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A STUDY ON THE STRONG MOTION CARACTERISTICS OF WOODEN DWELLING HOUSES (RESPONSE HYSTERESIS LOOP AND PERIOD)

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ABSTRACT

In recent years, an energy absorber device such as the vibration control device is utilized in Japanese wooden houses for the purpose of decreasing earthquake response. Wooden houses are structures with strong nonlinearity, where the structural system and the finish method vary. Therefore, the damping performance and dynamic characteristics, that are essential factors for the evaluation of damping effects in a high damping wooden house complex, are not clearly understood and it is important that they are cleared. The authors attempt to grasp the energy absorption performance of the wooden house and the dynamic characteristic at the earthquake turbulence in this research as part of the method of evaluating the effect of high damping wooden houses.

The laboratory at the Kogakuin University has executed shaking table tests on wooden houses (Miyazawa et al., 2000; Oda et al., 2003; Watabe et al., 1996; Miyazawa et al., 2001; Yanano et al., 2006; Tsuda and Miyazawa, 2006; Miyazawa et al., 1996). By the report of past study (Nishimura and Miyazawa, 1995) a building is tuned to the period characteristic of the earthquake turbulence. In this study, the method of calculating the characteristic of an equivalent, viscous damping ratio and the period are defined clearly from the report of past study and the correlations of the energy absorption performance, the response period and the response displacement are grasped by using the result of the full scale shaking table test that have been executed before. Moreover, those dynamic characteristics are explained by the linear theory analysis in this study.

Introduction

This report contains analytical and experimental considerations on the behavior of wooden houses during a strong earthquake. Chapter 1 describes the outline of specimens and the test set up. Chapter 2 reports on the analysis of the experimental result. First of all, experimental result is analyzed from the viewpoint of the energy absorption performance, and an equivalent viscous damping ratio is considered as an index of the energy absorption performance. The correlation of an equivalent viscous damping ratio, the story drift, the stiffness and the equivalent period is shown. Next, the characteristic of a response period is analyzed from the experimental result. Here, an arbitrary loop of one cycle is extracted from the curve of the story shearing force-story drift, the cycle time is defined as response loop period. Next, the response period is the equivalent loop period and the equivalent period. First it is calculated from the equivalent stiffness of

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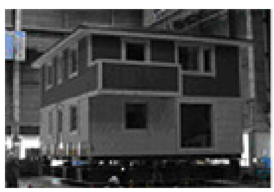
the skeleton curve, and next it is calculated from an extracted loop on the story shearing force-story drift. Mass is considered with this as well. Chapter 3 reports on analytical consideration. One spring-mass damper system linear response analysis is made, and the characteristic of the period of the structure at the time of earthquake turbulence is verified by the analytical study. In Chapter 4, the characteristic of the response period (experimental result) at the time of earthquake turbulence and a theoretical interpretation is given based on the analysis.

Summary of the Full-Scale Shaking Table Test

Seven specimens are used in this research, which consist of six new wooden houses with full scale shaking table tests and one dismantled and reconstructed full scale wooden house with shaking collapse experiment. These experiments were executed from 1995 to 2006. Of the test specimens, there are two two-story wall frame constructions, one three-story post and beam construction, and three two-story post and beam construction as shown in Photo 1 and Table 1. Model 6^{*TI} is post and beam construction, built in 1980 (25 years old at the time of the experiment) and dismantled and reconstructed house specimen for shaking collapse experiment on a shaking table. The structural specification of these seven specimens is typical for wooden dwelling houses in Japan. Each specimen is tested with a shaking table test with several kinds of recorded earthquake motion as show in Table 2. For the same specimen, many shaking table tests were carried out while changing parameters for maximum acceleration for a recorded earthquake motion. The curve of shear force-story drift that was measured on the first story in a shaking table test is used for the experimental analysis in Chapter 2. Data from story drift was measured from a strain gauge type displacement transducer and laser displacement transducer on each story. The acceleration was measured by servomechanism type and strain gauge type accelerometer installed in each floor. In addition, collecting data was filter cut by an appropriate filter band for noises. In addition, the story shear was calculated as a value multiplied the mass shown in Table 1 by the acceleration recorded by an accelerometer.

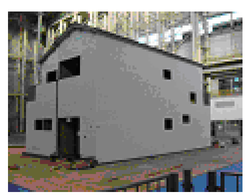

Model1^{*E} [1]


Model2^{*S} [2]


Model3^{*I} [3]


Model4^{*D} [4]


Model5^{*H} [5]



Model6^{*TI} [6] (Existing state) (Removing and reconstruction)


Model7^{*TB} [7]

Photo 1. Test piece.

Table 1. Summary of test piece.

