EVALUATION OF INPUT SEISMIC MOLTION LOSS AND STRUCTURE RESPONSE USING STRONG GROUND MOTION RECORDS

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ABSTRACT

A new technique to evaluate the real input motion called the soil structure interaction (SSI) appeared; this new tool on structural analysis has clearly shown that a reduction of the motion occurs when a building is on a specific study site compared with free field surface questioning the fixed base design.

Now, the discussion is, if this reduction is so important or it could be neglected in structure design, although the fixed base design have been considered as an overestimation on the seismic design which assure the structure compared with SSI.

The input motion reduction has economic meaning because it means a reduction of base shear force and overturning moment acting on the structures reducing the structural elements size.

This study presents a verification of the input motion reduction on the foundation using strong ground motion records and also presents how the input motion reduction changes the building response compared with that considered in the fixed base design. The effect of the foundation depth was also evaluated by using a numerical method which considers the frequency domain soil response on a massless system. The reduction of the motion was observed and it becomes more important as the foundation depth increases.

Keywords: Input motion, Spectral ratio, Frequency domain, Soil Structure Interaction

1. INTRODUCTION

Nowadays Soil Structure Interaction (SSI), has become one of the most important concept to evaluate the real behavior not only of new structure but also existing ones, and it has generated new issues of researching related to seismic design, also have awaken the interest of researchers on this new field of structural design.

One of the last issue in this field is the evaluation of seismic input motion on structures; the general discussion presented in some researches is, if the input motion decrease or increase related to the traditional input motion used in structural design described in many seismic codes and, if the input motion evaluated in soil structure interaction is beneficial or not to the structural design. Actually the technique used to evaluate directly this phenomenology is through geotechnical instrumentation and it consists of installing devices of seismic motion record on the buildings, beneath and around it.

Strong ground motion records devices are used for evaluating soil structure interaction, they give results of the building response including the site effect which is referred to the wave propagation in the immediate vicinity of the site; and propagation effect which is related to the complete path from source to receivers. Strong ground motion itself is the final product of source, path and site effects.

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2. PREVIOUS RESEARCH AND AWARNESS OF THE ISSUE

The input seismic motion has been one of most important issues treated recently in earthquake engineering. In many researches, the results have shown that reduction on the input motion occurs and it have been considered as a benefit to the building design because the force and overturning moment acting on the structures are reduced. However for other ones it is not, but rather increases the responses of the buildings when soil structure interaction is considered.

Some researchers consider that SSI may indeed hold for a large class of structures and seismic environments. However, it is not always because there is evidence documented in numerous historic cases that the perceived beneficial role of it is an unjust over simplification that may lead to an unsafe design of both the superstructure and the foundation.

The design spectra presented in most seismic codes around the world are based on a statistical analysis of the response spectra for the ensemble of ground motions. The problem is that it does not resemble the spectra recorded on deep soft soil which increase the fundamental period when SSI is taking into account. This effect also leads to an increased response which contradicts the expectation incited by the conventional design spectra.

The traditional design spectra hold that an increment in natural period of the building (and damping) due to soil deformability leads almost invariably to smaller accelerations and stresses in the structure and its foundation.

Other discussing point is the traditional design demand spectrum. It differs from those when soil structure interaction is considered. For getting the demand spectrum a series of oscillators are used and they are forced using the same input motion, but when ground motion is calculated or determined in the middle of foundation the resulting demand spectrum concern only to a specific structural dynamic characteristics. Only one point of the curve is correct which corresponds to the effective structural period, so another structure with different demand characteristics will have a different demand spectra curve. To vary the input motion for every oscillator in order to consider the real condition of the structures is the most important action to solve this problem.

The analysis point of the previous researches turns around to the importance of evaluating the input motion as an indicator of safe buildings design.

3. TARGET BUILDING

In this research, the annex building at Building Research Institute (BRI) was chosen. It is located in Tsukuba City, Japan, about 50 km northeast of Tokyo. The building lies on diluvial heights between the Sakuragawa River flowing into the Kasumigaura Lake and the Kokaigawa River.

