STRATEGIC OBSERVATION PROGRAM FOR DYNAMIC RESPONSE OF BUILDINGS

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ABSTRACT

This paper reports proposal of the strategic observation program, its practice, and the future scope for obtaining high quality substantial observation records efficiently. This observation program aims to separate and analysis effect of soil-structure interaction (SSI), non structural member etc., which affect dynamic response of buildings. We observe buildings under construction, because natural frequency and damping factor changes remarkably with increase of the number of stories and installation of non structural member. Those records are equivalent to some buildings, as which have different number of stories, though which have same soil, foundation and structural type. After construction, in case of extension of the building, it is useful to investigate changes of torsional vibration which caused by eccentricity. In case of adjacent building construction, it is possible to investigate the effect of structure-soil-structure interaction (SSSI). This is important for the building which stands close together in the city.

There are a large number of buildings in Nagoya University campus. We can observe original construction and additional construction of various buildings. In addition, many seismic retrofit constructions are carried and planning in these years. We can observe before and after seismic retrofit, and can be clarifying the change of dynamic property of those buildings.

INTRODUCTION

It is most important factors for the use of seismic design and disaster mitigation that to understand dynamic response of buildings. There are a lot of experimental or observational research for skyscrapers (Satake et al., 2003), isolated buildings and other important buildings. On the other hand, researches for low and medium-rise buildings which exist in city region mostly are a little. Dynamic response of these buildings is strongly affected by SSI (Fukuwa, 2001) and non structural member. It is difficult to investigate using computed simulation, because dynamic response of low and medium-rise building is complicated and SSI effect, non structural member are difficult to make numerical analysis models. Thus, there is a real need for high quality substantial experimental or observational records which enable to separate and analyze these factors. However, it is necessary for a lot of cost and times when we adopt usual measure techniques. Thus we propose newly observation program, which plans minutely in order to extract and clarify SSI effect, non structural member etc., and to rectify lack of experimental and observational records, especially low and medium-rise building. The feature of this observation program is 1) observe under construction buildings, 2) observe buildings which have different combination of foundation and structural type, 3) observe the building where eccentric changes by a extension, 4) observe the building where the adjacent building will construct. 5) observe buildings which have different height and structural type but have almost same soil condition. Execute this observation program which is planned minutely, we can obtain high quality and sufficient records from small number of buildings, we name this strategic observation program.

STRATEGIC OBSERVATION PROGRAM

Almost all microtremor tests and seismic observations have been conducted at constructed buildings. In these cases, in order to reveal dynamic response of buildings based on statistical study, it is necessary to
accumulate sufficient number of records by observing many buildings or long period observation. If we make the observation program closely, it is possible to obtain useful records for investigating SSI et al. from a small number of buildings. Fig.1 shows the outline of strategic observation program which is aimed to extract factors which influence dynamic properties of buildings.

(a) Under construction building

At foundation construction stage, the following constructions are conducted: 1) soil excavation; 2) foundation construction; 3) bury foundation side soil. When the building is observed at the end of each construction, useful records can be obtained. Those records include different boundary condition, which is useful to investigate the effect of excavation, the effect of foundation mass and foundation side soil.

At superstructure construction stage, 4) the number of stories increases. As for weight of the building is mainly floor weight, the building is observed at the end of each floor construction, we can obtain records which have almost same ground and foundation conditions, but have different number of stories. Those records are useful to investigate Period lengthening, damping effects of SSI and effective input motion. After construction of structural body, 4) non structural member is installed. When the building is observed before and after installation of non structural member, it enables to explore the stiffness of non structural member.

As for only 5) the live load increases when service of the building is started, it enables to investigate the influence that weight changes of the superstructure affect SSI by the observation of before and after service.

After construction, in case of the adjacent building is constructed, the building observation conduct at the existing building and the adjacent building by same way. It enables to obtain records which include the changes of SSSI which is affected by the construction of the adjacent building.

![Diagram of Strategic Observation Program](image-url)
(b) Different combination of foundation and structural type

It is useful to investigate SSI even one building observation during construction. In order furthermore to utilize observation records effectively, similar observations are executed for buildings which have almost same scale but have a different combination of foundation and structural type. It enables to compare SSI effects which caused stiffness balance of foundation and superstructure.

