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論 文

[2216] Behavior of Earthquake-Response Concrete Buildings Having the Natural Period Extended by Soft-First-Story

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1. INTRODUCTION

Through the studies about the Soft-Story structure, authors had proved that the structural designers can control the natural period of concrete buildings with using Soft-First-Story(S.F.S.). and the estimating equations of the natural periods proposed by authors can be applied not only to estimating the natural periods of concrete buildings with S.F.S. but also to determining the basic conditions of columns of S.F.S. for attaining the designed natural periods[1]. But, even if the results calculated from these equations are applied to adjust the conditions of S.F.S., the designed natural period can not be attained easily because applying these results has many restrain factors, for example; Young's modulus, the strength of concrete and the slanderness ratio, etc[2]. For attaining the designed natural period, these restrain factors must be studied to determine the amount of influence on the natural period of concrete buildings and then based on this research, the calculated values must be revised. And so the study on the influence of these factors on the natural periods had been researched in the area of the principal tendency, however, the study on the practical application of the results obtained from the research of this principal tendency has not been done. Besides, for using S.F.S. structure in concrete buildings as the earthquake-resistant-system the dynamic behavior of multistory concrete buildings with S.F.S. should be examined and analyzed carefully when these buildings are subjected to the earthquake.

Thus, firstly this study discusses about the practical method of adjusting the conditions of S.F.S. and examines the character of this S.F.S. in the earthquake response. Secondly, in this study the behavior of the earthquake response of concrete buildings with above mentioned S.F.S. and the influence of S.F.S. on the behavior of these buildings are studied.

2. ANALYSIS METHOD AND CONDITIONS

2.1 ANALYZED BUILDINGS

The original buildings used in this study are the 20-story building and the 8-story building. It is assumed that upper stories of these buildings maintain all properties of original buildings, but the first stories of these buildings are changed as S.F.S. for attaining the designed natural periods. The stiffness distributions and the yield displacement distributions of each story are shown in Fig.2. The weight and the height of upper stories are about 850t and 300cm in the 20-story building, 730t and 350cm in the 8-story building, but those of the first story are 1339t and 400cm in the 20-story building, 912t and 410cm in the 8-story building. The natural period of the 20-story building is 1.80sec in case of using the yield stiffness and 1.08sec with the initial stiffness which is smaller than

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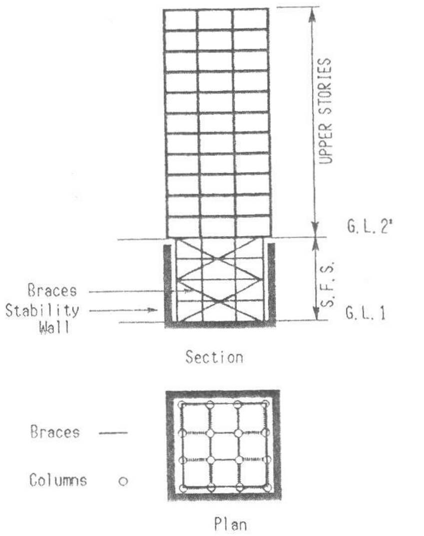
1.19sec estimated by the estimating equation of the design code of AIJ(T=0.02H,H is the height of a building). Then the natural period of the 8-story building is 1.68sec with the yield stiffness and 0.84sec with the initial stiffness which is larger than 0.574sec estimated by the equation of AIJ. For examining the behavior of the earthquake response of those buildings, they are modeled to the multimass shear system, in which S.F.S. and each upper story are considered as each one mass(Fig.3). Though S.F.S. is consisted with columns and the prestressing strand braces, the prestressing strand braces which have a large elastic range(the tensile strain is over 7.5%)[3] are assumed that they are used for restraining the gravity effect which is known as a secondary product of the interaction between the vertical gravity and the lateral displacement. The amount of the prestressing strand braces(Ab) satisfying this purpose can be probably induced from the following equation[2].