The annex building is a steel reinforced concrete structure with nine stories, eight stories above the ground level and one story under ground. It is supported by a mat foundation in 8m depth on a sandy clayey and clay layer, with a floor area of approximately 546 m^2 on every story and total high of approximately 43.05 m (see Fig. 1).

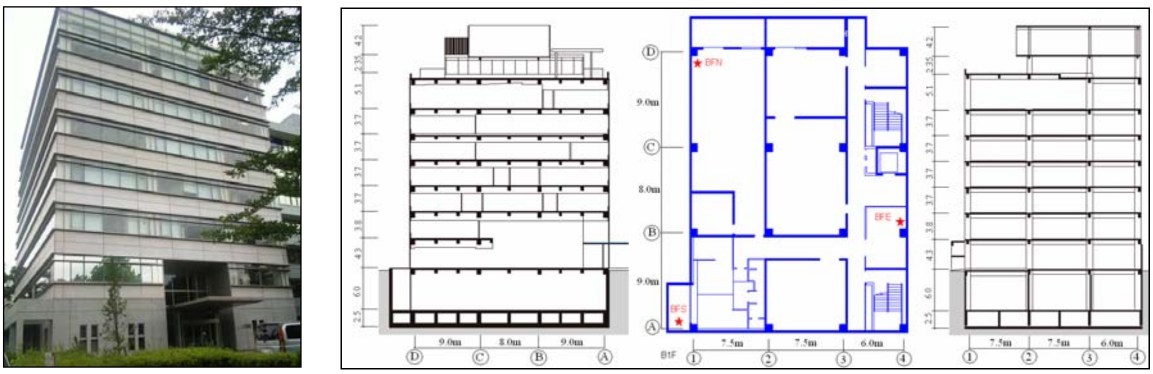


Figure 1. Target building

The building lies on diluvial heights between the Sakuragawa River flowing into the Kasumigaura Lake and the Kokaigawa River. The subsoil properties beneath the building were identified until 88m depth where a relatively hard gravel layer was found (see table.1).

Table 1. Soil profile beneath the target building

N_0	$H(m)$	$D(m)$	$V_P(m/s)$	$V_S(m/s)$	$\rho(t/m^3)$	Soil Classification
1	2.0	2.0	170	110	1.30	Loam
2	6.0	8.0	1430	200	1.30	Sandy Clay & Clayey Sand
3	6.0	14.0		160	1.50	Sandy Clay & Clay
4	8.0	22.0	1630	260	1.80	Fire sand & Clayey Fine Sand
5	6.0	28.0	1500	200	1.75	Sandy Clay and Clay
6	14.0	42.0	1570	270		
7	6.0	48.0	1880	460	1.90	Gravel
8	8.0	56.0	1780	340	1.75	Sandy Clay and Clay
9	12.0	68.0	1690	290		
10	12.0	80.0	1790	380	1.95	Gravel & Fine Sand
11	8.0	88.0	1600	280	1.75	Sandy Clay & Clay
12		88.0		500	2.00	Gravel

H :Thickness, D :Depth, V_s :Shear Wave Velocity, ρ :Density

The target building was instrumented since 1998 with a detailed strong ground motion observation system on, around and beneath it, just when construction of the building finished.

The monitoring system consist of 11 sensors on annex building, 7 in surrounding ground (see Fig. 2) and 4 in the main building of BRI.

