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A study on inter-building coupling behavior with link-members

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ABSTRACT: A cross shaped 12-stories composite building, that is constituted of 4 identical wings connected by 2 link slabs at every floor and 2 link braces every two floors, is used to discuss analytically the vibration characteristics and to compare these results with the data measured in a forced vibration test. In the analysis model, it is assumed that each mass has 3-degrees of freedom (X- and Y- translation and rotation) and is connected to the isolated link-members which has freedom only in the axial deformation. The results show the special modes called "link-modes" which are recongnized from the analysis and forced vibration test. These link-modes are mainly caused by the deformation of the link-members which take important roles in reducing and simplifying the deformation of each wing in an earthquake response behavior.

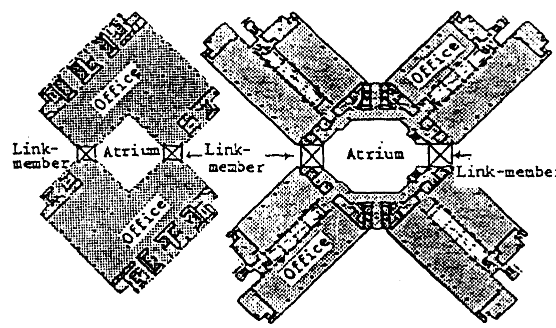
1 INTRODUCTION

The use of this type of link-members is extending widely (refer to Fig.1.a).The multi-mass vibration system and the link-members used as connections represent the configuration of this complex building structure shown in Fig.1.b.

The reasons to use link-members are; (1) to reduce a torsional vibration when each wing has an eccentricity in the plane; (2) to get a structural damping effect when each wing vibrates slightly at different modes; (3) to make an atrium space with high-side lighting and ventilation thus providing ample space for working environment. From a structural point of view, it is expected that an inter-building coupling behavior will occur in this type of building. This will be discussed analytically in this paper and then compared to the data measured in the forced vibration test.

2 ANALYSIS SYSTEM

The multi-mass vibration system and the link members connected are shown in Fig.2. The corresponding vibration equation is Eq(1). Each mass has 3-degrees of feedom (X- and Y-translation and rotation), and the isolated link-members have only axial deformation. However, as a set of link-members, it could resist against bending, shear and axial deformations in the plane. The component of K_L matrix was determined from the equilibrium condition at each mass center, as shown in Fig.3.



(a) 20-storey steel building (b) 12-storey composite(SRC) building

Fig.1 Examples of building plans with link-members

$$[M]\cdot\{\ddot{u}\}+[K_B]\cdot(\gamma_B\{\dot{u}\}+\{u\})+[K_L]\cdot(\gamma_L\{\dot{u}\}+\{u\})=\{f\} \quad \cdots\cdots\cdots \quad (1)$$

where K_B and K_L represent the stiffnesses of each mass and link-members respectively. γ_B is the damping factor for each mass = $2h_B/\omega_1$, γ_L is the damping factor of the link-members = $2h_L/\omega_1$.

The basic model in this study consists of 4 wings named A,B,C and D which are connected to each other through 2 link-slabs and 2 link-braces as shown in Fig.4.

