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EXPERIMENTAL CONSIDERATIONS ON EARTHQUAKE BEHAVIOURS OF A LARGE LONG STRIP-TYPE OF ACTUAL STRUCTURE

Fukuzo SUTO[1] and Shyuichi ASAYAMA[2]

1) Dept. of Arch.& Eng., Tokyo Denki University, JAPAN
2) Dept. of Arch.& Eng., Tokyo Denki University, JAPAN

SUMMARY

In this paper an earthquake-response experiment related to a long strip-type of 4-storied reinforced concrete frame structure is treated as compared with theoretical simulation analysed using the results based upon the 'Composition Method of Stiffness Matrices' which have been researched and developed by the authors these several years. The objective building has dimensions of 116 meters, 16 and 16 in its length, width and height respectively, and the records acquired through 10 acceleropickups set in and around it are controlled by a central control unit synchronously. The comparative considerations are carried out according to the results gained by analyses of response-spectra and correlation-coefficients of respective responded waves relevant to the standard wave, picking up two typical cases of recorded quake-responses. Finally they lay stress upon the need for the slab flexibility and phase-difference to be taken into the analysis for this sort of structures as conclusive remaks.

INTRODUCTION

The authors have been engaging these several years in building up and publishing the general-purpose theory on 'Composition Method of Restoring Matrix' based upon genuine stiffness matrix method and developing its computational system on the problem of earthquake-response related to 'Large Long Strip-Type of Structures'. As the analytical conditions, there are included flexibility of slabs, phase-differences as earthquake input, foundation rocking and swaying.

Togetherwith this, they have been continuing measuring of quake-responses on an actual building. The measuring has been carried out for their university's research building of reinforced concrete structure of 4 stories with 10 acceleropickups. The soil under the foundation for each column is constituted by considerably hard layers of sand-gravel lying over the region.

The 3-D frame analyses are applied for 10 blocks of the structure divided to evaluate respective stiffness matrices in reduced form to be used for 10 parallel rows of Lumped-Masses Bar System, which are connected adjacently by slab stiffness matrices. Soil springs are calculated by modification of Dr.Tajimi's formula. A constant time delay as phase-difference is assumed relevant to the forced quake-input for each lumped-masses bar system standing upon actual quake records measured.

Among nine cases of acquired quake-responses until now, in this paper two cases are selected because of their clear characteristics.
Figures drawn for comparisons of measured records with analytical values of the two quake-responses for EW on the roof are thought to present as a whole good agreements.

Through various comparisons of other measured data with analytical ones solved by the foresaid computational system, it has been clearly recognized that the precise explanation on any earthquake-response behaviour can not be attained without taking into analytical processes such necessary factors as slab flexibility, phase differences for input and other neglected conditions till now.

METHOD OF MEASURING AND MODELLING OF THE OBJECT STRUCTURE

Acceleropickups are set in and around the Research-Building in the Hatoyama Campus of Tokyo Denki University (Photo.1) constructed with 4-storied reinforced concrete and dimensions of 116 meters in length, 16 in width and 16 in height (Fig.1). No.1 and 7 of them record data being set on the ground near the building, No.2 to 6 and 8 on the foundations, and No.9 and 10 on the roof surface (Fig.1 & Photo.2).

Photo.1

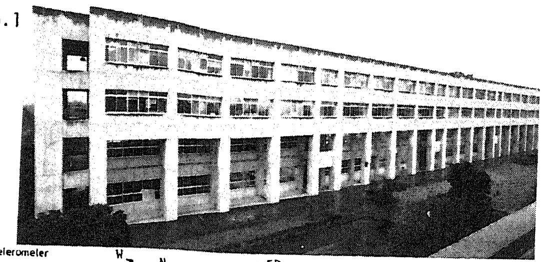
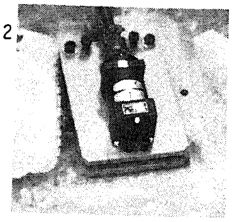