Test Piece Name	Model1^{*E}	Model2^{*S}	Model3^{*I}	Model4^{*D}	Model5^{*H}	Model6^{*TI}	Model7^{*TB}
Construction	Wood frame construction		Framework construction				
Floor Number	Two stories			Three stories	Two stories		
External Wall	Plywood			Plaster board	Plywood	Brace	Brace
Inner Wall	Plaster board			Plaster board	Plaster board		
External Wall Finish	Siding board			Plaster board	Plywood	Cement plastering	
Weight[kN]	234	192	149	201	199	186	355
Mass[kN/gal]	0.24	0.20	0.15	0.21	0.20	0.19	0.36
Live Load	It Put it	It Put it	It Put it	It Put it	It Put it	It Put it	It Put it
Floor Height [cm]	278	268	273	262	307	287	287
Total floor area [m^2]	129	102	92	85	128	87	135

*Weight(Mass) is estimated weight(Mass) between the height of ridge of roof from 1/2 height between first story

$$First\ Story\ Shear\ Force \quad Q_1 = \sum_{p=1}^{n} \alpha_p m_p \quad , \quad \alpha\ ;\ Accelerati\ on\ Data \quad m\ ;\ Mass\ (it\ is\ shown\ in\ Table.11) \quad Exp.1.1$$

Table 2. Recorded earthquake wave in the shaking table test.

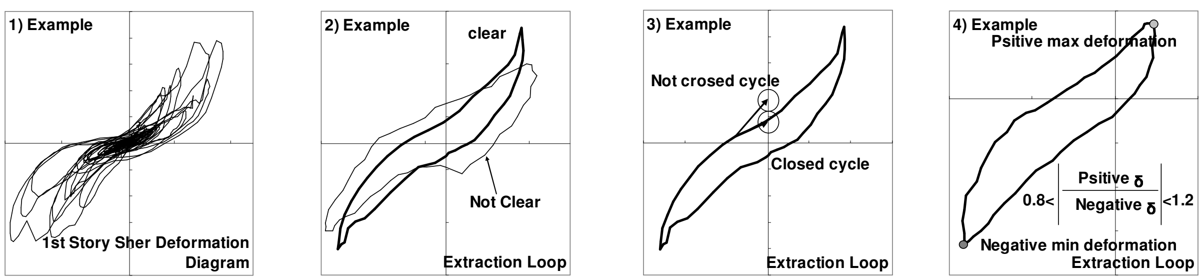
Model1*E			
Model2*S		El_Centoro_EW_1940	
Model3*I		BCJ_Sumirated earthqwake	
Model4*D	JMA_Kobe_NS,EW_1995	El_Centoro_EW_1940	Hachinohe_NS_1968
Model5*H			
Model6*TI		K-NET_Ojiya_EW_2004	
Model7*TB		El_Centoro_EW_1940	

Verification of Experimental Result

Extraction of response Hysteresis loop

Many clear hysteresis loops are extracted from the shear force-story drift curve according to the following rules. This extracted loop is described as "the extraction loop" at the following examination. A wooden house has a strong nonlinearity, and an equivalent viscous damping ratio depends on the size of a story drift. To calculate an equivalent viscous damping ratio for the story drift, the following three rules have been adopted.

Rule.1 ; The load-displacement curve is clearly drawn.
Rule.2 ; The loop is roughly closed circle.
Rule.3 ; The loop whose difference of positive and negative maximum amplitude is within 20%



A state before extraction   Rule.1   Rule.2   Rule.3

Figure 1. Extracted method of a loop.

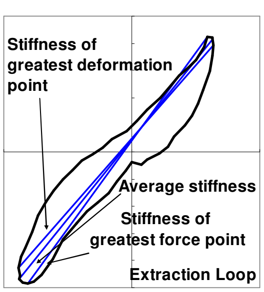
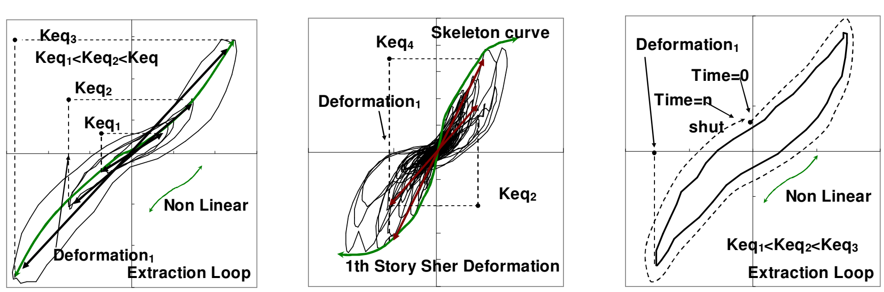


Figure 2. Decision method of stiffness.