(c) Different combination of soil and foundation

It enables to investigate the effect of SSI, when we observe buildings which have different soil and foundation condition but have same superstructure, such as elementary school. Yagi et al. (2000) investigated this kind of research in detail.

(d) Change of eccentricity

In case of extension, it enables to observe changes of torsional motion and three dimensional motion which caused by eccentricity. This is important for low and medium-rise buildings because these buildings usually have complex plan, and its dynamic property is often difficult to understand analytical study.

(e) Seismic retrofitting

To observe before and after seismic retrofitting provides similar records. These records usually include alternation of superstructure only. Thus, it is useful to investigate changes of dynamic behavior, especially SSI. And it is valuable to verify seismic performance of the retrofitted building.

CHANGE OF STRUCTURAL AMPLIFICATION AND EFFECTIVE INPUT MOTION DUE TO MICROTREMOR DURING THE CONSTRUCTION

Figure 2 shows the building which microtremor was observed at superstructure construction stage. These three buildings have almost same scale, but have different structural type and foundation. Fig.2 (a) is 10-story steel-frame & R.C. pile building, Fig.2 (b) is 7-story precast prestressed concrete (PCaPC) & prestressed high-strength concrete (PHC) pile building, Fig.2 (c) is 10-story steel-reinforced concrete (SRC) & PHC pile building.

Figure 3 shows the results of semi completion at 6 and 8 stories are shown in addition to the results for completion of 10 stories. However, the PCaPC building is shown the result of semi completion at 5 stories and completion of 7 stories. Figure 3 provides comparisons of Fourier spectrum ratios of microtremor records between soil and top floor of under construction building (Top/GL), between foundation and top floor (Top/1F), and between foundation + rocking motion and top floor (Top/(1F+H)). Top/GL means flexible-base model, Top/1F means sway fixed-base model and Top/(1F+H) means sway and rocking fixed-base model.

There are large differences on the first modal frequency of three case (Top/GL, Top/1F, Top/(1F+H)) in PCaPC building and SRC building, the frequency of Top/GL is lower than that of Top/1F, and that of Top/(1F+H), particularly in shorter buildings. In contrast, there is almost no difference on three frequencies in the steel building.

Amplification of three building becomes high when each building becomes taller. The steel building has higher and shaper Fourier spectrum ratio than others. The PCaPC building shows intermediate character of steel building and SRC building. Therefore, there is a greater SSI effect in the stiffer building, particularly in shorter buildings.

Figure 4 presents a comparison of Fourier spectrum ratio of microtremor records between soil and foundation (1F/GL), it indicates input loss effect and effective input motion. The triangle index in figure 4 means flexible-base natural frequency. Fourier spectrum ratio decreases as frequency becomes high in all case. This tendency is almost same in three buildings. Thus, input loss effect and effective input motion does not depend on the number of stories or structural type, but depends on foundation size, embedded depth and soil condition. However, superstructure affects foundation at flexible-base natural frequency.

CHANGE OF SEISMIC RESPONSE OF HIGH RISE BUILDING DURING CONSTRUCTION

Seismic observation at construction field need to overcome some problems, 1) observation space, 2) electronic power for seismic sensor and recorder, 3) easy to move so as not to become the obstacle of construction, 4) time adjusting method for seismic recorder, 5) simultaneous observation method and so on. Problem 1 and 2 is easy to get over by worker’s cooperation, but other problems are difficult to get over with usual observation technique. Therefore, we develop newly seismic observation technique.
Fig. 2 The Building which was Observed Every Construction Stage

(a) 10-story Steel Building
(b) 7-story PCaPC Building
(c) 10-story SRC Building

Fig. 3 Fourier Spectrum Ratio of Microtremors between 10-story Steel Building, 7-story PCaPC Building and 10-story SRC Building (Top/GL, Top/1F, Top/(1F+Hθ))

Fig. 4 Fourier Spectrum Ratio of Microtremors between 10-story Steel Building, 7-story PCaPC Building and 10-story SRC Building (1F/GL)
We adopt transportable seismometer which contains seismic sensor and recorder (Fig.5), and install GPS receiver for time adjusting. This is useful for problem 3 and 4. Usually, in order to observe simultaneously, the synchronous cable is laid. But, we install GPS receiver in each seismometer, because it is easy to adjust seismic records by using the time stamp of each records. This technique can overcome Problem 5. In addition, we use local area network (LAN), which was used for watching and verifying the safety on construction field through networking camera. Fig.7 shows seismic observation system. It is possible to install some seismometer easily, using sub-network which is newly create in construction field. Moreover, it enables to operate seismometer and to acquire records through internet. To observe change of seismic response of high rise building, the seismometer which installed top of the under construction building is moved at the end of each floor construction (Fig.6).

