conducted. Also, it is visible how in a short distance in the north-south direction the depth of the engineering bedrock varies; being shallower in the north area. This fact leads to take the N-S direction for study.

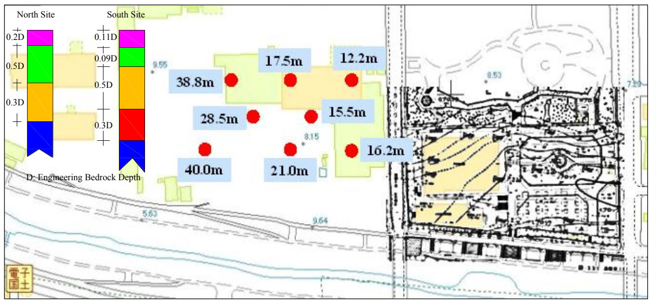

Figure 3. Depth of Engineering Bedrock Taken in the Modeling Process and Stratum Ratio

Table 1. Mechanical Properties of the Soil Layers

Layer	Vs (m/s)	ρ (t/m3)	ν	h(%)
1	110	1.6	0.494	2.0
2	150	1.8	0.461	2.0
3	110	1.8	0.494	2.0
4	310	1.8	0.474	2.0
5	410	1.6	0.491	2.0

The next step was to take the target points and set the control point as well; i.e. GL-N, B1F, 09F, GL-C and GL-S and the control point was B1F. Also, with regard to the thickness of the soil layers the assumption made was a relation of 20%, 50% and 30% for the north side and 11%, 9%, 50% and 30% for the left side as Figure 3 also shows. This assumption was taken accordingly to the SPT tests obtained in the Iwaki Government site.

Regarding the frequency, it was considered for the model to be a range from 0.1 up to 10Hz, then, the finite element sizes were obtained in accordance with the shear wave velocity of the soil layers. The shear waves velocity, soil density, Poisson ratio and damping for all the soil layers are presented in Table 1.

3.2. Preliminary 2D FE Model of the Soil-Structure

The superstructure was modeled as lump mass as Figure 4 shows, the unit area was taken as 1,566 m^2 and the weight per unit area as 1.2 t/m^2. The storey stiffness was assumed linear according to Eq. (1).

Where, *k:* stiffness of the "*i*" storey, *N:* Number of stories, m: Mass of each floor, *ω:* Natural frequency of the First Mode, in this case T=1 then ω=2π.

$$k_i = \frac{1}{2}\{N(N+1) - i(i-1)\}m\omega^2 \quad \textbf{(1)}$$

The piles as the superstructure masses were assumed as lumped in the four edges. Figure 7 presents the pile geometry.

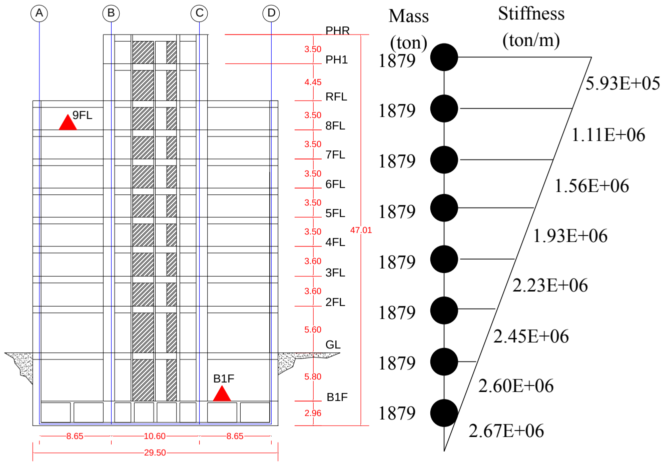

Figure 4. Geometric Characteristics of the Target Building in North-South Direction and Storey Lump Masses

The model consisted in a half space of 200m length per 100m depth. The model was conceived with transmitting boundaries at both sides, while at the bottom viscous boundary.