$$Ab = Pt((L/h)^2+1) / (Ep \cos q \; L/h)$$

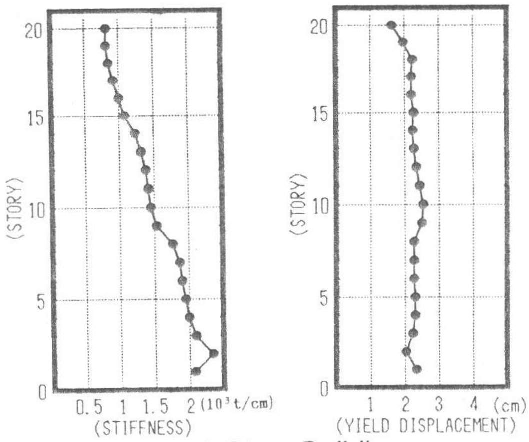


*G.L.2 : when the S.F.S. is placed underground

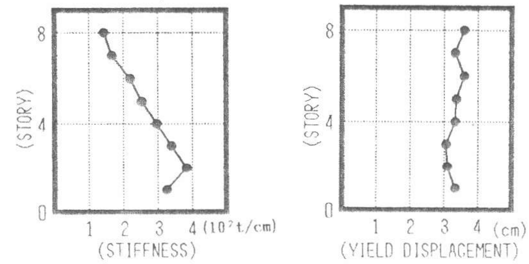
Fig.1 Concept of S.F.S. Structure

where, **Pt** is the weight of the building, **L** is the horizontal length of the prestressing strand brace, **h** is the vertical length of the prestressing strand brace, **Ep** is Young's modulus of the prestressing strand brace and **q** is the angel of the prestressing strand brace with the horizon level.

The amount of the gravity effect is calculated from the single degree of freedom system in this study. Therefore, the spring constant of S.F.S. can be determined by only the stiffness of the column of S.F.S. on condition that the prestressing strand braces properly restrain the gravity effect without changing any other conditions of S.F.S. In this study, the gravity effect is neglected in the process of the response analysis to assume that the prestressing strand braces properly restrain it.



a) 20-Story Building



b) 8-Story Building

Fig.2 Conditions of Original Buildings

2.2 ANALYSIS METHOD

Three recorded earthquake waves, EL centro 1940 NS (maximum ground acceleration, Agmax = 314.7gal, Duration, to = 29sec), Taft 1952 NS (Agmax = 152.7gal, to = 30sec) and Hachinohe 1968 NS (Agmax = 183.6gal, to=30sec), are used in this study. They are normalized through the spectrum intensity in the range of the natural period, t = 0.5sec - 5.0sec[4] and the results of the earthquake responses are calculated by Newmark β method (β = 1/4) with the time interval, Dt = 0.005sec. The normalizing factors for the waves listed above are 1, 1.98 and 1.24 respectively and the damping is considered as 3% in the elastic range and 5% in the inelastic range.

The height of S.F.S. or the diameter of the column of S.F.S. is determined by multiplying the height of the original first story and the revised height increase ratio(CRh) or by multiplying the diameter of the column of the original first story and the revised column diameter decrease ratio(CRd). CRd and CRh are values revised from the diameter decrease ratio(Rd=Diameter of Column of S.F.S/Original Diameter of Column of The First Story) and the height increase ratio(Rh=Height of S.F.S./Original Height of The First Story)[1] which are calculated by author's proposing the estimating equations as the following equations(Reference Fig.5).

* Estimating equations induced from the simple linear regression method(S.L.M.)

$$Te=0.62+0.027Ns+0.028X \quad (X<=96-1.6Ns)$$

$$Te=2.208+0.0114X \quad (X > 96-1.6Ns)$$

$$X= Rh^3/Rd^4$$

where **Te** is the designed natural period and **Ns** is the number of the story

* Estimating equation induced from the theoretical study(Theory)