Photo.2



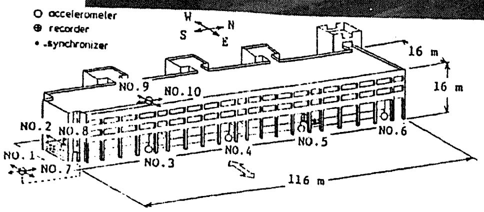


Fig 1. 4-story Research Building Showing Observation Points

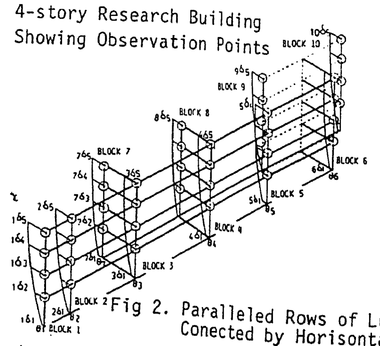


Fig 2. Paralleled Rows of Lumped Masses Conected by Horisontal Spring

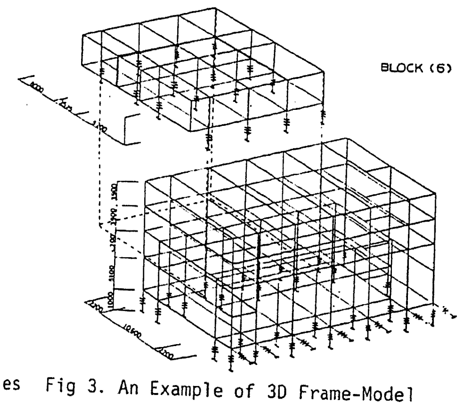


Fig 3. An Example of 3D Frame-Model

In this paper, using a vibratory model of the structure replaced by 10 rows of Lumped-Masses-Bar System connected with slabs as shown in Fig.2, a comparative explanation between actual behaviors and analytical ones under quake responses is tried. As the details on the modelling have been already published (Rf.1-2), in this place only its outline is observed.

Firstly the building is divided into 10 blocks of frameworks, and they are analysed respectively through the 3-D Stiffness Matrix Method to obtain their stiffness matrices.
Secondly their matrices are connected by slab stiffness matrices taken into consideration of their characteristics for slope-deflection by bending and deflection by shear so as to get the total structural matrix. However between the building and staircases constructed with reinforced concrete wall-tube only the spring for axial force is set. In Fig.3 an example of frame-model made by the 3-D frame analysis is shown.

Thirdly as for the vertical soil spring it is obtained approximately by a method of modification under the condition of stratified soil of the result through the fundamental function published by Dr.H.Tajimi (Rf.3), which gives the displacement of soil beneath foundation under an action of vertically concentrated force for the semi infinite elastic solid. The spring for swaying is also got according to the same way. Finally these springs are composed also into the total stiffness matrix of the structure as a whole.

EXCITATION OF HIGHER ORDER VIBRATION ACCORDING TO THE SLAB FLEXIBILITY

Fig.4 and 5 show comparisons of the accelero-response spectra relevant to waves for E-W direction aquired at the roof surface with those to waves on soil surface near the building, which are all calculated under the condition of 5% damping. In the case of the earthquake epicentered at the border of Kanagawa-Yamanashi Prefecture Feb.14 '84 (M=5.4) shown in Fig.4, the first intrinsic period 0.24 second of the building is remarkably perceived. On the contrary, in the case of the earthquake epicentered at the Offing of Ibaragi Prefecture Feb.2 '86 (M=6.1) shown in Fig.5, an intrinsic period of the higher order is clearly excited, which corresponds with the sixth period of 0.08 second when refered to the analytical result got from the modal analysis in relation to the transversal direction shown in Fig.6. Further in this case of higher order excitation, it is clearly recognized from the mode figure some large local slab deflection is induced.

