コンクリート工学年次論文報告集, Vol.15, No. 2, 1993

[2222] Study on Controlling the Natural Period of Concrete Building with Soft-First-Story

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1. INTRODUCTION

It is important that the natural period of building is far from the predominant period of the ground motion. Therefore, if structural designers are able to control the natural periods of buildings, they have a lot of benefits in the earthquake-resistant design. Such control-capability by Soft-First-Story (S. F. S.) is investigated and the possibility to control the natural period of building by the reduction of diameter of column and the increase of height of S. F. S is found. [1]

The purpose of this study is to prove the possibility of controlling the natural period by the usage of S. F. S structure, and to propose the estimating equations of the natural period that relate with the governing factors

2. ANALYTICAL METHOD

In this paper, the buildings dealt with are multistory-concrete frames that have S. F. S. with the laterally confined reinforced concrete columns, but their upper stories have the typical reinforced concrete columns. A dynamic analysis model that is a multimass shear system is shown in Fig. 1-a, in which S. F. S. and each upper story are made of each one mass.

The conditions and the properties of analysis are given as the followings;

(1) Story numbers (Nf) of buildings are five, ten, fifteen and twenty.
(2) The weight and the height of each story is basically fixed at 450tons and 300cm respectively and the yield displacement of each story is limited to 2cm. The Young's modulus of elasticity of concrete is assumed $2.1 \times 10^5 kg/cm^2$, reinforcement ratio of column is 2% and strength of concrete $450kg/cm^2$
(3) The stiffness distribution of the entire building is made from Akiyama's equation [2] (Fig 1-b), but the stiffness of S. F. S becomes smaller by the diameter redution ratios of column [Rk (Diameter of column of S. F. S./Original diameter of column of the first story) =0. 7, 0. 8, 0. 9, 1] and the height increase ratios of S. F. S [Lk (Height of S. F. S /Original height of the first story) =

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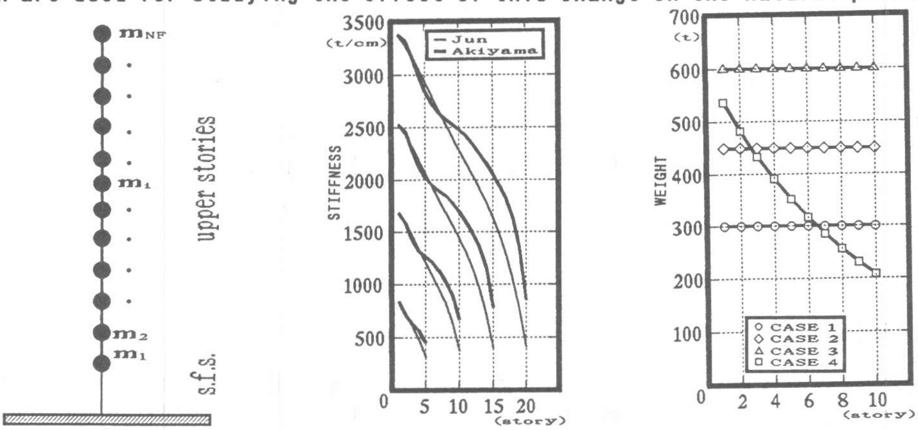
1, 2, 3, 4].
(4) To obtain the natural periods, Jacobi method, which is an iterative method to calculate the eigenvalues and eigenvectors of the system, is used.
(5) fig. 1-b and c show the changed distributions of stiffness and weight which are used for studying the effect of this change on the natural periods.



(a) Analysis Model (b) Akiyama's & Jun's Stiffness Distribution (c) Weight Distribution

Fig. 1 Properties of Analyzed Buildings

3. RESULTS AND CONSIDERATION

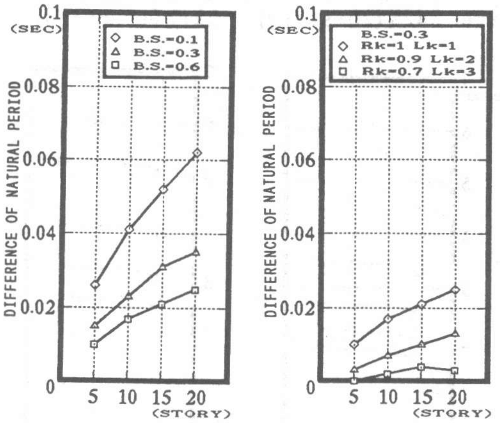
3.1 EFFECT OF STIFFNESS DISTRIBUTION

To study the influence of the stiffness distribution change of the upper stories, the natural periods of Akiyama's stiffness distributions are compared with the natural periods of Jun's stiffness distributions[3] which have smaller stittness values in upper stories (Fig. 1-b). Fig. 2-a shows the difference in the natural period values between the two distributions to the base shear coefficient (B. S.) change and the variations of those differences due to changing conditions of S. F. S. are shown in Fig. 2-b. Because any values in figures do not exceed 1/10 Sec. and the stiffness reduction of S. F. S. descends these values, it is said that the stiffness variation of upper stories have little influence on the natural periods.