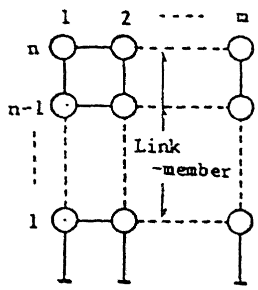


Fig.2 Analytical model with link-members

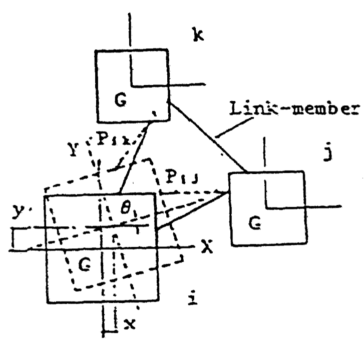


Fig.3 Plane equilibrium of each mass caused by stress in link-members

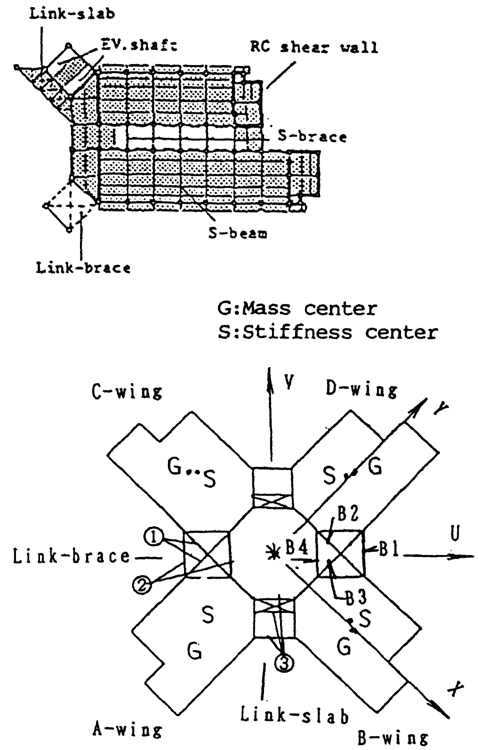


Fig.4 Structural plan of the building and analytical model of inter-building coupling

3 COMPUTATION AND RESULTS

Fig.5 shows the natural frequencies and the vibration mode shapes in the plane at the roof of the basic model structure. These are obtained from the eigen value analysis when an excitation is applied in the X-direction. The first seven modes correspond to the horizontal 1st mode, and from the 8th mode and above correspond to the horizontal 2nd mode. The 1st mode is a motion in the U-direction (45° un-clockwise from X-axis) coupled with a torsional motion, the 2nd mode is a motion predominant in the V-direction (45° un-clock wise from Y-axis), the 3rd mode is a predominant torsional motion coupled with the 1st mode. As the 4th to 7th modes are mainly caused by the deformation of the link-members, they will be referred as the "link-modes" in this study as they are main modes for these types of structures. The link-modes were also recognized from the forced vibration test.

The participating coefficients of the first 7 modes are shown in Fig.6. These are evaluated taking the stiffness of link-members as parameters, and varing it from 0.1 to 6 times. It is possible to observe that coupled lateral-torsional motion modes will occur less and link-modes participating coefficients will be close to zero when link -members are stiffer.

Fig.7 (a) corresponds to the resonance curves at the D-wing roof, when this is subjected to an unit harmonic force excitation, and the comparison between analysis and vibration test is shown in Fig.7(b). Case 1 shows the results when the damping factor is 5% for the two translational motions, 0.1% for torsional and link-motion,case 2 shows the results when all the damping factors are 5%.

The peaks around 1.6 Hz show the fundamental vibration mode of the building. The vibration direction is almost the same as the excitation direction, the peak values are nearly twice of the vibration test values. But when the damping factor is about 13%, the response values will be in good agreement with the vibration test values as shown in Fig.7(b).

The peaks around 3-4Hz show the link-modes of the building, and the effect of the damping factor is clearly explained. The peak values are higher for case 1, and are very small for case 2, the shaded area shows the difference of response drift between case 1 and case 2. The peak values of case 1 are in agreement with the vibration test.

