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RESIDUAL STORY-DRIFT OF WEAK-BEAM PORTAL FRAME WITH SLIP-TYPE RESTORING FORCE CHARACTERISTICS OF COLUMN-BASE SUBJECTED TO GROUND MOTION

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SUMMARY

This paper shows the magnitude of residual lateral displacement of weak-beam portal frame subjected to earthquake ground motion. Herein, considering slip-type restoring force characteristics of exposed steel column-base at the bottom of column in the first floor, the effect of frequency of harmonic wave and the maximum velocity of random wave as ground motion on the residual displacement is evaluated in the earthquake response analysis.

INTRODUCTION

We have some construction methods of steel column-base to reinforced concrete foundation beam in steel frame. Exposed column-base type among them is frequently employed, because the mechanism of stress transfer from column to foundation beam is simple and clear, besides the construction work is considerably easy.

In the exposed column-base type, anchor bolts through base-plate welded to column-end are used to connect with RC foundation beam, and only these anchor bolts yield under bending moment of column. Then, in general, restoring force characteristics under repeated and reversal moment shows slip-type in moment ∼ rotation relationship, as well known. However, in spite of many investigations on static behavior of exposed-type of column-base exist, it is not enough to be made clear on the dynamic response behavior of frame considered column-base deformation to ground motions yet.

From this point of view, the author already describes the maximum story-drift of frame considering slip-type restoring force characteristics of column-base subjected to ground motion, in comparison with considering elasto-perfectly-plastic-type and degrading-stiffness-type of column-base[1] [2][3]. As the result, there is no significant difference on the maximum story-drift of frame among these three types of column-base, in spite of usual understanding on the less energy absorption capacity of slip-type being inferior to the other types.

In addition to the above seismic behavior, it can be strongly pointed out that slip-type restoring force characteristics of column-base has an advantage rather than elasto-perfectly-plastic-type and degrading-stiffness type of column-base in residual deformation of frame damaged after earthquake. That is, lateral displacement of frame due to ground motion may easily return to its initial upright position after the stop of ground motion , because the rotational deformation of column-base freely slips at the zero moment level. On the contrary, there is no possibility of zero deformation of column-base if once the other type of

restoring force characteristics of column-base experienced plastic deformation.
For repair of frame damaged by earthquake, it is desirable to rest at the initial position of frame after the end of ground motion. Therefore, exposed-type column-base showing slip-type restoring force characteristics can be strongly recommended. However, magnitude of residual deformation of frame subjected to earthquake ground motion is not clear yet.

The objective of this study is , in weak-beam frame with slip-type restoring force characteristics of exposed column-base, to estimate the magnitude of residual lateral displacement after plastic excursion of frame subjected to dynamic loads. Two cases of parametric response analysis of frame model are carried out for this purpose. In the first case, both period ratio of external Sin-function to natural period of frame model and maximum velocity of Sin-function as parameters are used. In the second case, eight earthquake ground motions, for example, El Centro NS , with two levels of maximum velocity of these motions are applied to frame model. Finally, the magnitudes of residual lateral displacement of frame as the results are described in the both cases

FRAME MODEL AND METHOD OF RESPONSE ANALYSIS

Weak-beam frame model for response analysis

5-story-1-bay frame model is used for earthquake response analysis as a typical low-rise steel frame. Overall dimensions, values of weights concentrated on beam-to-column connections and sectional inertia moments are shown in Fig.1. Rotational deformation of column-base at the bottom of the first floor column is considered. Flexural rigidity is allocated to the beams and columns so that lateral stiffness of each story becomes to be approximately linear distribution in the height. Full-plastic moments of the beams are equal to elastic moments due to the story-shear distribution factor Ai with the standard base-shear coefficient Co=0.25 in Japanese code. Large flexural strength of column rather than its of beam is assumed so that weak-beam strong-column is realized. Elastic rotation stiffness K_B of column-base is assigned by ratio 1.0 of K_B to flexural stiffness 3EI/h of the first floor column, in which the notation E(=2100ton/cm^2) is Young's modulus, I is sectional inertia moment and h is column-height. The natural period To of the first mode of vibration is 0.98 second.