3.2 EFFECT OF WEIGHT DISTRIBUTION

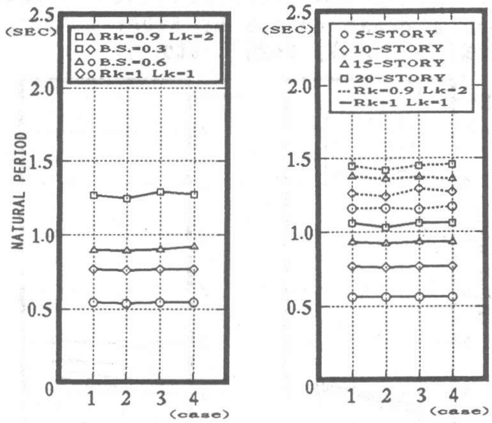
Though 4cases of weight distribution are studied to see the effect of weight distributions (Fig. 1-c), the difference in the natural periods due to weight distribution change does not appear in any results of the analysis (Fig. 3) because the variations of weight distribution must be followed by the overall stiffness ditributions change. If the weight distribution is changed without the stiffness distribution change, the natural period should increase with increasing building weight. But a gain come from the weight increase of building is offsetted by a loss of the stiffness increase, since the building weight increase generally invites the stiffness increase.

After all, the change of weight distribution do not almost make the change in the natural period, except the special case.



(a) Difference (b) Variations by S.F.S.

Fig. 2 Influence of Stiffness Distribution



(a) B.S. (Nf=10) (b) Story Number (B.S.=0.3)

Fig. 3 Influence of Weight Distribution

3.3 EFFECT OF DIAMETER REDUCTION OF COLUMN

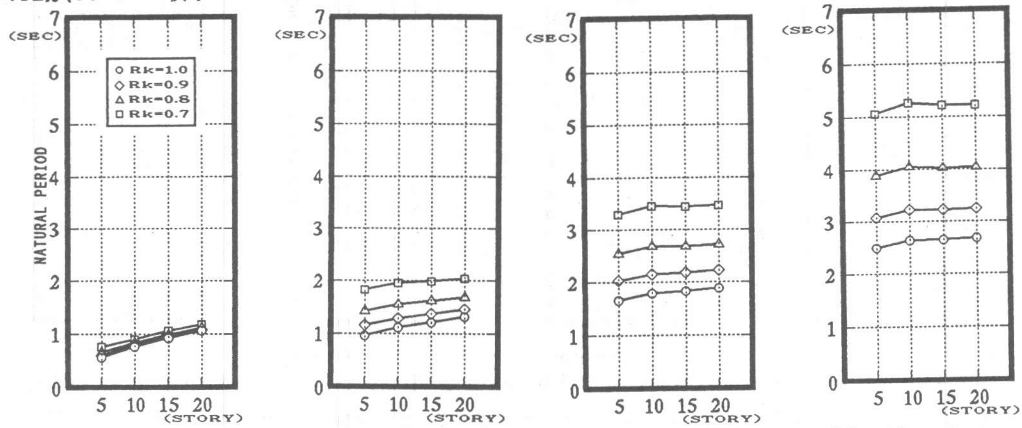
Fig. 4 presents the variations of the natural period values by the diameter reductions of column. It is observed from the figures that these have influence on the natural periods, but then these increase amounts depend on the height of S.F.S.. For example, in case that the height increase ratio (Lk) is 1, these amounts are 0.113Sec. in twenty-story building and 0.2Sec. in five-story building. On the orther hand, if Lk moves to 4, they become 2.538Sec. in twenty-story building and 2.557Sec. in five-story building. And the increase ratios of the natural periods due to this reduction is varied with the number of story, but these differences are not large. Though the method of the diameter reduction of column is effective to increase the natural period, only the usage of this method does not overcome the limit of the number of story which dominates the natural period.