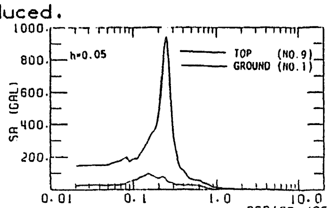


Fig 4. RESPONSE SPECTRA OF ACCELEROGRAMS MEASURED WHEN KANAGAWA-YAMANASHI PREF. BORDER EARTHQUAKE OF FEB. 14. 1984 OCCURED

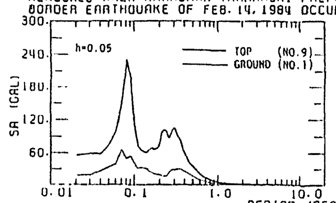


Fig 5. RESPONSE SPECTRA OF ACCELEROGRAMS MEASURED WHEN IBARAGI PREF. OFFSHORE EARTHQUAKE OF FEB. 12. 1986

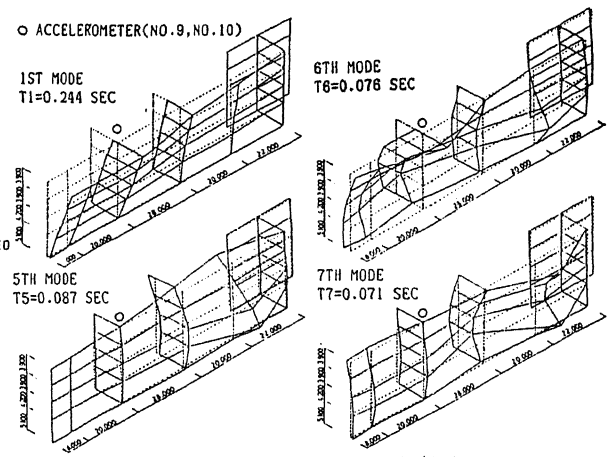


Fig 6. Mode shapes of Research Building

Table 1 Acquired and Applied Quakes

EARTHQUAKE / PERIOD	0.24 (sec)	0.08 (sec)
KANAGAWA-YAMANASHI PREF. BORDER (FEB. 14, 1984)	15.0	5.1
IBARAGI PREF. OFFSHORE (FEB. 12, 1986)	5.5	4.7

Table 1 shows ratios between the value on the roof and that on the ground surface at both points of the first period 0.24 and the sixth period 0.08 second in relation to response spectra. From this Table it is known that in the former earthquake case the ratio related to the first period is 15.0 times and that to the sixth period is 5.1 times, while in the latter earthquake case the above ratio related to the first period decreases to 5.5 and on the contrary it shows 4.7 with very little decrease as regards the sixth period.

PHASE-DIFFERENCES INFERRED FROM DATA RECORDED AT FOUNDATIONS

To observe the phase-difference related to the quake start-time at respective foundations from that of one end of the building taken as the standard point, correlation-coefficients between them in relation to their quake-waves were calculated, in which respective maximum-values of time-difference as of phase-difference were searched through mutual slides of the time axes.

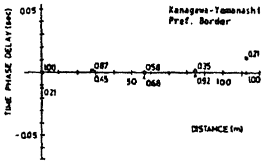


Fig 7. TIME PHASE DELAY WHICH EXISTS IN ACCELEROGRAM OBSERVED AT THE BASE OF BUILDING

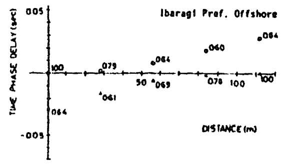


Fig 8. TIME PHASE DELAY WHICH EXISTS IN ACCELEROGRAM OBSERVED AT THE BASE OF BUILDING

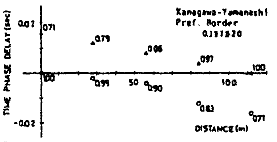


Fig 9. TIME PHASE DELAY WHICH EXISTS IN ACCELEROGRAM OBSERVED AT THE BASE OF BUILDING

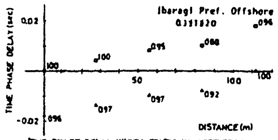


Fig 10. TIME PHASE DELAY WHICH EXISTS IN ACCELEROGRAM OBSERVED AT THE BASE OF BUILDING

Fig.7 and 8 show the time-difference obtained through vertical axis and the location of measured points through horizontal axis as regards two earthquakes mentioned in the above.
The coefficients in the case of Kanagawa-Yamanashi Border earthquake are very small showing time-differences nearly as zero, while in the case of Ibaragi-Offing earthquake a considerably good tendency is presented showing them nearly as proportional to the distance between objective two points.