4 EARTHQUAKE RESPONSE ANALYSIS

The response analysis of the building was

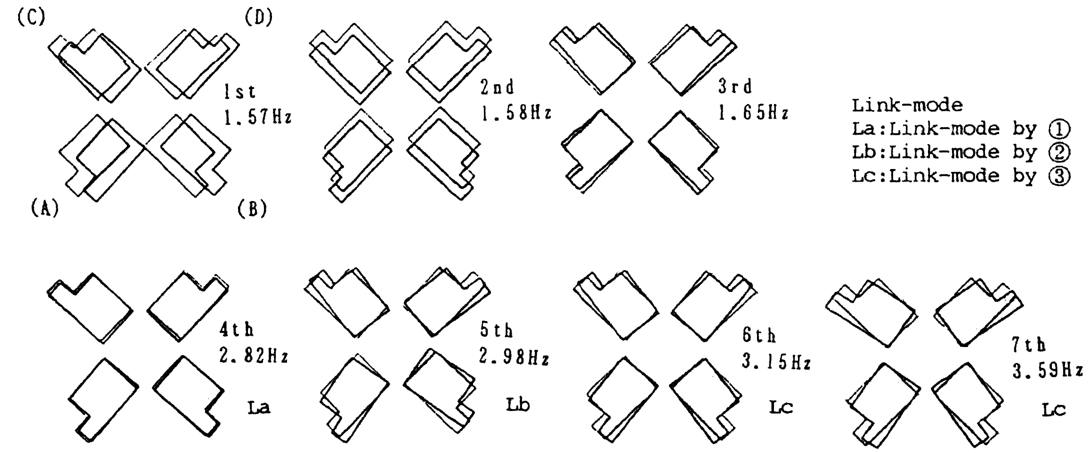


Fig.5 Plane mode shapes on the roof (X-Excitation)

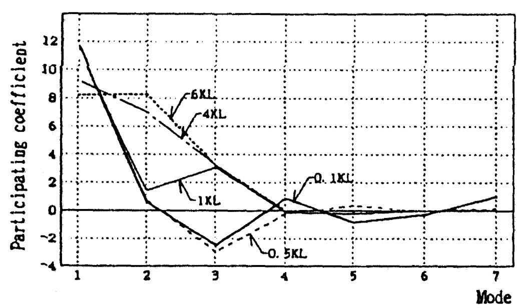
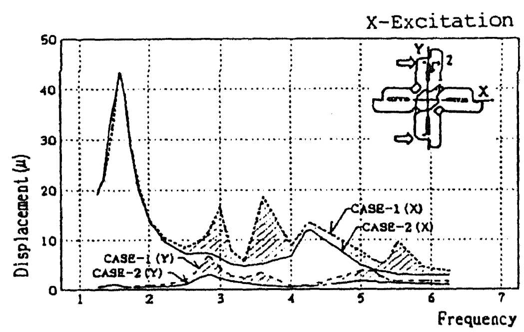
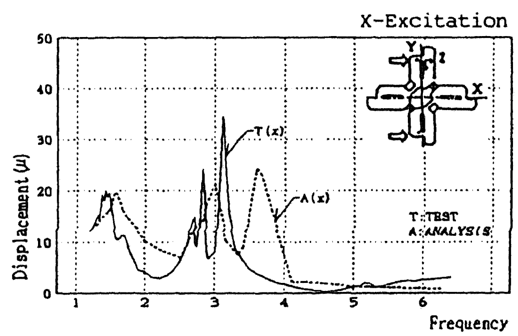


Fig.6 Participating coefficients of the modes of vibration



(a)Resonance curves



(b)Comparison between analysis and test

Fig.7 Resonance curves at the roof of D-wing

carried out using 2 horizontal components of the ground motion recorded at EL CENTRO, with peak accelerations of 342 gal.(NS) and 210 gal.(EW). Fig.8 shows the response motions and the response hysteresis of the mass center at the roof of the buildings for the basic model S1, the model S0 which has no link-members connected and, the model S6 whose link-members stiffness is 6 times as much of that in the basic model. This figure shows the response for the time interval 2-4 seconds, when this building is subjected to EL CENTRO -NS in X direction and EL CENTRO -EW in Y direction simultaneously.

The maximum response story shear force and torsional moments for A-wing are shown in Fig.9.

From these figures, it is possible to observe that S1 and S6 vibrations are mainly translational motions without torsion, thus link effects can be recognized. In the other hand, S0 vibration shows different response behaviors for every wing and, it was also indicated that the coupled lateral and torsional motions were quite different according to the direction of the earthquake excitation.