The maximum increase ratios of natural periods by the column's diameter reduction, which are slightly influenced by the number of story, are 94%(20-story), 96%(15-story), 99%(10-story), 102%(5-story).

3.4 EFFECT OF HEIGHT INCREASE OF S.F.S

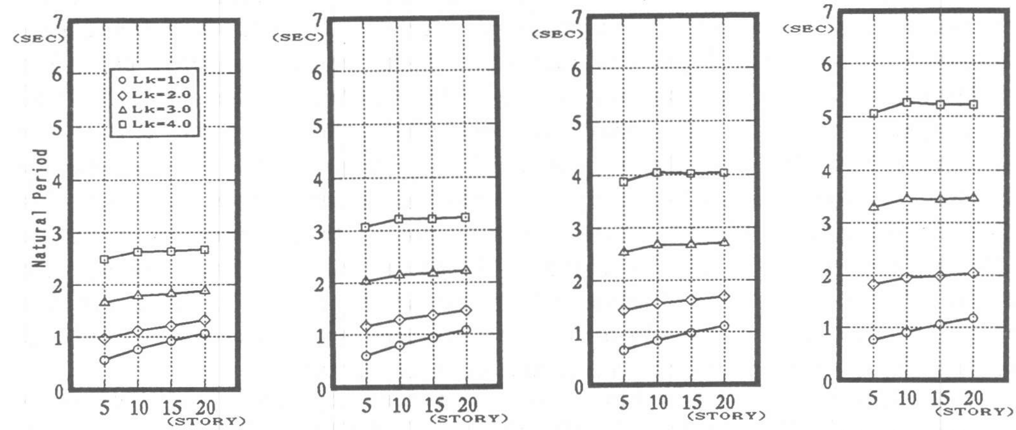
The variations of natural periods by increasing height of S.F.S. is shown in Figs. 5. From the figures, it is found that the height increase of S.F.S. has a great influence on the natural period of building with S.F.S. Also, the method of the diameter reduction of column becomes more effective as the height of S.F.S. increases. Therefore, if this method is used applicably, the low story building can be made to have the long natural periods regardless the number of story. For example , when the increase ratioes became over 3, the story number does not have influence on the natural periods at all in buildings higher than ten-story. However, if structural designers want to make that the low rise buildings have over 3sec as their natural periods, the height increase ratio (Lk) must be made over 3. It is practical difficulties that this ratio becomes over 3 in the low story buildings, therefore the means that S.F.S. set up underground can be considered as a solution for these difficulties.

The maximum increase ratios of natural periods due to this method, which have a great change by story number, are 342%(20-story), 391%(15-story), 482%(10-story), 562%(5-story).



(a) Lk = 1 (b) Lk = 2 (c) Lk = 3 (d) Lk = 4

Fig. 4 Influence of Diameter Reduction of Column



(a) Rk = 1 (b) Rk = 0.9 (c) Rk = 0.8 (d) Rk= 0.7

Fig. 5 Influence of Height Increase of S.F.S.

4. ESTIMATING EQUATIONS

4.1 SIMPLE LINEAR REGRESSION METHOD

The preproposed equations to estimate the natural periods of concrete buildings are unsuitable to apply for assuming the natural periods of concrete buildings with S.F.S., because these were made to estimate the natural periods mainly based on the number of story. Thus, it is necessary to make new estimating equations applied to those buildings.

At first, the simple linear regression method is selected for making a plain estimating equation. From results of this study, it is known that the height increse ratio of S.F.S. (Lk) and the diameter reduction ratio of column(Rk) are the most significant factors on the natural periods. Lk^3/Rk^4 is decided as a variable(X) considering the connection between the natural period and the stiffness. But only this effect factor cannot get the proper estimating values, because the number of story has influence on the natural periods when this variable stays in low range.