Equivalent stiffness   Equivalent stiffness of skeleton curve   Loop period

Definition 1   Definition 2   Definition 3

Figure 3. A definition of three kinds of periods.

$$Equivalent\ Viscous\ Damping\ Ratio = \frac{1}{4\pi}\frac{\Delta W}{W}$$

ΔW ; *An area of a extraction loop*

$$W\ ;\ Equivalent\ potential\ energy = \frac{1}{2}Keq_{(average)}\delta_{(average)}^{2}$$

EXP.2.1

Definition1	*Definition2*	*Definition3*
$Teq = 2\pi\sqrt{\frac{m}{Keq}}$	$Teq_{sc} = 2\pi\sqrt{\frac{m}{Keq_{sc}}}$	*Loop Period*
Keq ; Keq_1 , Keq_2 , Keq_3 *etc*	Keq_{sc} ; Keq_4 *etc*	

m ; *it is show in Table1.1*

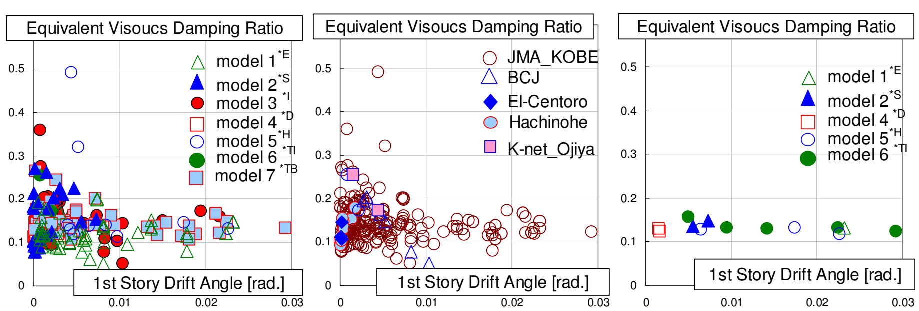
EXP.2.2

A calculation method for equivalent viscous damping ratio

Decision methods for equivalent stiffness influence energy ratio greatly. The shear force-story drift curve of a shaking table test has more noise than the static loading test. Therefore, in this study, an equivalent stiffness have been adopted, the mean value of two equivalent stiffness that is decided from the maximum shear force point, the maximum story drift point. Therefore, the equivalent viscous damping ratio is the damping ratio at resonance. This is shown in EXP.2.1 (after this, the average stiffness is described with equivalent stiffness). In addition, the mean value of the positive and negative maximum response displacement was used for the value of displacement for the calculation of potential energy.

A calculation method for response period

To understand the response period of the specimen during the earthquake turbulence, the following three calculation methods of the period are defined. Because the nonlinearity is strong for a wooden structure, the force rises against the strength of the maximum displacement with nonlinearly at repetition vibration after the structure damage. Therefore, the equivalent stiffness depends on the response deformation volume. This dependency is necessary to consider in the equivalent period, and the equivalent stiffness is decided every extraction loop. The calculated method for the equivalent period that is used is shown in definition 1. With definition 2, the equivalent stiffness is decided from the deformation on the skeleton curve of specimen, and the equivalent period is calculated with it. With definition 3, from the reason that a specimen may respond with the period of earthquake turbulence, this period is decided from a time passing to one cycle of an extraction loop. After this, a period from definition 1 is described with an equivalent period. Next, a period of definition 2 is described with an equivalent period from a skeleton curve, and a period of definition 3 is described with a loop period.



(1) Specimen classification

(2) Earthquake wave classification

(3) Only the extraction loop that reach first deformation

Horizontal: 1st story drift angle

Figure 4. Equivalent viscous damping ratio.

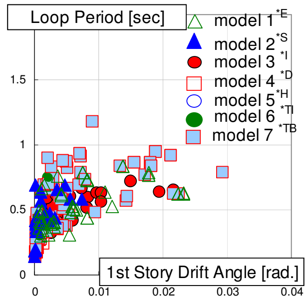
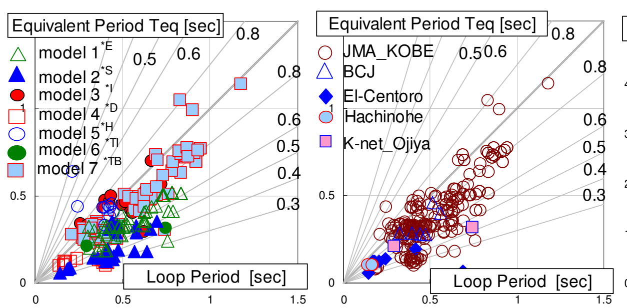
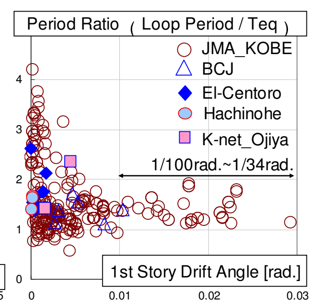


Figure 5. Loop period.