Next, applying the method of Band Pass Filter for the calculation to eliminate any influence of the building vibration, outsides of the range from 0.25 to 2 second were filtered, and the same comparisons were carried out as shown in Fig.9 and 10. Through this processing, in both cases respective coefficients were improved considerably to show good values of both 0.71 and over 0.88, and each time-difference shows a remarkable tendency proportional to its distance from the standard point.

However when compared the filtered waves of one end of building with those of the other end, there is clearly observed only in the case of Ibaragi-Offing quake the same wave shape reappears for each measuring point in almost constant time-difference (Fig.11 and 12).
In this case the time-differences between both ends of building with the length of 112 meters calculated by non-filtered and filtered method give 0.028 and 0.018 second.

COMPARISONS OF MEASURED VALUES WITH SIMULATED ONES BY THEORY

Here results obtained from measured data are compared with those analysed through response-analyses according to the model described above concerning the vibration for transversal direction, in which the following two cases about the E-W component of earthquakes acquired on the ground-surface near the building are treated according to the forced conditions given to the analytical response-model; (1) a constant time-difference is given for each foot of lumped-masses system sequentially and (2) equiphasic state is given to all.

As for the damping ratio related to the structure, though there is a theory expressing the value of any intrinsic period of MDOF vibratory system multiplied by its corresponding damping ratio makes a constant and accordingly the damping ratio increases in any higher mode than in the first mode, in this place the following two values have been selected respectively from the result of various trial comparisons as the most appropriate ones for explanations of vibratory characteristics on quake-responded waves as a whole;

1) 2% in the case of Kanagawa-Yamanashi Border earthquake, where the structural response shows the 1st mode, and
2) 6% in the case of Ibaragi Offing earthquake, where the structural response shows clearly the 6th mode.

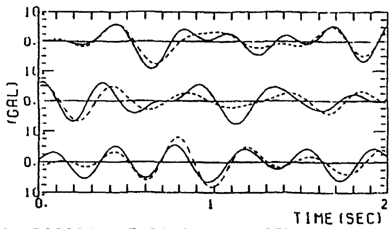


Fig 11. Comparison of filtered accelerograms obtained on the base at a distance of 112 meters (Kanagawa-Yamanashi Pref. Border Earthquake of Feb. 14, 1984)

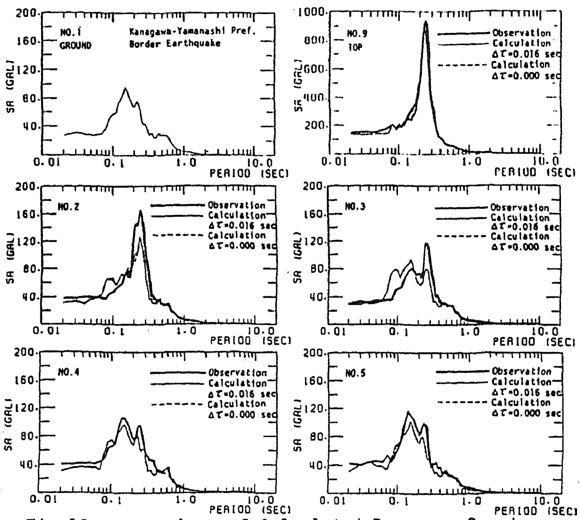


Fig 13. Comparison of Calculated Response Spectra on The Base with Measured One

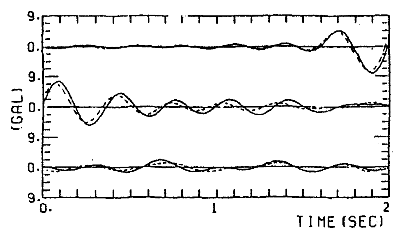


Fig 12. Comparison of filtered accelerograms obtained on the base at a distance of 112 meters (Ibaragi Pref. Offshore Earthquake of Feb. 12, 1986)