$$Te=To(1+(X-1)/Xo)^{0.5}$$

$$To=6.28(XoM/k1)^{0.5}$$

$$Xo=0.48+0.52Ns$$

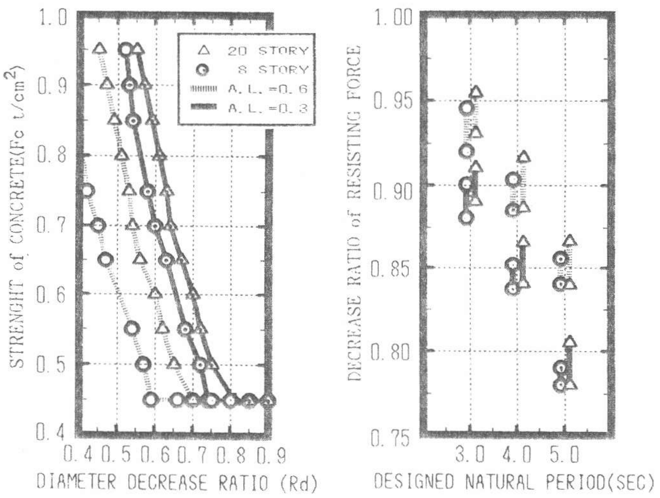
*where **M** is the entire mass of a building, **k1** is the original stiffness of the first story of the original building, and **Xo** is the equivalent spring constant*[5].

Fig.3 Analytic Model

The laterally confined reinforced concrete is used in the columns of S.F.S. The pitch of the lateral reinforced steel is 5cm in the area of the presumed hinge and the vertical reinforcement ratio is 4-7% in the 20-story building and 3-5% in the 8-story building which is verified by the diameter of the column.

3. CONDITION AND RESPONSE OF S.F.S.

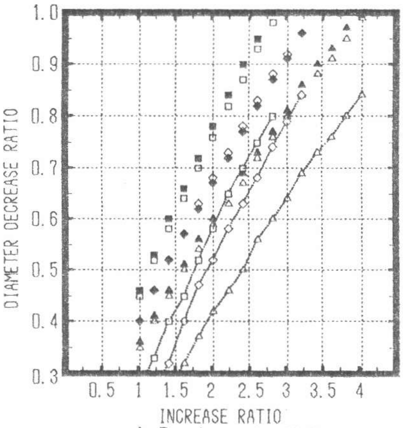
For obtaining the designed natural period, Rd and Rh calculated from the estimating equations should be applied to the first story of the original building. But in case of applying Rd to the column, the applied column should satisfy the limit of the axial stress(A.L). Thus the strength of concrete is increased with decreasing the value of Rd. But it is difficult to uniformly determine this increase amount satisfying the limit value of the axial stress because it is influenced by several factors, such as the weight of the building, the span of columns and the ratio of the reinforce steel, etc. Fig. 4-a shows the strength of concrete connected with Rd, of which the minimum value is 450kg/cm^2 and the increase amount is 50kg/cm^2. The limited value of the axial stress is 0.3 and 0.6 in this figure. This figure presents that the increase of the concrete strength is changed nearly in proportion to the decrease of Rd. The change of the limit ratio of the axial stress makes the very large variation in the connection between the increase of the concrete strength and the decrease of Rd. Practically, in case of the 8-story building if the maximum value of the concrete strength is limited to 950kg/cm^2, the minimum value of Rd satisfying the limit of the axial stress is 0.52 when the value of the limit ratio is set 0.3, but the value is changed 0.6, the minimum value of Rd is decreased to 0.32. And then in case of the 20-story building this minimum value of 0.55 is decreased to 0.44 for the same variation. Therefore, for the efficient application of S.F.S. structure, it is necessary to study about the limit value of the axial stress considering the usage of the laterally confined concrete in columns. Fig. 4-b presents the decrease ratio of the resisting force(Dr = Decreased Resisting Force/Original Resisting Force) with increasing the slenderness ratio on each designed natural period as Rd and Rh are applied to the column of S.F.S. The decrease ratio should



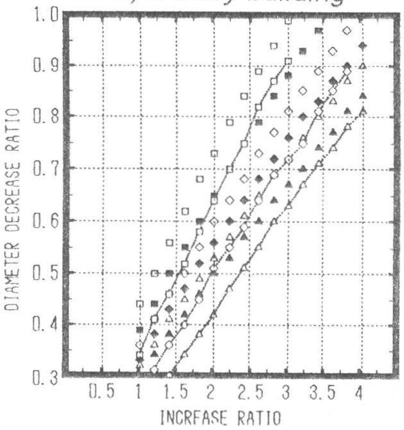
a)Concrete Strength *b) Decrease Ratio*

Fig.4 Influence of Restrain Factors

be described with the range on each designed natural period because the slenderness ratio is changed by the combinations of Rd and Rh having the tendency that the small Rd makes the small slenderness ratio. In this figure, because the resisting strength of a column of the 8-story building is more decreased in the average values by the slenderness ratio than the 20-story building on the same designed natural period, the decrease of the resisting strength of a column should be more carefully examined in the case that S.F.S. is applied to the low rise buildings. And also, the decrease ratio is influenced by the limit value of the axial stress, that is; if the limit value increases 0.3 to 0.6, Dr is increased about above 5% without the number of stories.