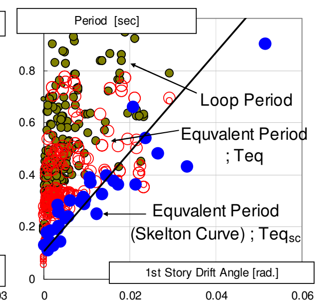
1) Specimen classification (2) Earthquake wave classification

Figure 6. Equivalent and loop period.



Horizontal: 1st story drift angle

Figure 7. Period ratio.



Horizontal: 1st story drift angle Teq , Teq_{sc} , Loop period

Figure 8. Period ratio.

An equivalent viscous damping ratio

At first, the viscous damping that is structure damping (this is a friction damping of joint and an inner friction damping) and hysteresis damping are included in the equivalent viscous damping ratio from using the experimental results from a shaking table test in this study. So that viscous damping of wooden dwelling houses depend on deformation, a correlation for the first story drift angle is shown in Fig. 4 (1),(2),(3) and the correlation is considered. The equivalent viscous damping ratio has remarkably wide distribution. In particular, it gathers from 0.1 within the span of 0.2 where the first story drift angle is small (1/100radian around). Its minimum was 0.05, maximum was 0.49. Next, in more than 1/100radian, the distribution shrinks and it tends to gather from 0.05 within the span of 0.17.

Next, in the results of many shaking table tests, the damping ratio of the extracted loop is shown in Fig. 4 (3), the deformation of the loop reached the first deformation when the loop was extracted and it does not reach the first deformation until extracted time (after this, the loop is described as an inexperienced loop from the damage). Though the extracted loop is small, the equivalent viscous damping ratio is stayed within the span from 0.11 to 0.16 entirely. Because the unevenness is large in the span for the small equivalent stiffness and the story drift angle, and because it is small in the inexperienced loop of the damage, the unevenness of the equivalent viscous damping ratio occurs in the span of repetition vibration after the damage in the small deformation.

From the above, the damping ratios of wooden houses gather from 0.1 within the span of 0.1. Especially, it is clear in the large story drift angle. But, if the energy ratio changes every hour at the time of repetition vibration after the damage, the equivalent viscous damping ratio has unevenness. (Especially, it is thought that the change of the equivalent stiffness is large.)

A period of response vibration

A previous study (Nishimura and Miyazawa, 1995) reported that story drift vibrates with earthquake period without vibrating with a natural period from consideration of a full scale shaking table test with wooden dwelling houses. In this report, to show the tendency more definitely, an extraction loop is defined in more depth and the target specimens were increased more than the report. (A span of maximum response drift was enlarged). The calculation of period used is the method shown in Fig. 3 and the tendency of a response period is considered form using the equivalent period “Teq” and the equivalent period of a skeleton curve “Teq_{sc}”, the loop period.

Mutual relations of the equivalent period and loop period are shown in Fig. 6. With a general tendency, the loop period shows a longer period than the equivalent period. In the Partial span, for example, the loop period has unevenness in the span from 0.43 within 0.84 seconds where the 0.5 second of equivalent period. This result means to vibrate with the period from 0.86 within 1.68 times for the equivalent period. Especially, the unevenness has large span at the shorter span than equivalent period of 0.5 second and the equivalent period and loop period are near the period at the span from 0.5 within 1.0 second. In addition, relations of the equivalent period and loop period do not show an especially clear tendency for reason of influence that has different causes of earthquakes or specimens. At the relation of the loop period for the story drift angle in Fig. 5, the loop period becomes long with the increase of story drift angle. But the loop period has large unevenness within story drift angle that is 1/100radian. Therefore, these specimens vibrate with the wide span of period. For the specimens that have nonlinear characteristics that were shown in definition 1 of Fig. 3, where the story drift angle is small, the equivalent stiffness changes and the equivalent period changes too. Because of these changes, it is possible that the response period varies. (Only a change of the equivalent period is not a factor and a change in the viscous damping is an important factor too.) However, in Fig. 3, even as for a certain one specimen, because the loop period has a wide span for a constant equivalent period at the span of short period the earthquake period that is one another factor greatly influences response period. It is thought that the response of wooden dwelling houses may occupy the earthquake period than the equivalent period in lower than 1/100radian of story drift angle around on the time of the earthquake.

Next, the period ratio is shown in Fig. 7 to grasp the difference between the equivalent period and the loop period. The period ratio that is used here is the ratio of a loop period for an equivalent period. The period ratio is 4.2 at the maximum and its minimum is 0.56. Distribution of the period ratio is wide in the small span of story drift angle. The distribution of the period ratio becomes narrow and the ratio tends to get closer to1.0 when the story drift angle is beyond 1/100radian.

A decision method for a building period is thought a few. Periods of three ways are defined in this report and these periods are compared. The equivalent period, ”Teq”, and loop period have large unevenness for equivalent period of the skeleton curve and it is longer than another period. In particular, these periods are different for the equivalent period of the skeleton curves greatly where the story drift angle is small.