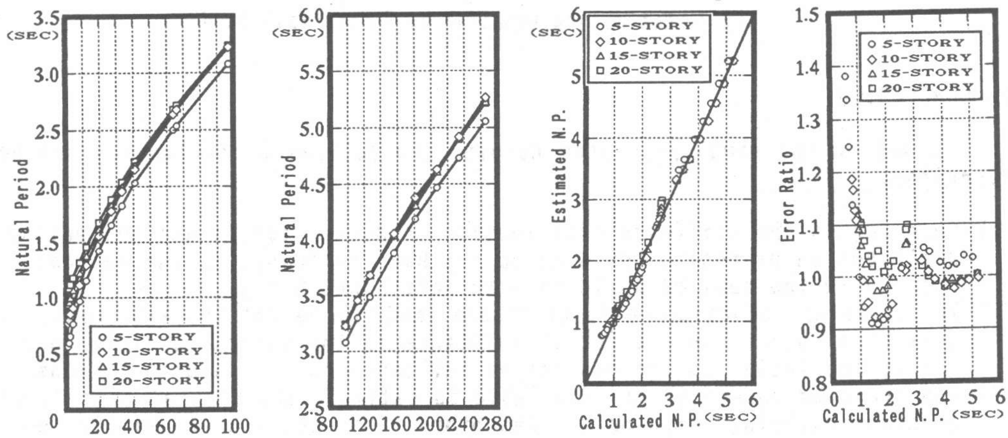
The estimating equations considering the above conditions are

$$Ts= 0.62+0.027Nf+0.028X \quad (X<= 96-16Nf)$$

$$Ts= 2.208+0.0114X \quad (X > 96-16Nf)$$

$$X=Lk^3/Rk^4$$

Fig. 6-a and b show the data used to make the equations. Fig. 6-c shows comparing the natural periods calculated by Jacobi's method with the natural periods estimated by these equations and Fig 6-d shows the error ratios (Er=Estimated value/Calculated value). Though these equations get the relatively exact natural periods over 1sec, the accuracy of this equations becomes worse below 1sec. But these equtions have a practical applicability because they are usually used over 1sec for estimating the natural periods.



(a) Used Data (X < 100) (b) Used Data (c) Comparing Results (d) Error Ratio

Fig. 6 Estimating Equations by Simple Linear Regression

4.2 EQUATION INDUCED FROM THE THEORETICAL STUDY

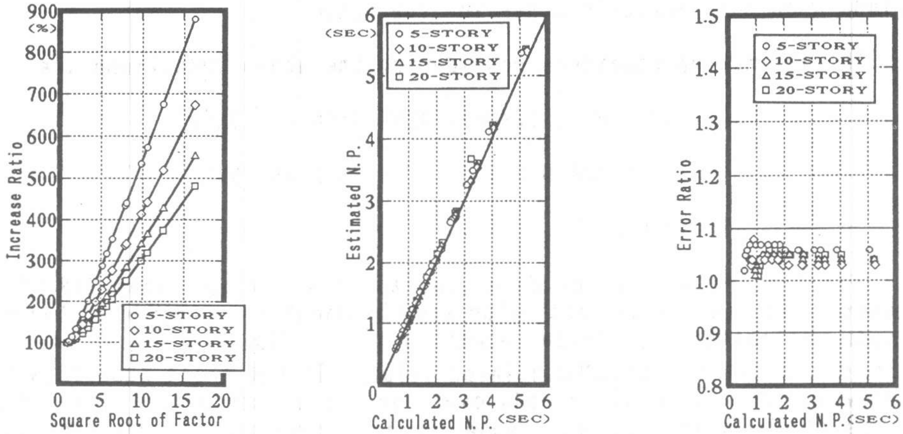
Another equation is made on the basis of the increase ratio connected with the square root of the influence factor and the ratio of the first story spring constant to the equivalent spring constant (X0=0.48+0.52Nf) [4]. This equation originally get the increase ratio of the natural period, therefore it has the complex style and the complexity in calculation but the high accuracy.

The estimating equation is as follows;

$$Ts= T0(1+1/X0(X-1))^{0.5}$$

$$T0= 6.28(X0*m/k1)^{0.5}$$

where, m is the entire mass of building and k1 is the original stiffness of the first story. Fig. 7-b shows the comparision between the natural periods calculated by Jacobi's method and the natural periods estimated by this equation. The maximum error of this equation is 8%(Fig 7-c).



(a) Increase Ratio of Natural Period (b) Comparing Results (c) Error Ratio

Fig. 7 Estimating Equation by Theoretical Study

5. CONCLUSION

Based on the study presented herein, the following conclusions can be described;

(1) Changing in the stiffness distribution in upper stories and the weight distribution of entire building do not have influence on the natural periods in the case of building with Soft-First-Story.
(2) The diameter reduction ratio of column and the height increase ratio of Soft-First-Story have a lot of influence on the natural periods, especially the latter factor has larger influence on the natural periods.
(3) The proposed equations are available to estimate the natural periods of concrete buildings with Soft-First-Story. The equations by simple regression method are simple and have practical applicability, and the equation induced from the theoretical study is accurate.

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