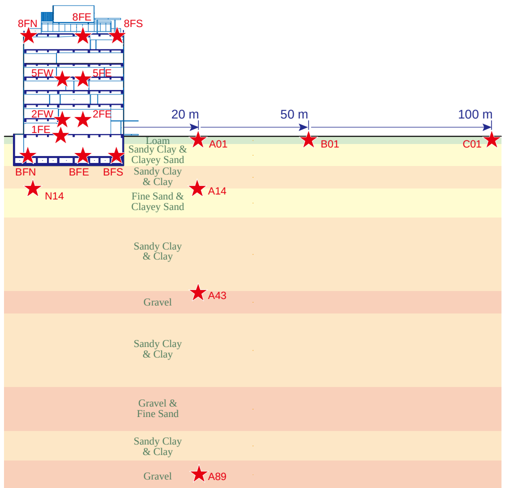


Figure 2. Monitoring System on the target building

4. DATA

Six hundred fifty eight (658) strong ground motions record were used. They were recorded since 1st of June, 1998 up to 7th of May, 2010 with magnitude range between 2.6 and 8.2, and peak ground acceleration (PGA) range between 0.4 and 74.3.

The earthquakes were divided using the Japan Meteorological Agency Intensity (I_{JMA}) and earthquakes with intensity III were selected to evaluate the input seismic motion loss whose magnitudes vary from 4.6 to 7.1 and peak ground acceleration (PGA) from 7.9 to 74.3. These earthquakes represent the 5% of the all records (see Fig. 3).

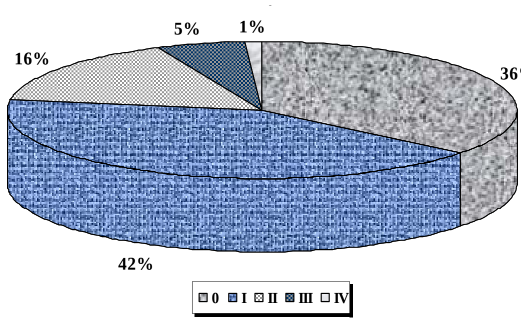


Figure 3. Strong ground motion record divided by JMA Intensity Scale

5. THEORY AND METHODOLOGY

One of most common form to explain the loss of the input seismic motion on the structures is comparing the motion on free field surface again that motion occurred when the building is on it.

In a general sense, decrease in the motion is expected when the building lie on the ground. There are some parameters which quantify this reduction considering the ground and building characteristics of a specific site.

Light structures lying on stiff soil will transmit little energy and the motion considered on response calculation due to earthquake will be same as that experiment on free field surface and also the motion of rigid soil will not interact with the dynamic response of building. This consideration is used on fix base design described in many seismic codes.

Different behavior is observed when a heavy structure lies on soft soil, in this case considerable energy is transferred by the building to soil, so the motion to consider on building design will be different from that one observed on free field.

In this study the input motion was firstly evaluated considering the peak ground acceleration, peak ground velocity and seismic intensity got in the sensors installed on foundation and free field surface. Two case were considered, first one correspond to earthquakes (52 records) occurred at epicenter distances between 7 and 370km, and hypocenter distances between 2 and 20km. The second one correspond to earthquakes (29 records) occurred at epicenter distances between 26 and 476km, and hypocenter distances between 80 and 100km.

The input motion was also evaluated through the spectral ratio between motions recorded on foundation and free field ground. Finally the input motion on foundation was calculated using the finite element method which also included the effect of foundation embedment in the input loss. A computer program based on numerical analysis called Finite element calculation for irregularly layered Soil in 2D analysis (FEIS2D) was used. It was developed by Professor Dr. Masayuki Nagano from Tokyo Science Institute; which is based on linear equivalent site response of wave propagation.

6. RESULTS AND DISCUSSION

6.1 Peak Ground Acceleration (PGA)

Peak ground acceleration is used sometimes to characterize the earthquakes and it give an idea how strong they are, but must be considered that light or important reduction of the input seismic motion will depend on the characteristics of the ground motion. In the first case, the 90% of the records showed decrease of PGA values between 10% and 50% compared with those recorded on free field surface, and for second case the 86% showed reduction of PGA values between 40% and 60%.

6.2 Peak Ground Velocity (PGV)

PGV is a better parameter to characterize strong ground motion than PGA because it is less affected by the frequencies contents produced by strong shaking. It indicates the capacity of ground and building for dissipating energy produced in high frequencies. In the first case the 63% of the records showed decrease values between 1% and 20%. Because suddenly shaking, building can not dissipate enough energy on high frequencies contents, but in the second case the 69% of the records show decrease of PGV values between 20 and 40%.