a) 8-story building

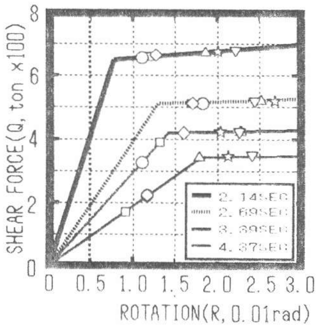


b) 20-story building

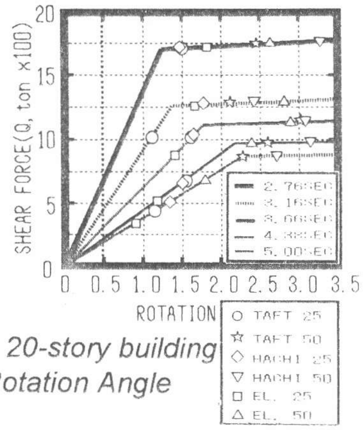
Fig.5 Combination of CRd and CRh

The values of combinations of Rd and Rh shown with the dots in Fig.5 were calculated from the estimating equations proposed by authors and the revised values of these combinations shown with the dashed line in the same figure were obtained by considering the restrain factors. It is known through the comparison Fig.5-a and Fig.5-b that the difference between two values is larger in the 8-story building than in the 20-story building. This means that the combinations of the 8-story building are more influenced by the restrain factors. Therefore, the structure designers should more carefully examine the restrain factors when they want to use S.F.S. to the low rise-building.

The maximum story rotation angle of the earthquake response of S.F.S. and the model of hysteresis on each extended natural period are shown Fig.6. Fig.6-a is the case of the 8-story building. In this figure, the buildings of having 3.39sec or 4.37sec as their natural periods are considered to have the safety in case of 25kine because they resist against the earthquake of 25kine in the elastic range except one case. In case of 50kine the response of the 3.39sec-building has the nearly similar values on each earthquake wave, however the 4.3sec-building has a very different values. Therefore, the most desirable value in the presented natural periods is like 3.39sec to extend the natural period of the 8-story building used in this study with applying S.F.S. From the response of the 20-story building presented in Fig.6-b, it can be shown that the response against 25kine become to have the safety if the natural periods of buildings exceed 3.66sec but the buildings having the natural period of above 4sec show the very different values on each earthquake wave in the response of 50kine. Therefore 3.66sec can be considered as the most desirable natural period to the 20-story building used in this study.