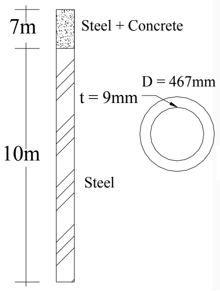

Figure 7. Pile Geometry

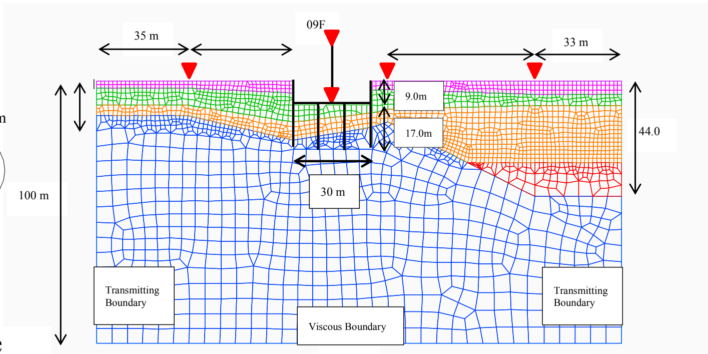

Figure 7. Preliminary 2D FE Model →

ertical propagating aves arose from the ttom to the top and the insfer functions were tained. It is important to ention that a linear alysis was carried out ice the aftershocks are t larger compared with e main shock. However, for the preliminary model, only the aftershock of July 10th, 2011 was considered since the agreement of the observed record and the 2D FE Model are not as good as what was expected.

In this sense, transfer functions were multiplied by the band passes filtered time histories from the basement (B1F) of 4 aftershocks; with this step the analytical time histories in the points GL-N, GL-C, 09F and GL-S were obtained. The following phase was plotted these function and compared those with the observed records. Figure 5 summarized the methodology.

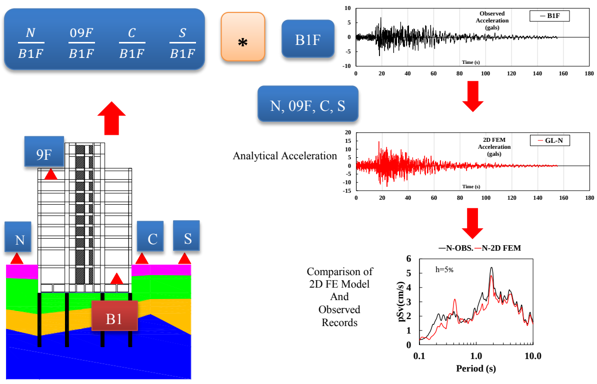

Figure 5. Flow Chart of the Modeling

3.3. Preliminary 2D FE Model Outputs

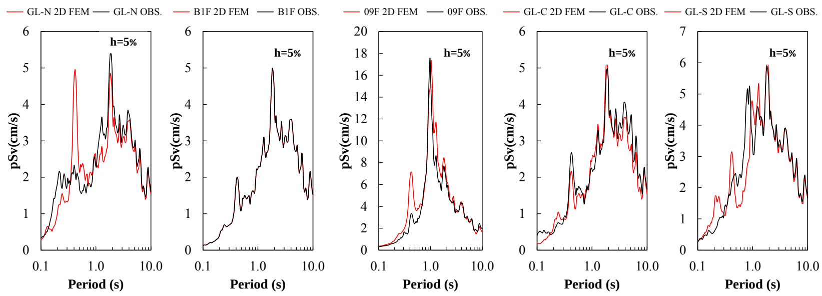

Figure 8. Comparison of the Response Spectra from the Preliminary 2D FE Model and the Observed Record, for the 2011/07/10 Aftershock in Off Sanriku

Figure 8 presents the response spectra; in all sites except for the GL-C the shape agreements are not good as expected, however, in the long period range they match. The peak in the North site is not conservative since the red line shows a predominant period of 0.4 and a large amplitude, meanwhile the observed records present a regular shape in the period less than 0.5s. In the South site the observed line presents a peak around 0.9s, while the 2D FE Model shows a peak around 1.0s and two more peaks in the short period range, which are not in agreement with the black one. The GL-C site presents good agreement in the whole spectra, just in the period less than 0.2s the line goes beyond the observed one. For the 09F site the predominant peak matches very well with the observed data, however in the period less than 0.5s the spectra overestimates the response.

The decision to create a new model was a priority; however, the question was "what should be modified?" In this sense, considering the discrepancies of the North and South site, Microtremor measurements were performed. The idea was to analyze the surface waves using the H/V spectra, adjusting the thickness of the soil layers in the target points and computing the analytical H/V analysis, so that the both shapes match in the respective period.