6.3 Seismic Intensity

Unlike of the seismic intensity used around the world so far, Japan Meteorological Agency Intensity (I_{JMA}) is a parameter used as a quantitative measure of earthquakes and it is better than PGA and PGV because already include the distribution of all peak amplitude on the frequency domain.

In the first case the 64% of the data showed decreasing of I_{JMA} between 1 and 20%. In the second case only the 69% of records showed decrease of I_{JMA} between 20 and 100% (see Fig. 4); all parameters taken into account to evaluate input motion loss showed that reduction of seismic motion occurs. It becomes more notable as epicenter and hypocenter distance and earthquake intensity increase.

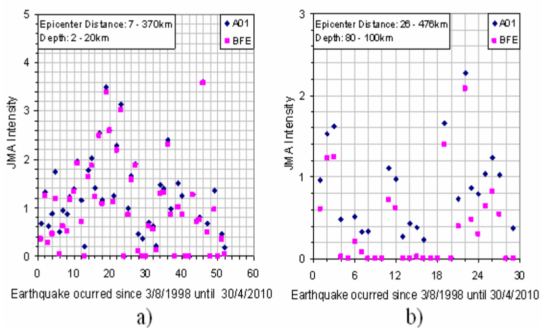
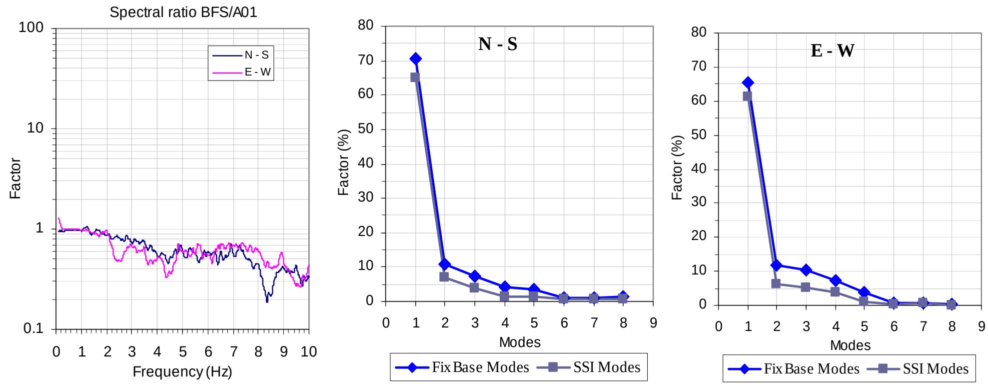


Figure 4. Decreasing of seismic intensity

6.4 Spectral Ratio

Motion reduction was quantified through the spectral ratio between the motions on the foundation and free field surface. It was observed beginning on 1.3 Hz approximately on both directions (see Fig. 5a). This reduction occur when building begin to vibrate in its fundamental period. The input motion reduction is very important in short frequencies because most building have its fundamental vibration frequency less than 1.5Hz.

Important reduction can be observed on high frequencies higher than 2Hz which are not only directly related to the fundamental frequency of the building but also with the different vibration modes of the structure. The first three fixed base vibration frequencies of the target building were considered on the motion reduction. Decreasing of input motion for these frequencies are 12, 36 and 46% on N – S direction, and 6, 47 and 49% on E – W direction. Their influences in the total response considering the modal analysis were 6, 4 and 3% in the N – S direction (see Fig. 5b) and 4, 6 and 5% in the E – W direction (see Fig 5c).



a) b) c)

Figure 5. Input motion reduction and its influence in building total response

As is observed on Figures 5b and 5c, the influence of the motion reduction on the total response is not large when theses vibration frequencies are considered in the modal analysis.

6.5 Effect of foundation embedment depth on input motion loss

There are various parameters whose influences on the building response, which are layering of the site, the flexibility of the base and foundation embedment. The latter was evaluated considering different foundation depth 0m, 2m, 4m and 12m in order to evaluate its influence on the input motion.