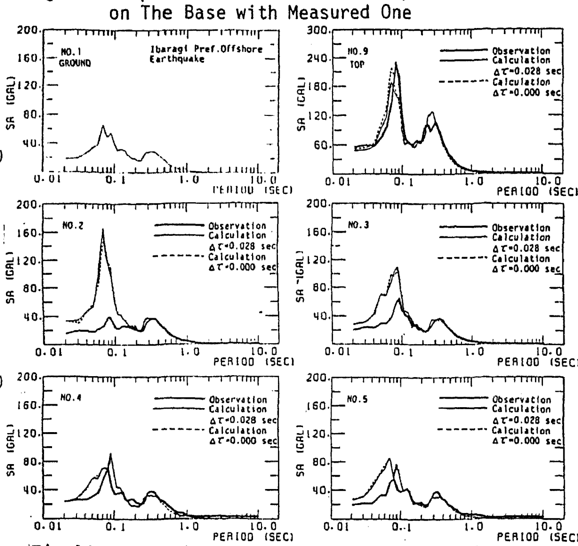


Fig 14. Comparison of Calculated Response Spectra on The Base with Measured One

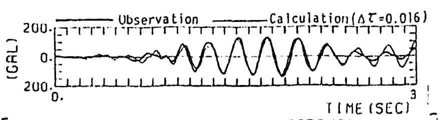


Fig 15. Comparison of calculated response acceleration at the top with measured one (Kanagawa-Yamanashi Pref. Border Earthquake of Feb. 14, 1984)

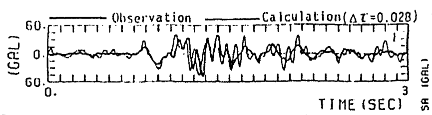


Fig 16. Comparison of calculated response acceleration at the top with measured one (Ibaragi Pref. Offshore Earthquake of Feb. 12, 1986)

In Fig.13 and 14 show the response-spectra of responded waves processed under the damping ratio of 5%. Fig.13 concerning the former case shows a considerably good accordances between the expermental and analytical results, whereas Fig.14 related to the latter case shows generally some extent of differences between both values in spectra concerned with experiment and analysis in relation to foundation-position No.2 & 3, except those in spectra to the roof with nearly mutual consistent values at the peaks of curves, of which cause is thought possibly due to a large reduction of stiffness matrix to decrease unknowns and evaluation of soil springs.

The appearance of the 6th order mode at the roof level in the latter case is well explained by the introduction of time-differene to each foot of lumped masses bar.

Fig.15 and 16 show comparisons of measured response-waves at the roof in both cases of earthquake with those of analyses, of which shapes present considerably good consents.

CONCLUSION

As the conclusion of this paper treating an experimental considerations on an actual building of long strip type vibrated by earthquakes, the authors describe the following remarks to be notified;

(1) for the building of long strip-type the assumption of infinite rigidity of slabs can not be thought as applicable, but the flexibility of slabs must be taken for granted and rather is inevitable for analytical condition,
(2) according to the above there emerges very remarkably some higher order of vibratory mode due to the slab deflection as described in the case of Ibaragi-Offing earthquake,
(3) as for the phase-difference in relation to earthquake start-time to be adopted as the input condition for the foot of each lumped-masses-bar shows a functional distribution rather than a constant value as a whole in view of correlation-coefficients,
(4) the distribution of the phase-difference seems to be clearly decided in very complicated process of the wave propagation through complex soil strata and the shape of subgrade soil over the wide and local range surrounding the building site from any quake source, and
(5) it will be very important for some adequate mean value of time-difference necessitated at the time of designing any long strip-type of frame structures in a certain region to be found out statistically based upon careful deliberation from its geographical and geological point of view in the future.

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