2 chapters of conclusion

(1) A damping performance that includes structure damping and hysteresis damping.

The damping performance of a wooden house is the span from 0.1 within 0.2 at the time of earthquake turbulence. Especially, when the response drift is large its tendency is clear. But because the equivalent stiffness changes every time at the time of repetition vibration after the damage, it is thought that the damping ratio has large unevenness.

(2) A response period at the time of earthquake turbulence.

The response of story drift is influenced greatly in an earthquake period characteristic. Especially, when the story drift angle is smaller than 1/100radian, the response is influenced in an earthquake period greatly, as a result, the wooden house vibrates with the period of the wide span. But the influence of an earthquake period is small and the response period of the wooden house depends greatly the equivalent period when the story drift angle is over 1/100radian and the equivalent period become around 1 second.

Analytic Verification of Response Period

In this chapter, understanding of a response period is made clear by analysis. A response analysis is implemented and the displacement of analysis result is divided into a periodic component by Fourier transform and from making clear the tendency of predominant amplitude and a theoretical factor with a change of natural period (an equivalent period) of an analysis model, and the tendency of a response period at the time of an earthquake turbulence is grasped.

The specimens in chapter 1 and 2 have a nonlinear structure characteristic and therefore, actually, the equivalent period that is wooden structure changes instantaneously with temporal continuity by the damage. The change of an equivalent period does not have continuity in this study and the response period is considered with this result from using the combination of each analysis result in chapter 4. In addition, the specimens are two story or three story, but this analysis model is single degree of freedom system to make understanding simple and its result is considered. (The upper part story of the wooden dwelling house has the story shear coefficient that is higher enough than the first story in these past several years in Japan. For this reason, if it is a two story structure, the second story structural stiffness of analysis model will be rigid and the dynamic response is not greatly different from the model that its stiffness is not rigid. Its analysis result has enough precision).

An analytical method and analysis model

A Frequency response analysis method (Fourier transform method) is used for analysis. Using the Fourier displacement amplitude spectrum that is the product of a Fourier spectrum of ground motion and transform function, the predominant period of the Fourier displacement amplitude is grasped. The analysis model is a shingle degree of freedom system. The damping of the model is set so that the response equivalent viscous damping ratio becomes constant. This setting is expressed in the hysteresis damping of wooden structures and it is supposed that frequency dependence on the hysteresis damping is small and is grasped. In addition, the hysteresis damping has amplitude dependence but it is not considered. And the evaluation that is isolated each the damping of amplitude is possible and is supposed. The damping factor has four kinds; 0.01, 0.05, 0.1 and 0.2 in this analysis. However, because the damping factor that is 0.01 is almost an undamped system, it is clear that the resonance period is predominant. Therefore, the analysis result that the damping factor is 0.01 is omitted in this report.

A lot of natural frequency of the analysis model (an expression of a period was used in chapter 2, but in chapter, an expression of a frequency is used) were set but the analysis results of the frequencies of four kinds (0.5Hz, 1.0Hz, 3.3Hz and 5.0Hz) that are its span fit a wooden dwelling house are reported in this report. (From a lot of results of consideration the tendency of analysis results can be explained enough with four frequencies.)

Many of the recoded earthquake waves and the simulated earthquakes are used in this analysis.

JMA_KOBE_NS (1995), El-CENTORO_NS (1940), TAFT_NS (1952), TOKYO_NS (1956)
HACHINOHE_NS (1968),TAKATORI_NS (1995),SENDAI_NS (1963),
TOHOKU_NS (1978)
BCJ (The Building Center of Japan)_Level2 (Simulated earthquake)

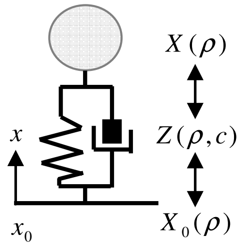


Figure 9. Analysis model.

$$\ddot{x} + \frac{2heq\omega^2}{\rho}\dot{x} + \omega^2 x = \ddot{x}_0 \qquad Heq\,;\, Damping\ Factor\ at\ the\ \mathrm{Re}sonancefrequency$$

EXP ; 3.1 $\qquad \omega$; *Natural Circular Frequency* , ρ ; *Circular Frequency of External Force*

$$Z(\rho,h) = \frac{1}{\omega^2(1-\frac{\rho^2}{\omega^2}+2h\frac{\rho}{\omega}i)} \qquad X(\rho,h) = -Z(\rho,h)\cdot \ddot{X}_0(\rho), \quad \ddot{X}(\rho,h) = \rho^2 Z(\rho,h)\cdot \ddot{X}_0(\rho)$$

EXP.3.2

Analysis Results

In many analysis results, the analysis results that are used the JMA_KOBE that is included the wave pattern of pulse, EL_CENTORO and BCJ is shown in Fig. 10, Fig. 11 and Fig. 12. In addition, the tendency of analysis results was similar to the analysis results of other earthquake waves.