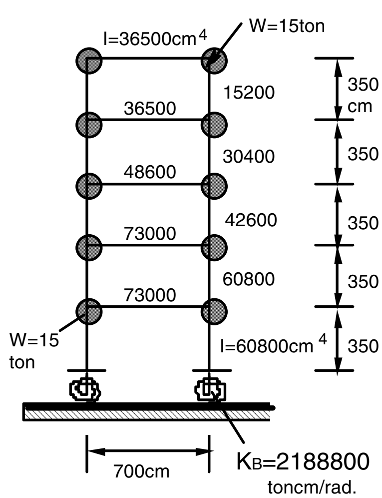


Fig.1 Frame model

Table 1 Strength of beams

Beam	Full-plastic Moment bMp(toncm)
Roof	1548
5F	3210
4F	4488
3F	5808
2F beam	5551=bMp
Base	3296=My

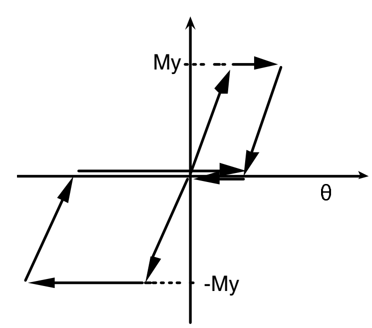


Fig.2 Slip-model of column-base

Idealized slip-type restoring force characteristics model in moment-rotation relation as shown in Fig.2 is assumed for the column-base, in which the notation My is yield moment. The value of My is equal to

0.8cMp, in which cMp is the value of moment at the bottom of the first floor column used Co=0.25 and Ai mentioned above. At the beam ends in frame, restoring force characteristics of elastic-plastic hinges is elasto-perfectly-plastic model. Again, all of the columns in frame are elastic.

Method of response analysis

Mass matrix of the frame is composed of lumped-mass. Stiffness matrix is formulated assuming only flexural deformation of the beams and columns without axial and shear deformation. Damping matrix is made in proportion to initial elastic stiffness of the frame with damping constant 3% for critical. Equation of motion of the frame is solved by step-by-step direct integration employed Newmark's β (β =1/4) method in which time increment between 1/100 and 1/1000 sec. is used.

RESIDUAL DISPLACEMENT OF FRAME MODEL TO HARMONIC GROUND MOTION

Parameters in response analysis

At first, it is assumed that the frame is subjected to a harmonically varying ground motion of amplitude A and period T.

$$Z = A \sin(2\pi t/T)$$

where Z is acceleration, t is time. Four values of the period T for parametric study is given as T/To=0.4, 0.8, 1.2, 1.6 where To is the first natural period (=0.98sec.) of the frame. Since the maximum acceleration A is equal to $2\pi V/T$ in which V is the maximum velocity, as another numerical parameter, 50, 75 and 100kine of V are selected to investigate the effect of intensity of harmonic ground motion on residual lateral displacement of the frame. Time duration of numerical response analysis is 15 seconds in this case. Residual displacement of the frame is evaluated at each floor level as shown in Fig.3. Fig.4 is an example of residual point estimated at the end time 15 second after calculation by moving average in time history of lateral displacement response.

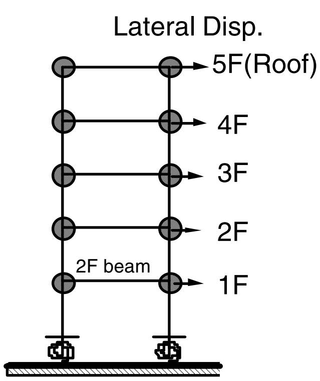


Fig.3 Displacement of floor level

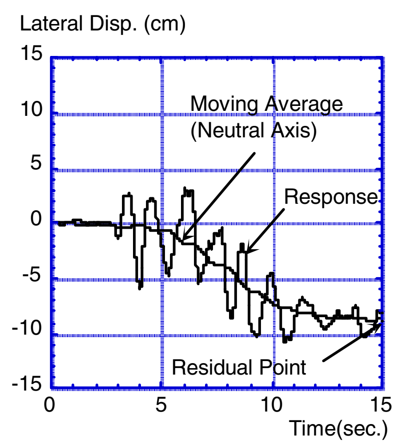


Fig.4 Examples of residual displacement

Lateral displacement behavior

Fig. 5 shows time history of lateral displacements at 1F, 3F and 5F of the frame. It is recognized that lateral displacements shift to one direction in early time of response history in ratio T/To=0.4 rather than in T/To=1.6. For the maximum velocity V=100kine rather than V=50kine, neutral positions of the oscillation move to one direction with the passing of time in the response duration.