a) 8-story building

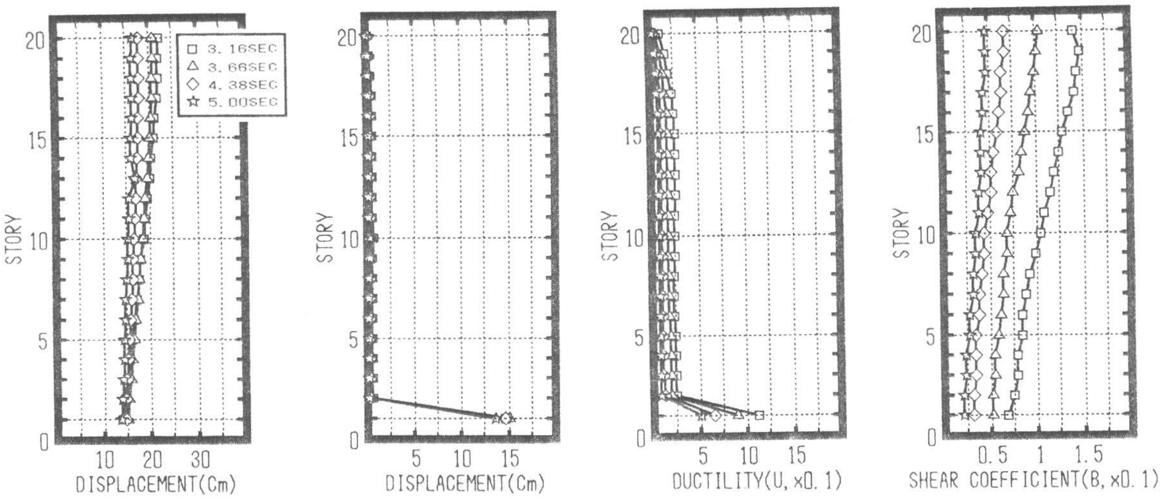


b) 20-story building

Fig.6 Maximum Story Rotation Angle

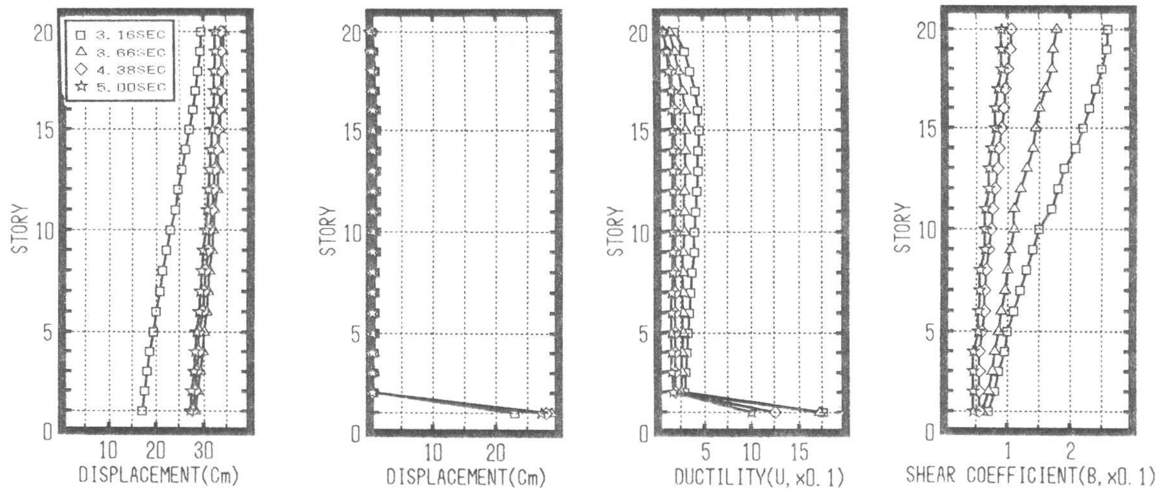
4. DYNAMIC RESPONSE BEHAVIOR OF BUILDINGS WITH S.F.S.

Fig. 7 and 8 show the response values of the 20-story building in which the presented values are the average values of the responses of 3 earthquake waves. From those figures, it can be shown that the amount of the maximum displacement is decreased in proportion to increasing the natural period in case of 25kine but this tendency is not appeared in 50kine. If the natural period is extended from 3.17sec to 3.66sec, this values is largely increased in 50kine but the natural period is increased above 4sec, this value does not mostly changed. The displacement of S.F.S. holds more than 80% of the whole displacement of the building, so that the story displacement is not nearly happened in upper stories, in other hand, it has a large value in S.F.S. regardless the natural period and the



a) Displacement b) Story Deflection c) Ductility d) Shear Coefficient

Fig.7 Response of 20-Story Building (25kine)



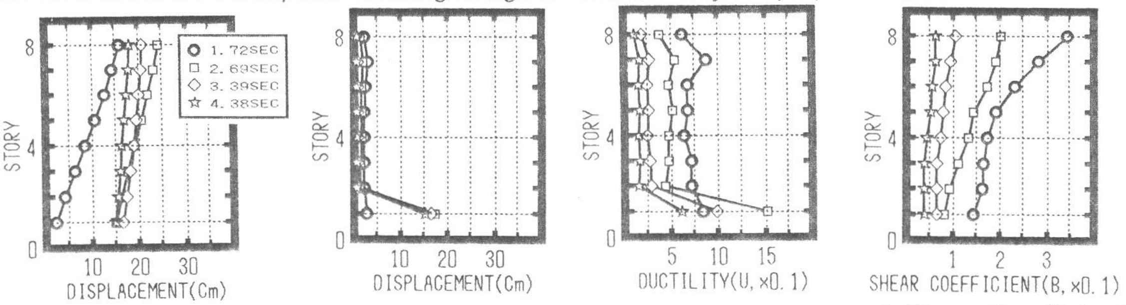
a) Displacement b) Story Deflection c) Ductility d) Shear Coefficient

Fig.8 Response of 20-Story Building (50kine)

magnitude of the earthquake wave.