Decrease of the motion was not observed on foundation in case of embedment depth is 0m. It was due to decreasing of the damping because only the bottom area of foundation reflex the wave that come on it, which mean the contact area with ground decrease.

In case of 2m important reduction between 23 and 60% in frequencies higher than 5Hz was observed, in case of 4m, it appears since 3Hz between 25 and 70%. In case of 12m it appeared early on 1.8Hz between 26 and 75% (see Fig. 6). Generally speaking, a decreasing of the input motion is observed as embedment foundation depth increase.

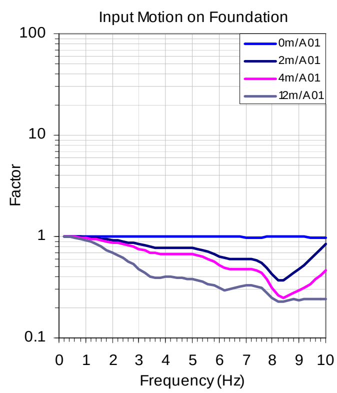


Figure 6. Effect of embedment depth in the motion reduction

7. CONCLUSIONS

Input seismic motion loss on the foundation was verified using strong motion records from the monitoring system of the building. A decrease of the motion occurs in the higher frequency than 1.3Hz which is the fundamental frequency of the target building.

A decrease of the motion with increase of the foundation depth was observed. This reduction can be attributed to an increment of the contact area between the foundation and the ground, so increment of the radiation damping is generated.

8. RECOMMENDATION

Clear evidence of reduction of the motion on foundation was observed in this research. To generalize the obtained results, the following subjects should be considered:

i. Evaluation of the foundation input seismic motion loss on buildings supported by different foundation systems to identify in more detail its effect on reduction of the motion.
ii. Development of two dimensional dynamic response analysis of soil or site response in time domain, in order to take into account the irregularity of the boundary layers. Strong motion records were used in this research and no good agreement was found with linear equivalent frequency domain response because the supposition of the constant shear modulus and damping values, so soil nonlinearity must be taken in to account.

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REFERENCES

Boore, D. M. (1983). Bulletin of the Seismological Society of America, Vol 73, No 6, pp. 1865-1894,
Chopra, A. K. (1995). New Jersey: Prentice Hall.
Chowdhury, I., & Dasgupta, S. P. (2009). London: CRC Press/Balkema.
Clough, R. W., & Penzien, J. (2003). Berkeley, USA: Computers & Structures, Inc.
Data, T. K. (2010. India: John Wiley and Sons Pte Ltd.
Dunnicliff J. (1988). New York: John Wiley & Sons, Inc.
Elghazouli, A. Y. (2009). London and New York: Taylor & Francis e-Library.
Elnashai A. S. & Di Sarno, L. (2008). United Kingdom: John Wiley & Sons, Ltd.
Gazetas, G. (2006). Paper presented at ECEES, Geneva, Switzerland
Ishihara, K. (1996). New York: Oxford University Press Inc.
Kashima, T., & Kitagawa, Y. (2006). Paper presented at ECEES, Geneva, Switzerland.
Katsanos, E. I., Sextos, A. G., & Manolis, G. D. (2010). Vol 30, issue 4, pp. 157-169.
Kramer, S. L. (1996). New Jersey: Prentice Hall.
Kuwata, Y., & Takada, S. (2002). Japan: Kobe University.
Lee, J. W. (2009). Michigan: University of Michigan, Library.
Madenci, E. & Guven, I. (2006). Springer, United State.
Park, D., (2004). National Science Foundation Mid America Earthquake Center, Illinois.
Pitilakis, K., Pitilakis, D. & Karatzetzou, A. (2010). Paper 7CUEE & 5ICEE, Tokyo, Japan.
Towhata, I. (2008). Berlin: Springer- Verlag Berlin Heidelberg.
Wolf, J. P. (1985). New Jersey, USA : Prentice Hall.