Residual lateral displacement

Residual lateral displacement in the frame to harmonic ground motion is shown in Fig. 6. Inclination angles 1/200, 1/100 and 1/50 rads. of column deformation are described in the figure. The residual displacements as the response results are almost not over around 1/200, 1/100 and 1/50 rads. for V=50, 75 and 100kine, respectively, as shown in Fig.6. The residual incline angles of column for T/To=0.4 are slightly larger than the others for T/To=0.8, 1.2 and 1.6.

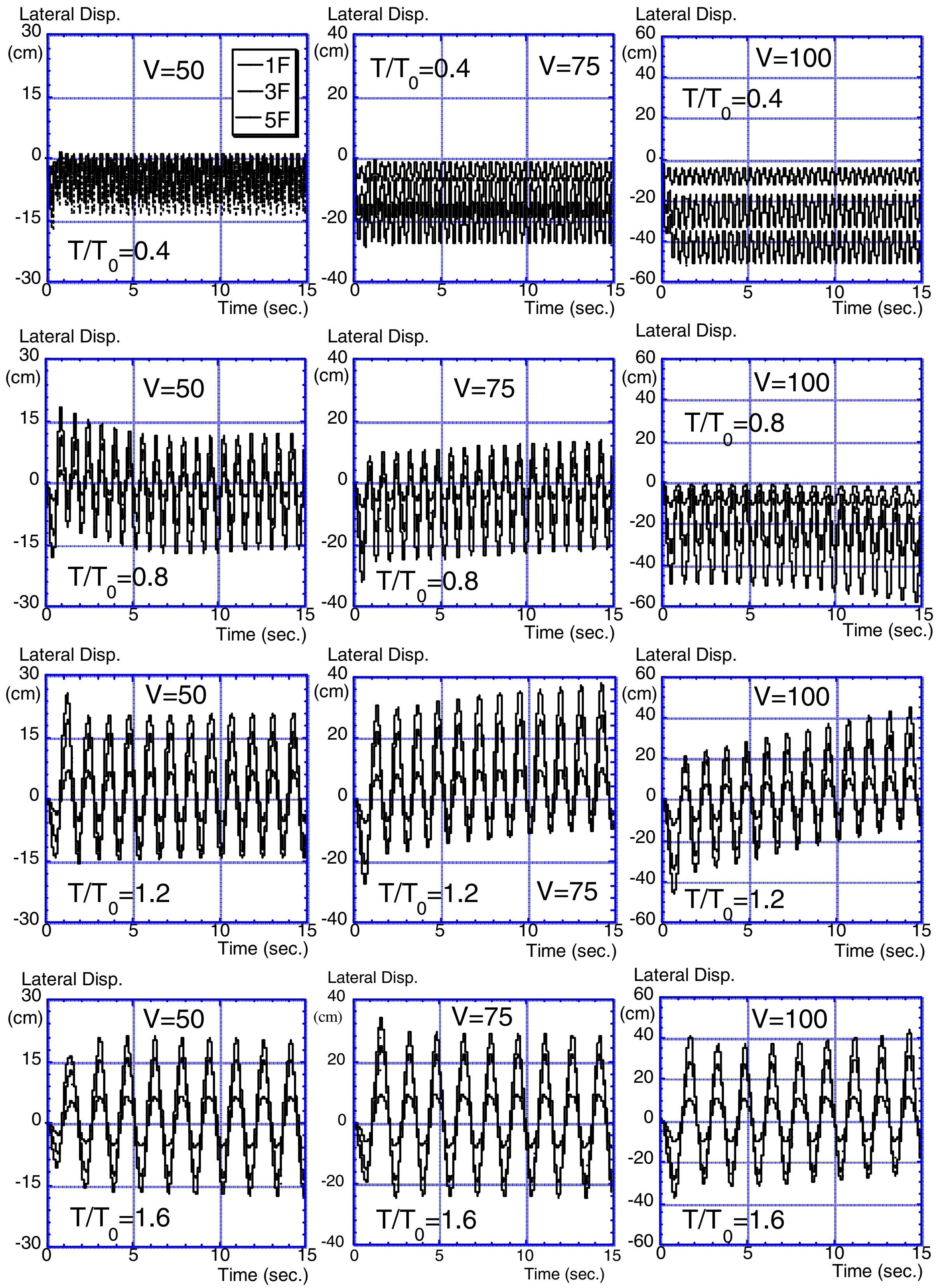


Fig. 5 Lateral displacement of floor levels to harmonically varying ground motions