1) The Fourier displacement amplitude when a change of a damping gives

The response of the earthquake turbulence is predominant for the Fourier amplitude of resonance frequency especially and the analysis model vibrated with the natural frequency in an undamped system. In Fig. 11, the amplitude of resonance frequency is decreased greatly when the damping factor is increased. In the spectrum of the natural frequency “5.0Hz” that is shown in Fig. 10 and Fig. 11 (TAFT), especially, the frequency ratio (it is frequency of ground motion for the natural frequency) is predominant at 1.0 around when the damping factor is 0.05. In addition, the amplitude of the frequency ratio that is 1.0 around is decreased when the damping factor is 0.1. But because the amplitude of the resonance frequency is decreased, the amplitude that the frequency ratio has the wide span has predominant averagely when the damping factor is 0.2. In the small deformation span (the span is domain when the damage of structure does not experience and the small deformation is not included deformation at the repetition vibration after the damage of certain displacement), if the damping factor of a wooden house is the span that is from 0.03 within of 0.05 the wooden house may have at the resonance frequency. But the prospect that the structure vibrates with resonance frequency is decreased when the hysteresis damping began to occur with the small damage. Its tendency is similar where the span is shorter with a natural frequency of ”5.0Hz”. But because the decrease of natural frequency that is described as follows influences predominant of amplitude greatly, the defined tendency at 5.0Hz around is negated.

2) The Fourier displacement amplitude when a change of natural frequency gives

When a damping factor increased at around the natural frequency that is 5.0Hz, especially, the Fourier amplitude of the response becomes average and the analysis model is vibrated with a wide span of the frequency ratio when the damping factor is 0.2. But as the natural frequency decreases, the Fourier amplitude is predominant at the small span of resonance frequency around when the damping factor is 0.2 and the tendency show in the Fig 10. In its conclusion, as the natural frequency decrease, the predominance of the displacement amplitude begins to go to the frequency ratio that is around 1.0. The transform function of a response displacement and acceleration for ground acceleration was shown in Fig. 12 (1), (2). Its damping factor is 0.1. The transform functions are decided from the ratio of the natural frequency for the frequency of earthquake in EXP.3.2. Even if the natural frequency was differenced, if its ratio (for the earthquake) was not differenced, the transform functions do not change. Therefore, if the transform function value is constant the band of frequency over its value is greatly different with depending of the natural frequency (the ratio of the natural frequency for the earthquake is the same). For example, in the frequency band of transform function that is over value of the transform function where the ratio of the natural frequency for frequency of the earthquake is small endlessly, the frequency band is 1.0Hz at the natural frequency 1.0 and is 7.2Hz at the natural frequency 5.0Hz in Fig. 12 (1). (Because magnitude of response displacement is not understood for this explanation, the overall picture becomes clear at a transform function of the acceleration for ground acceleration in Fig. 12 (2).)

For this reason, when the transform function is multiplied to the Fourier spectrum of earthquake wave, the transform function with narrow frequency band will have predominant of small frequency band than the transform function with the wide band. From this, if the natural frequency of the analysis model decrease (from 5.0Hz to 0.5Hz) the Fourier displacement amplitude has predominant with the frequency ratio of 1.0 around, and its tendency is cleared.