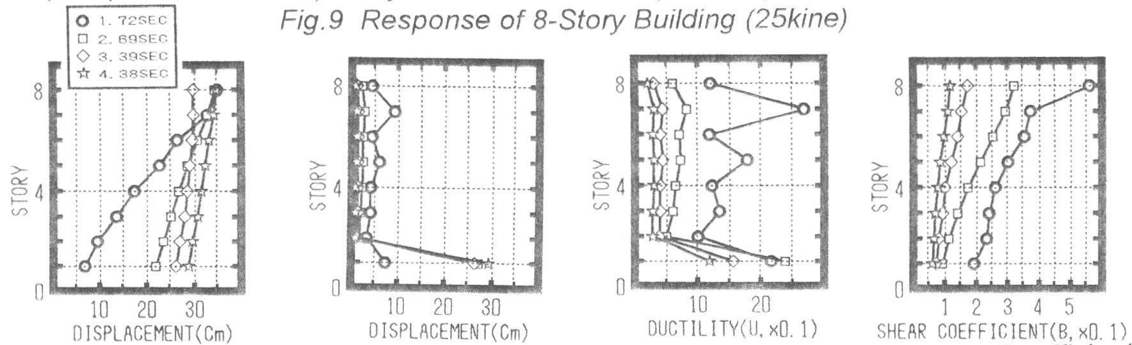
The maximum ductility of each story presented in each figure c is also concentrated to S.F.S. so that any upper stories resist the earthquake force in the elastic range regardless the magnitude and the kind of the earthquake. And the shear force coefficient presented in each figure d has the tendency decreased by increasing the natural period and the decrease amount becomes larger in proportion to the number of the story. Fig.9 and Fig.10 show the response values of the 8-story building in which the presented values are the average values of the responses of 3 earthquake waves. From these figures, it is known that the results of the 8-story building do not have the diference from the results of the 20-story building, in general. But, in the case of 50kine, the maximum displacements of all buildings include the original building have the similar value regardless change of the designed natural period. The 8-story building has the similar character in the earthquake response with the 20-story building but the case of the 20-story building has more typical tendency of buildings with S.F.S.

From results of the above study, it can be said that extending the natural period has a little effect on decreasing the maximum displacement but it is an effective method to resist the earthquake force on condition that S.F.S. is properly designed because the displacement is concentrated on S.F.S. and the design of upper stories will be become easy work. Therefore if S.F.S. is applied to concrete buildings as the method resisting the earthquake, the structural designers have an enough solution about the earthquake resisting design to examine only the proper usage of S.F.S.



a) Displacement *b) Story Deflection* *c) Ductility* *d) Shear Coefficient*

Fig.9 Response of 8-Story Building (25kine)



a) Displacement *b) Story Deflection* *c) Ductility* *d) Shear Coefficient*

Fig.10 Response of 8-Story Building (50kine)

5. CONCLUSIONS

The following conclusions can be drawn from the results of this study;

1) In case of adjusting the conditions of Soft-First-Story, the restrain factors, such as the slenderness ratio, the strength of concrete and Young's modulus etc., are more carefully examined in the low rise-building than in the middle or high rise-building because these factors have more influence on the low rise-building.(See Fig.4 and 5)

2) The proper natural period exists in extending the natural period with the usage of Soft-First-Story and in case of this study, the proper natural period of the 8-story building is 3.39sec and the 20-story building is 3.66sec.(See Fig.6)

3) The structural designers have an enough solution about the earthquake resisting design with neglecting the influence of the earthquake force acted to upper stories as they find only the proper usage of Soft-First-Story because the earthquake response is concentrated on Soft-First-Story.(See Fig.7,8,9 and 10)

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