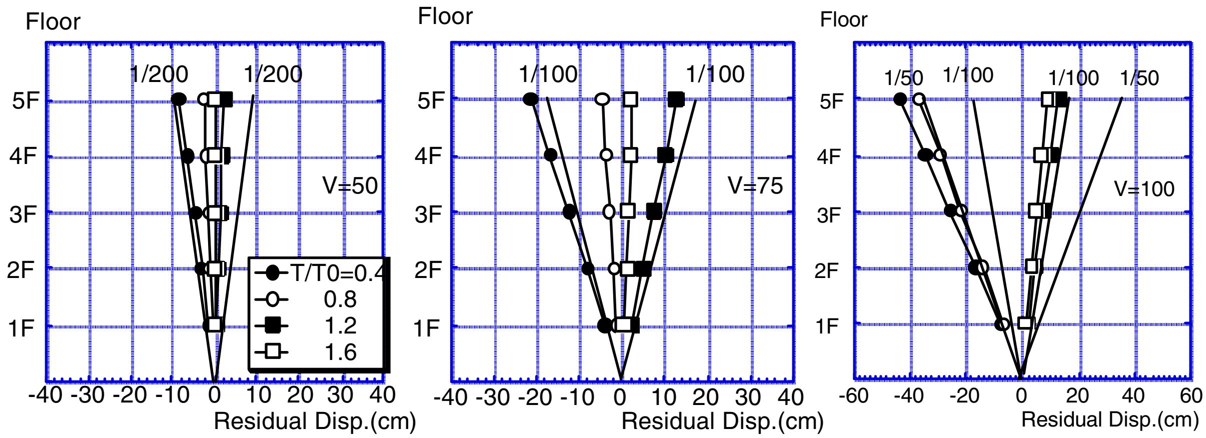


Fig.6 Residual lateral displacement at floors to harmonically varying ground motions

RESIDUAL LATERAL DISPLACEMENT OF FRMAE MODEL SUBJECTED TO RECORDED GROUND MOTIONS

Parameters in earthquake response analysis

In the next, seven recorded earthquake ground motions and one artificial ground motion (named Yokohama) are employed for estimation of residual lateral displacement of the frame. The ground motions used in response analysis is listed in Table 2 in which the original maximum accelerations, velocities and time duration including 5 seconds free vibration subsequent to the end of ground motion. However, base-line of the motion in the duration is not corrected. Fig. 7 and Fig.8 show time history of ground acceleration and response spectrum of equivalent velocity of input energy into elastic one-mass system, respectively. As a parameter in response analysis, maximum velocity V of the ground motions is changed to 50 or 100kine. As another parameter, full-plastic moment of 2F beam shown in Fig.3 is increased to 1.2 and 1.4 times of the initial value bMp of full-plastic moment in the original design listed in Table 1. The increase of full-plastic moment of 2F beam is indirectly to investigate the reduction of damage concentration into the first story having slip-type restoring force characteristics of column-base [4]. Due to the effect of avoidance on damage concentration, simultaneously, the influence of strength of 2F beam on residual lateral displacement of the frame is studied.

Maximum story-drift and lateral displacement behavior

Fig.9 shows maximum story-drift of the frame with the original bMp of 2F beam. In the case of the maximum velocity V=50 kine of ground motions, the maximum story-drifts are approximately 1/100 rad. of column chord angle and almost uniform distributions in all stories. However, the values of maximum story-drift in each story to V=100 kine are slightly scattered according to the ground motions. Examples of lateral displacement history at the roof floor are shown in Fig.10 , as two cases of very different behavior. The neutral axis lines by moving average method for response time histry are described in the figures. The plastic excursion of roof displacement is very small to Hachinohe EW both with V=50 and V=100kine. On the contrary, to San Fernando NS of V=100kine, one-direction shift of the neutral vibration axis at the roof floor gradually becomes large. Input energy into system having short natural period by San Fernando NS seems to be large a little as shown in Fig.8. However, against V=50kine of San Fernando NS, it is recognized that shift of the roof floor is very small.