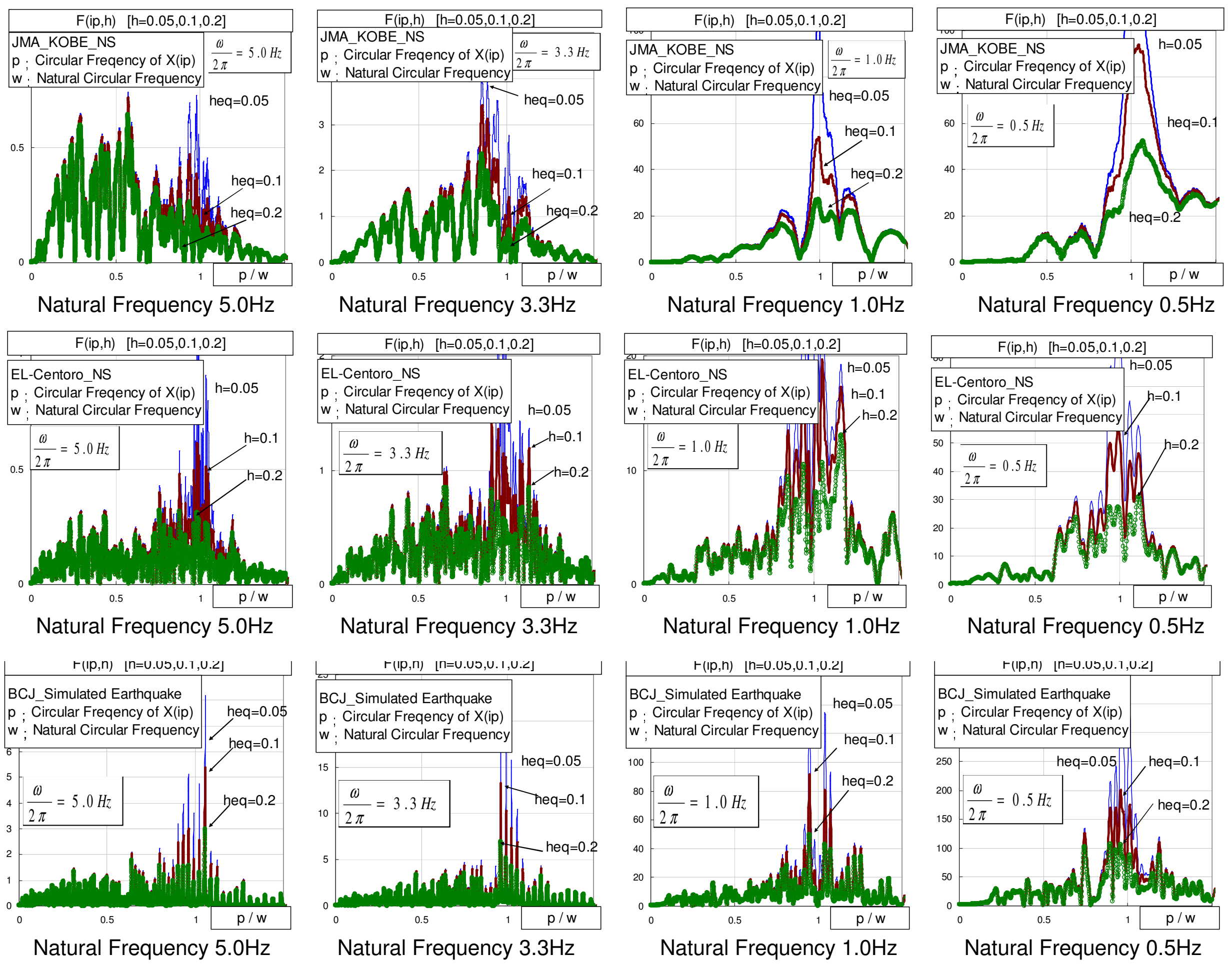


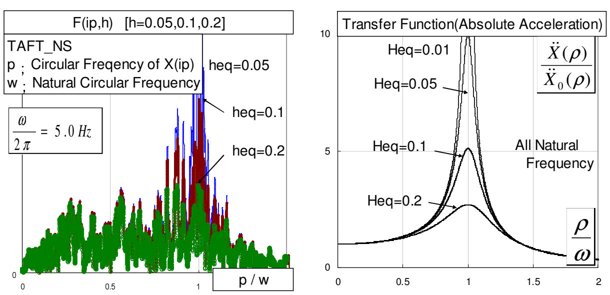
Figure 10. The Fourier spectrum of response deformation (Upper; KOBE, Middle; El-Centro, Lower; BCJ).

3) The Fourier acceleration amplitude of earthquake and Transfer function

Next, relations of the Fourier spectrum of the earthquake that is used in this study and the transform function (the damping factor is 0.1 and its transform function is acceleration for ground acceleration.) are shown in Fig. 13. (The results of similar earthquake of Fig. 12 and SENDAI are only shown in Fig. 13.) In all the Fourier spectrums of ground acceleration that are used in this study, these amplitude are predominant at the band of 3.0Hz from 0.5Hz greatly and the amplitude decreases from the maximum amplitude at the band of 3.0Hz from 0.5Hz in 3.0Hz over and lower than 0.5Hz. Therefore, if the natural frequency is more than around 3.0Hz, the Fourier amplitude of the band of frequency where the amplitude of earthquake is lower is increased greatly. And adversely, the increasing rate of the amplitude decreases compared with the amplitude of the band at below 3.0Hz. For this result, the amplitude is predominant averagely at all bands below 3.0Hz.

The Fourier ground acceleration amplitude is the band of the frequency with originally large amplitude in the natural frequency of around 1.0Hz. Furthermore, the amplitude at the band is increased greatly by the transform function. Additionally, because the transfer function is in a narrow frequency band, adversely, the amplitude is decreased in over 1.3Hz (for example, frequency band is over than 7.2Hz when the natural frequency is 5.0Hz.). As a result, the amplitude is predominant at the natural frequency around 1.0Hz.