Fig.10 shows the variation of the response axial force in the link-braces obtained by changing the stiffness of the link-braces in the basic model S1. The response results, when subjecting the building to 2 components of EL CENTRO earthquake simultaneously, show that the axial stress in the link-braces increase smoothly when increasing the stiffness of the link-braces. On the other hand,

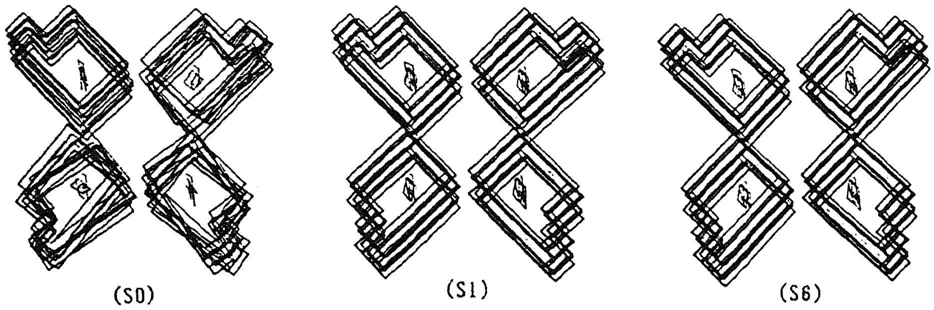


Fig.8 Response behaviors for the time interval of 2-4 sec. at the roof when subjecting to 2 components of EL CENTRO earthquake simultaneously

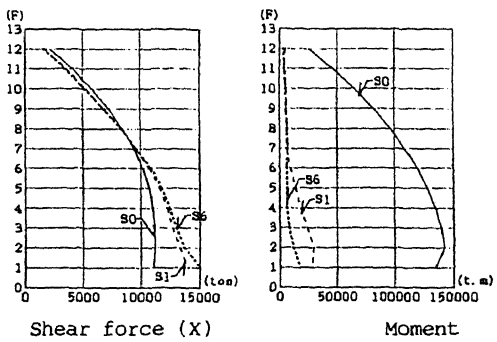


Fig.9 Response shear force and torsional moments for A-wing

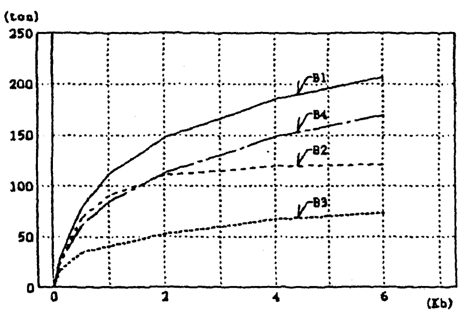


Fig.10 Variation of the response axial force in the link-braces at the roof

the axial stress in the link-members varies rapidly when decreasing the stiffness of the link-braces. In this way the rigidities of the link-members for the basic model S1 were confirmed to be appropriate for the inter-building coupling behavior.

5 CONCLUSION

The link-modes are considered special modes for this kind of inter-buildings connected with link-members. Theoretically, there are many types of link-modes corresponding to the rigidity of the link-members. The link-mode will disappear when the stiffness of the link-member is stronger. From the parametric studies; (1) the axial stress in the link-members is small when X- and Y- translational natural frequencies of each wing are close; (2) the axial stress in the link-members is significant when the axial stiffness of the link-member becomes larger; (3) small axial stiffness of link-members will cause the inter-building coupling behavior to be evident. To some degree, it is possible to prevent the torsional vibration of each wing.

The damping effect is also one important characteristic of the link-members. In this study, the smallness of damping coefficient was clearly indicated in the resonance curve obtained in the forced vibration test. The damping effect on inter-building with different vibration modes for each wing will be more evident if higher damping materials can be designed for link-members.

The storey shear forces or torsional moment in each wing and the axial stress in the link-members are sensitively affected by both the natural frequencies and modes of each wing, the axial stiffness of link-members, and either directions or phase differences of the input earthquake.

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