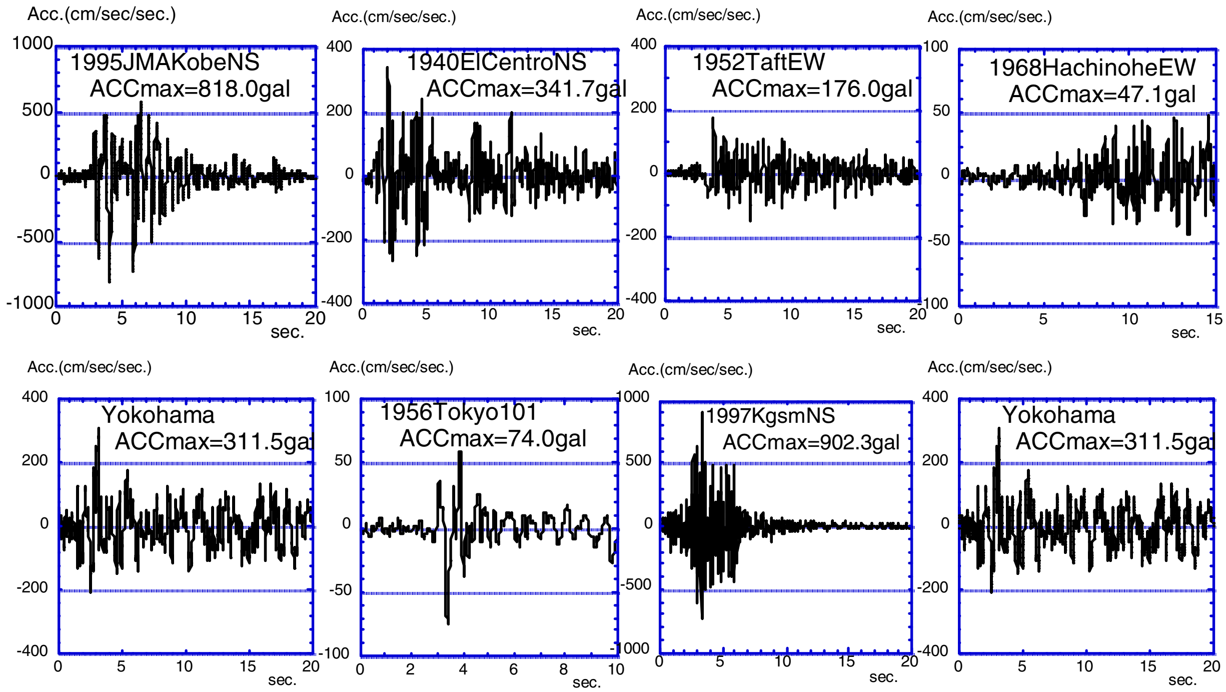


Fig.7 Earthquake ground motions for response analysis

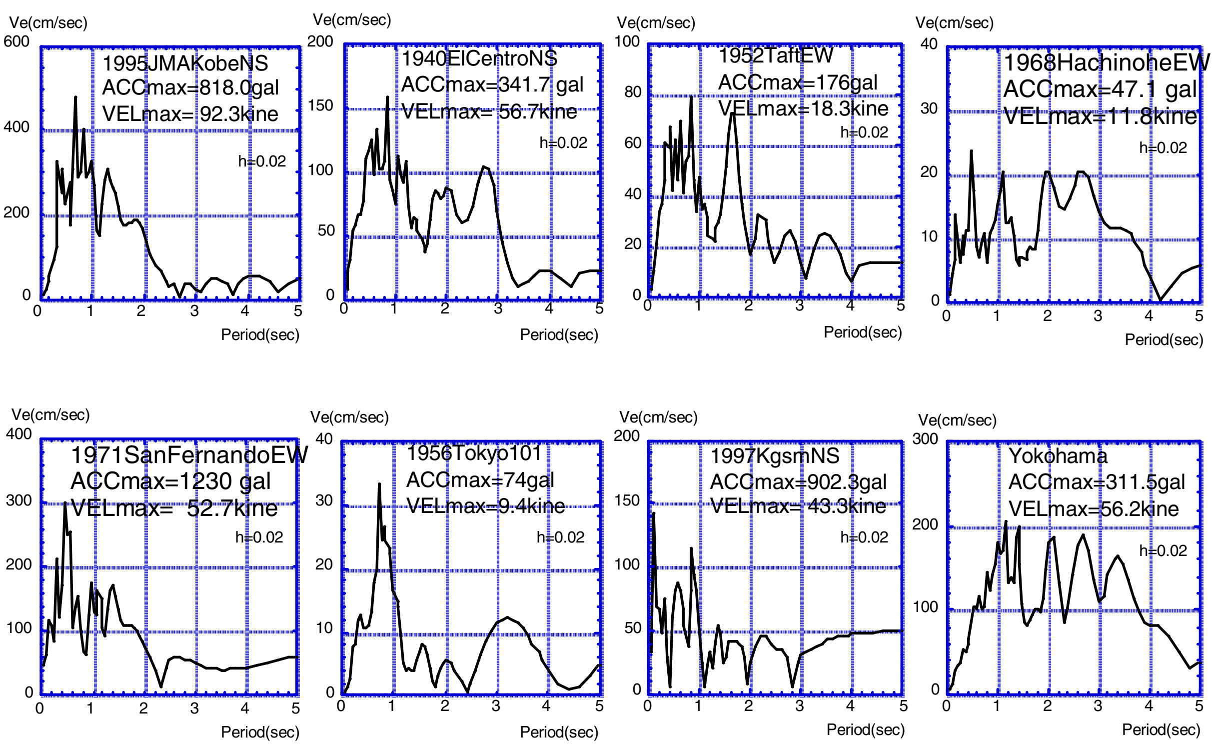


Fig. 8 Equivalent velocity of input energy due to earthquake ground motions

Table 2 Ground motions

Earthquakes	Max. Acc. (gal)	Max. Vel. (kine)	Time Duration (sec.)
JMAKobeNS(1995)	818.0	92.3	25
ElCentroNS(1940)	341.7	56.7	25