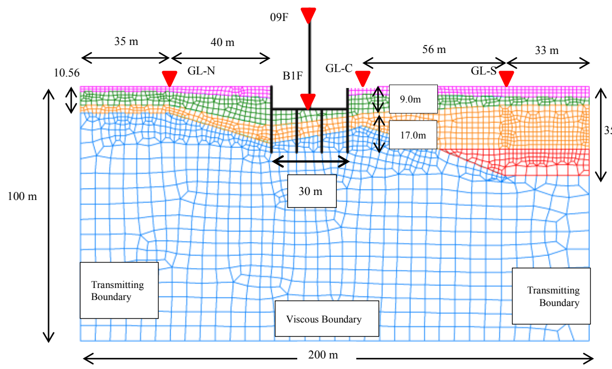

Figure 9. Modified 2D FE Model

3.4. Modified 2D FE Model of the Soil-Structure

Figure 9 presents the new model which the only parameter changed depth at the North and South sites were decrease in 20%. Only this modification was made.

The time history analysis of the 2D FE Model was performed considering 4 aftershocks. The response spectra of the July 10th, 2011 event presents concordance in the four sites (Figure 10); even though the lines did not exactly match, the tendencies were similar; else in the records of the North site it was visible that the predominant period was around 0.4 s, while in the South site it was around 0.9 s. At the point "C" the predominant period was 0.9 in both lines.

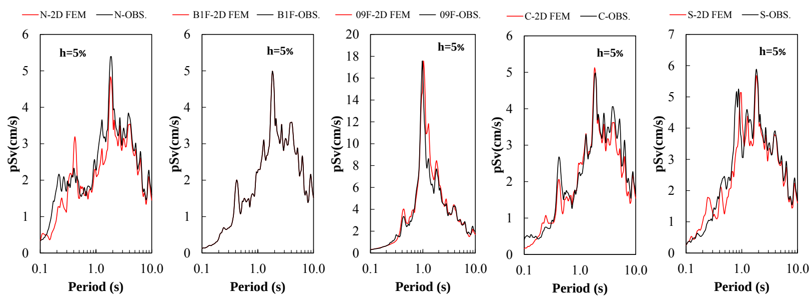

Figure 10. Comparison of the Response Spectra from the Modified 2D FE Model and the Observed Records, for the 2011/07/10 Aftershock in Off Sanriku

4. EFFECTS OF THE GEOLOGICAL IRREGULARITIES ON THE INPUT MOTION AND SEISMIC RESPONSE OF THE IWAKI CITY HALL

4.1. Effects of the Geological Irregularities in the Soil Response

Figure 12 presents the diagram of the analysis followed to investigate the effects of the geological irregularities in the input motion and seismic response of the Iwaki city hall. Two models are presented, i.e. the modified 2D FE Model and the Flat Soil Layer Model. Also, in the right side of the figures the soil profile of the control point N, C and S are presented, aiming to compare how the ground motion is affected by assuming that there is no inclination of engineering bedrock at those points.

The results are presented in Figure 11, for the "N" and "S" site the geological irregularities modifies the seismic response, however the decreasing is not remarkable.

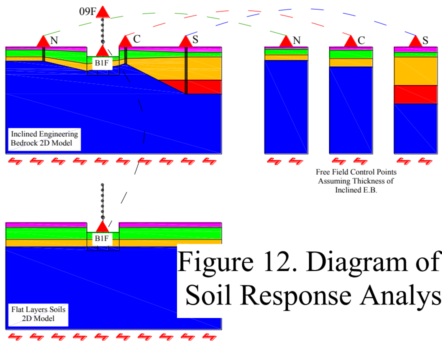

Figure 12. Diagram of the Soil Response Analysis

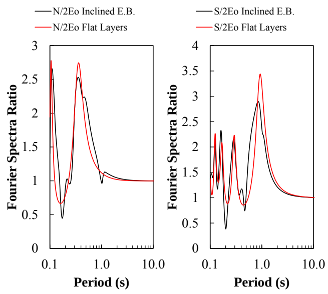

Figure 11. Comparison of Two Models in "N" and "S" sites

4.2. Effects of the Geological Irregularities on the Structural Response

Figure 13 shows the 2D FE Model considering flat-soil layers, in which the varying parameter is the depth of the engineering bedrock. Only 3 types of soil were considered, therefore the ratio of the stratums thickness was considered as 20%, 50% and 30%, also the soil properties are same as the previous model