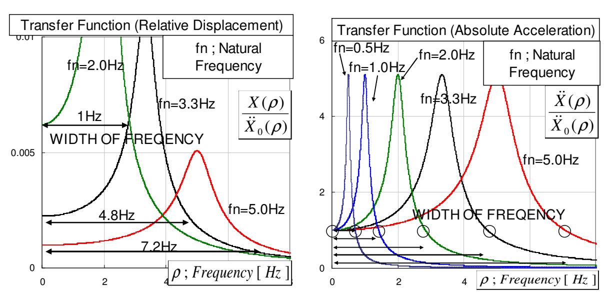
As above, the response frequency is influenced largely with the changing of the natural frequency and the Fourier spectrum shape of the earthquake. But so that there is a spectrum irregular that is having the two points predominant at around 1.0Hz and 4.0Hz, it is shown in the SENDAI of Fig. 13, the state of predominance has unevenness for a spectrum irregular for every earthquake. Its tendency occurs in Fig. 10. (But, for example, at the EL-CENTORO of Fig. 10, though the band of predominance is wide at the natural frequency of 1.0Hz, but the band is narrowed band from around 0.8Hz to 1.2Hz and the response frequency does not get into a state greatly).



Natural Frequency5.0HZ TAFT_NS

Horizontal ; frequency Ratio (ρ/ω)

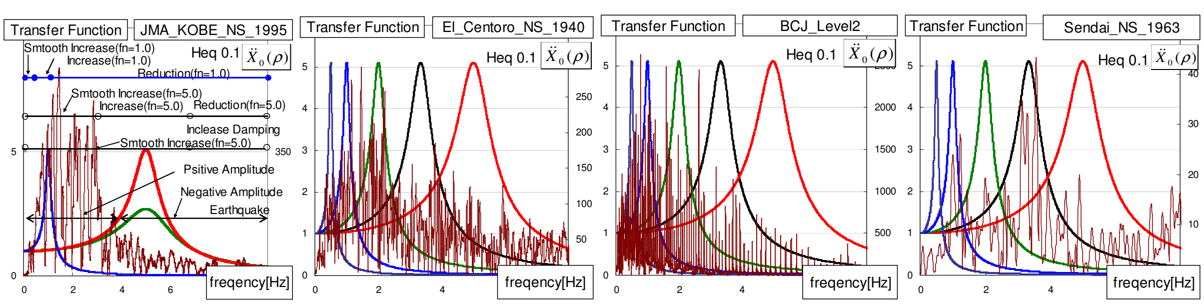
Figure 11. Fourier spectrum and transfer function.



Horizontal ; Frequency
(1) Response Deformation

Horizontal ; Frequency
(2) Response Acceleration

Figure 12. Transfer function.



JMA_KOBE El-Centro BCJ SENDAI

Figure 13. Fourier acceleration spectrum (ground motion) and transfer function (Heq 0.1).

3 chapters of conclusion

(1) If the analytical damping is almost no damping, the analysis model responds with the resonance frequency. But if the damping factor increases, the response has a large component of frequency. This means it vibrates with a wide frequency band.

(2) The response frequency of an earthquake turbulence changes to the response that has large predominance at the resonance frequency around with a fall of a natural frequency in comparison with a large natural frequency.
(3) From relations of a spectrum characteristic of earthquake and a transform function, unevenness occurs in response frequency.

Conclusions

An expression of frequency was used in the third chapter but this was after an expression of period. In chapter 2, the damping performance of the wooden house, an equivalent viscous damping ratio is the span from 0.1 within of 0.2 at the time of the earthquake turbulence. Especially, this is clear in 1/100radian over (first story drift angle). But the damping ratio has unevenness at the time of the repetition vibration after the damage. Next, from comparison of the loop period and an equivalent period, the structure responds with the period span of earthquake period characteristic in the narrowed span of first story drift angle. But when the structure occured damage with the large story drift, it vibrates at around the equivalent period. Such a tendency of the change is concluded.

In the analytical results of chapter 3, the response period of the analysis model changes for the damping factor and natural period and it had the unevenness and irregularity of an earthquake. The equivalent period of the wooden house was 0.1 second over in the result of chapter 2. But because it is the response period in the small deformation (lower than 0.1cm), this after, deformation at 1/200radian is based on. This reason is assumed being linear limit in a wooden dwelling house. As a result of chapter 2, the equivalent period is 0.2 second at the 1/200radian. The damage grows larger from its deformation and the period becomes around 1.0 second at around 1/30radian.

As above, when the response of a wooden dwelling house is around 1/200radian, the equivalent period is 0.2 seconds and the equivalent viscous damping ratio is 0.1, if these are assumed and the analysis result is considered, the structure vibrates with the influence of the earthquake. But, after this, if the damage is larger than at 1/200radian the hysteresis damping becomes larger than before. But for the damage, the equivalent period is long, Around 1.0 seconds. And in this result, the structure has the tendency of vibrating with the equivalent period. But the irregularity of an earthquake gives its consideration unevenness.

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