Fig.8 presents seismic response records for an 18-story steel frame-building during construction. Top floor and foundation motions are nearly same when the building is short. In contrast, top floor response is enlarged and shows low natural frequency at 17-story case. This is caused change of damping effect of SSI.

Fig.9 shows records that seismic input motion has long predominant period. Waves of building roof are beating each direction. In this case, it is necessary to pay attention for estimation of damping factor. Because these records often overestimate damping.

Seismic records shown in Fig.9 have different wave length. This is because that the stop trigger operated with each seismometer. Thus, in order to observe the response of the building appropriately, it is necessary to set the stop trigger with building apex, or to set the longer post trigger time.
CHANGE OF DYNAMIC PROPERTY CAUSED BY ADJACENT BUILDING CONSTRUCTION

To investigate the influence of adjacent buildings construction, three kinds of observation are conducted on the building shown Fig.10.
1) In order to compare seismic response of the existing building with the presence of adjacent buildings, seismic observation has been conducted before and after construction of adjacent buildings. Fig.11 shows seismometer layout of after construction of adjacent buildings.
2) In order to investigate the change of dynamic property of the existing building due to the construction of the adjacent buildings from long-term point of view, we observed microtremor in every approximately 4 days using seismometer which was installed in the existing building.
3) In order to observe the change of the west building and its influence to the existing building during construction of the west building, microtremor observation was conducted in the west building semi completion at 2, 3 and 5 stories. At the same time, we operated seismometer installed the existing building to observe ambient vibration of the existing building. Fig.12 shows sensor layout.

Fig.13 shows transfer function which compares presence of adjacent buildings. There is difference in phase lag of NS direction. Fig.14, Fig.15, Fig.16 shows relationship west and center building construction to wind velocity, natural frequency and damping factor of the existing building. There is almost no change in natural frequency. However, damping factor has been affected by adjacent buildings, especially second mode of NS direction after the 2003/4/5.

![Fig.10 Plan of Existing Building and Adjacent Buildings](image10)
![Fig.11 Seismic observation plan (after construction)](image11)
![Fig.12 Microtremor observation plan during construction](image12)
![Fig.13 Transfer Function Before and After Construction of Adjacent Building](image13)
![Fig.14 Wind Velocity and Construction of Adjacent Buildings](image14)
![Fig.15 Transition of Natural Frequency](image15)
![Fig.16 Transition of Damping Factor](image16)
CHANGE OF DYNAMIC PROPERTY BY EXTENSION

Fig. 17 shows change of the 10-story SRC building response which had large torsional motion before extension. In contrast, torsional motion become small and new mode shape is occurred after extension. This notable difference in the responses is caused by eccentricity. Fig. 17 (b) and (c) shows the mode shape at the frequency where the torsional or new response was predominant.

DIFFERENCE OF SEISMIC RESPONSE AMPLIFICATION AND INPUT LOSS WITH BUILDING HEIGHT AND PREDOMINANT FREQUENCY OF INPUT SEISMIC MOTION

Fig. 19 provides comparisons of Fourier spectrum ratios between soil and building roof, and between foundation and building roof. The maximum acceleration response ratio of the building is also plotted in Fig. 20 against soil response to show the amplification of the building response. The horizontal axis is predominant frequency of input seismic motion. Fig. 21 shows similar results for amplification of response of a building foundation vs. soil response. The responses vary with varying predominant frequency of input seismic motion. The results indicate that lower number of floors results in lower amplification, a higher predominant frequency, higher input loss effects.

CONCLUSIONS

This paper described new technique to obtain high quality and much quantity observation records of building efficiently, named strategic observation program. It enables to separate and analyze influential factors in dynamic response of buildings, including building height, structural type, soil condition, the effect of adjacent buildings and the effect of eccentricity.
REFERENCES


Fig.19 Average Fourier Spectrum Ratio of Seismic Records

Fig.20 Maximum Acceleration Amplification of Each Seismic Record

Fig.21 Maximum Acceleration Reduction of Each Seismic Record