TaftEW(1952)	176.0	18.3	25
HachinoheEW(1968)	47.1	11.8	20
SanFernandoEW(1971)	1230.0	52.7	15
Tokyo101(1971)	74.0	9.4	15
KgsmNS(1997)	902.3	43.3	25
Yokohama	311.5	56.2	25

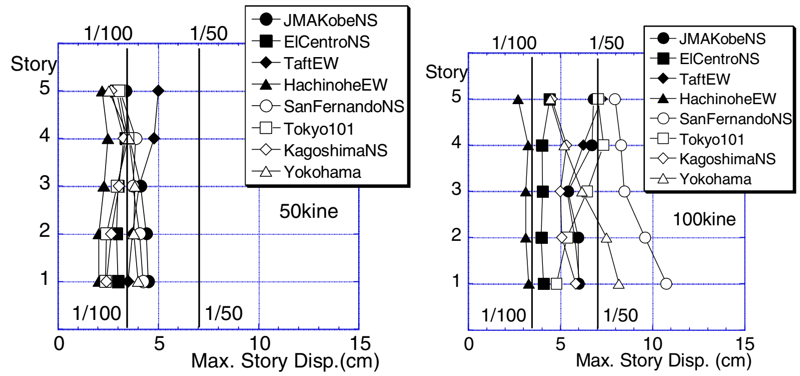


Fig.9 Maximum story-drift

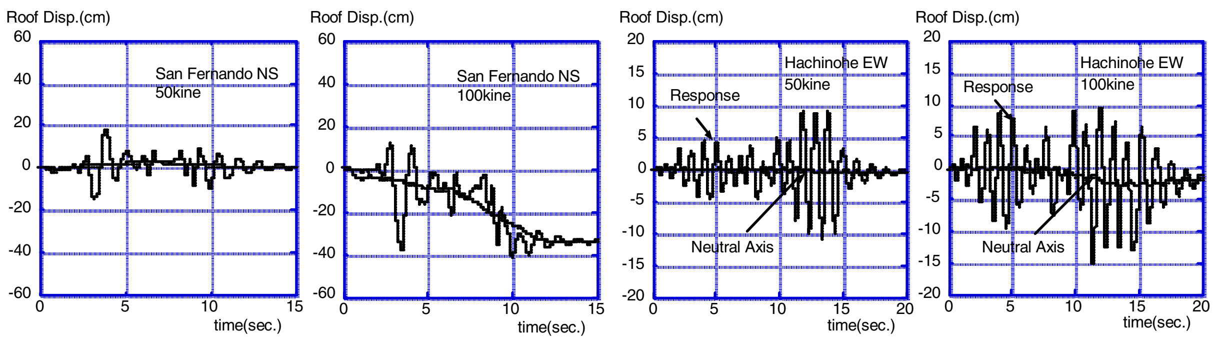


Fig. 10 Roof displacement history (to Hachinohe EW, San FernandoNS, 50, 100kine)