The charts of Figure 14 show the Fourier spectra ratio of the basement for the 3 models. The Model-A (D=22.5) presents a diphase of the natural period and a remarkable increase of the amplitude. For the Model-B, assumption of the average depth of the basement sites was made, therefore the average depth between 22.5m and 17.5 m is 20m. Finally, the Model-C which represents the depth of the right side of the basement boundary shows a good agreement between the two models. The amplitude is the same and the predominant period of the inclined bedrock model is 0.5 meanwhile the flat-soil layers present it at 0.6 s.

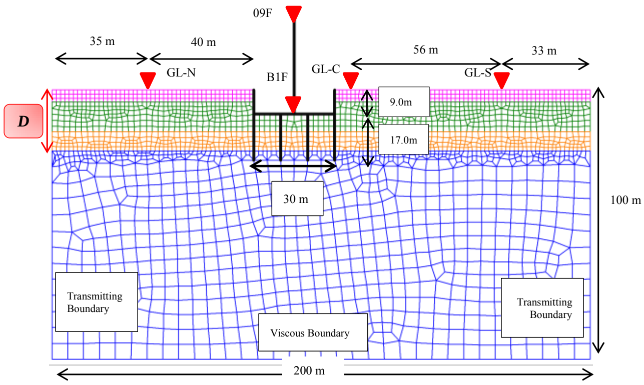

Figure 13. 2D FE Model of the Considering Flat-Soil layers.

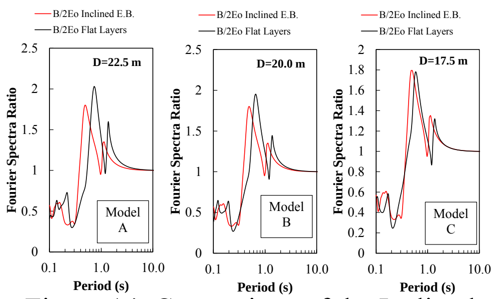

Figure 14. Comparison of the Inclined Engineering Bedrock and Flat Soil Layers Models

5. CONCLUSIONS

This study presented how the geological irregularities affects the input motion and seismic response of 8- storeys steel reinforced concrete building considering soil-structure interaction by a 2D FE Model.

The 2D FE Model used to compare the 4 aftershocks presented a good agreement with the observed data, validating the assumption of soil strata properties and stratums thickness. Also, the microtremor observation contributed in grand manner to establish the depth of the engineering bedrock at the control points.

The comparison of the response spectra on the North and South sites have differences in the predominant period, for the 4 aftershocks analyzed on the North site the natural period was around 0.4 s., while in the South around 0.9 s. As the observed records this trend was remarkable in every aftershock.

The maximum peak ground acceleration were found in the North site with values in the range of 14.7 to 47.7 gals, while in the South site from 11.8 to 31.9 gals, the underground characteristics have remarkable influences in the observed acceleration. In this sense, it is worth noting that the input motion of the building will be different and it cannot be directly compared with the records at these sites. However, for the "C" site the peak ground acceleration was in the range of 10.3 to 36.8 gals, which can be related to those found in the South site, therefore the influence of the underground characteristics of the South site have large influences in the superstructure.

This study demonstrated that the shape of the engineering bedrock can be equivalent to a flat-soil layers model considering the depth of the E.B. equal to 17.5m, which is the depth at the right basement site. This equivalency proved that the seismic response of the super-structure is not drastically affected; in order to save time in the design process this assumption can be made, however engineer judgment is vital.

The effects of the geological irregularities are remarkable in the soil response observed in the control points, especially in the North and South sites. The one dimension vertical waves experienced an amplification to the underground characteristics, but the interesting fact is the secondary waves originated in the interface of the inclined engineering bedrock not only propagated toward horizontally, but the effects on the seismic response of the building was no so large.

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