Residual lateral displacement

Fig.11 shows residual lateral displacement at roof floor in the frame with bMp of 2F beam. As can be seen in the figure, inclination angle of overall frame, which is defined as ratio of the residual lateral displacement at roof floor to the frame height, is less than around 1/200 rad. to V=50 kine of ground motions. To V=75 kine of ground motions, inclination angle is less than about 1/120 rad. Magnitude of the residual inclination depends on ground motions in case of V=100kine. For example, residual inclination happens around 1/50 to San Fernando NS, but it is less about 1/100 rad. to the other ground motions. The relation between the mean values of residual displacement at roof floor to all of ground motions and the maximum velocity of ground motions is shown in Fig.12. The mean values of residual inclination is slightly over 1/200 rad. in V=100kine. Besides, we can recognize that the effect of increasing of full-plastic moment of only 2F beam is not significant as shown in Fig.13.

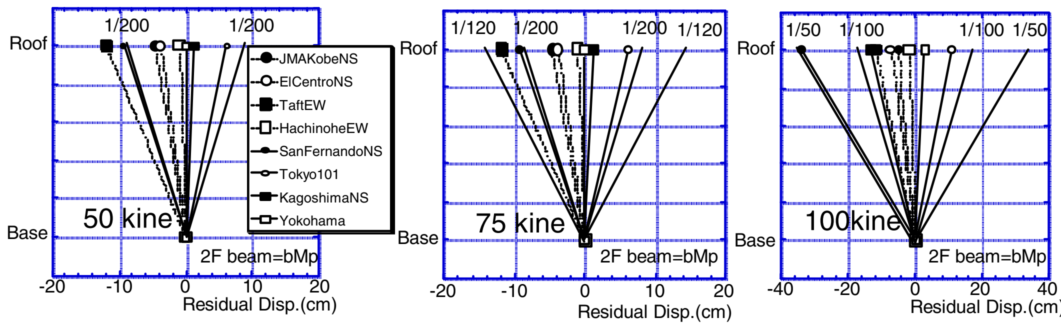
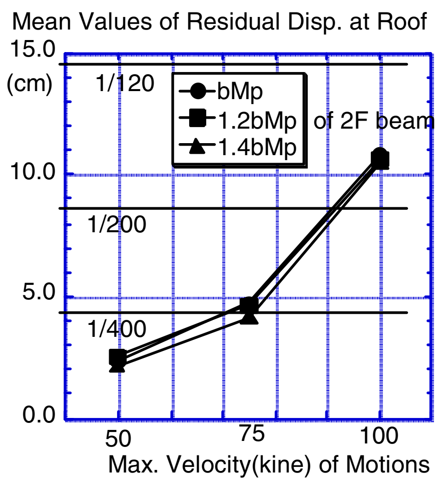


Fig.11 Residual lateral displacement at roof floor



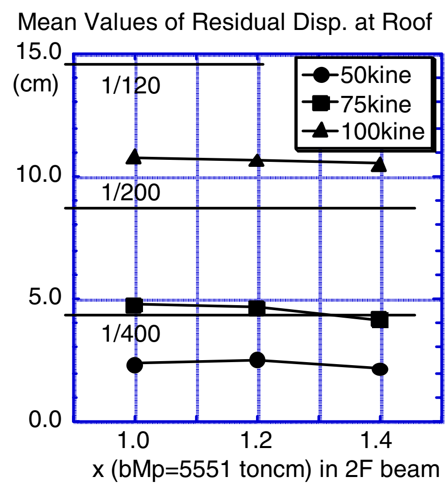


Fig.12 Mean value of residual displacement (influence of maximum velocity)

Fig.13 Mean value of residual displacement (influence of strength of 2F beam)

CONCLUSIONS

Inelastic earthquake response analysis for residual lateral displacement of weak-beam frame considered slip-type restoring force characteristics of column-base is carried out. The main purpose in this investigation is to confirm the superior characteristics of slip-type of column-base for easy recovery of frame after damage due to earthquake ground motion.

Conclusions in this paper are that short period component of ground motion wave may be related to the residual or permanent lateral displacement of frame, and the residual lateral inclination of frame is less around 1/400 rad. on average to the maximum velocity V=50kine or 75 kine of ground motions, even though residual inclination of frame about 1/120 rad. occasionally and individually happen.

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