Active structural seismic control including ground rigidity effects

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Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **79 (1998)**

PDF erstellt am: **23.06.2024**

Persistenter Link: https://doi.org/10.5169/seals-59959

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Active Structural Seismic Control Including Ground Rigidity Effects

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Summary

The characteristics of active structural control, namely active pulse control (APC) and active anchor rope control (AARC), on the six-storey frame structure considering soil-structure interaction (SSI) effects were examined. The results show that the effect of APC is better and the AARC may take no effect at all on soft ground due to the SSI effects. The APC force can be greatly reduced by 1/3 to 1/2 when the SSI effects are considered in comparison with the result of rigid-foundation assumption. The extent of control force reduced will be increased as the soil becomes softer. It seems unnecessary in some conditions to use active control facilities if the SSI effects are considered in the earthquake resistant design of building.

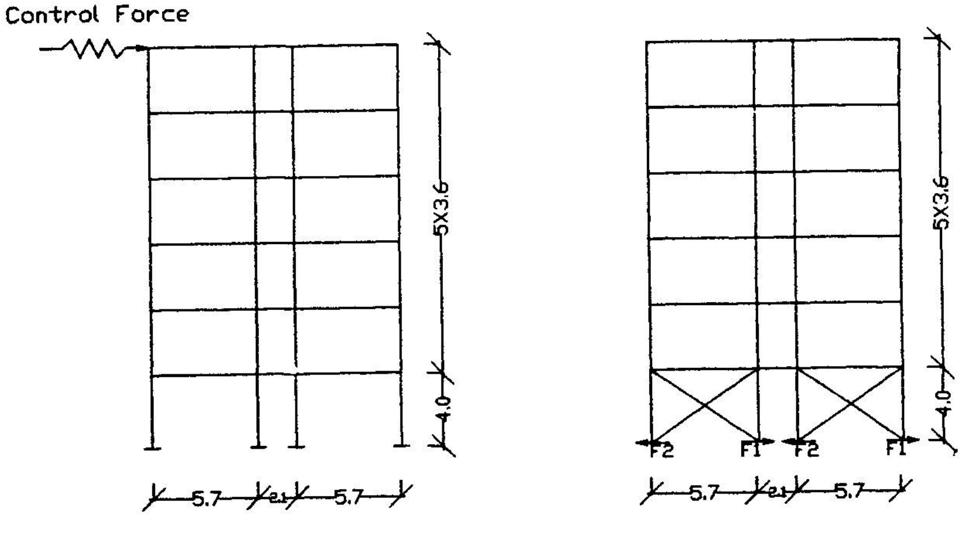
1. Introduction

The research carried out on structural seismic control so far was almost based on the assumption of rigid-foundations, but in reality, the interaction between superstructure and ground is always existent except for constructions directly built upon a well-integrated bedrock, which can be considered approximately as rigid-foundations. Therefore, it is worthy to investigate that whether or not the regular pattern of structural seismic control on rigid-foundations will reflect the real behavior of a building during earthquake. According to references [1][2], the rigidity of ground has an effect on passive seismic control that cannot be neglected and the optimum seismic design can take place only under considerations of the SSI effects as well as ground conditions. Hence, it may be inferred that the SSI effects also have a significant influence on the result of active seismic control. According to references [3][4], in order to achieve the goal of active seismic control there must be a modification in original control arithmetic when the SSI effects are to be considered. And changes needed for the control force are relevant to vibration characteristics of the soil-structure system. The research mentioned above is all based on such assumptions: the superstructure is a linear elastic system of single degree of freedom; the ground is elastic half-space and the input motion is simple harmonic waves. This paper will discuss the active seismic control of structure with emphasis on the effect made by using APC and AARC methods when the SSI effects are considered. The earthquake record is inputted under premise of inelastic structure and a real simulation of actual structural dynamic characteristics.

2. Computational model and method

In the research, the soil-building system is simplified to be two-dimensional, the ground soils are treated as viscoelastic medium which would be a plane strain subject and the lateral boundary of soil mass is treated as a simple boundary. The superstructure is simplified as a plane structure of bar system being composed of variable-section beam elements so that the rigidity difference on different sections of beams or columns caused by differential stress condition can be considered (the details of the rigidity matrix of varying rigidity beam element and the trilinear elasto-plastic constitutive model of reinforced concrete members can be found in references [2][5]

The research was based on the real six-storey frame structure and its sketch drawings of structural computation are shown in fig. 1. The foundation is regarded as a rigid block and the details of building design can be found in reference [2]. The softness and hardness of ground are represented by Vs of shear-wave velocity with which hard soil $Vs = 160H^{0.30}$(m/s) and soft soil $Vs = 120H^{0.30}$(m/s). Here H stands for the depth of soil layers. The depth of bottom boundary of the soil layer was taken as 40m and the damping ratio of the soil mass was taken as 5%. The soil dynamic nonlinear effects essentially soften soils thus the soil nonlinear behavior can be indirectly considered by changing soft-hard conditions of ground.



(a) Case of APC (b) Case of AARC

Figure 1, sketch for computational model of superstructure (unit: m)

The input motion is an El Centro earthquake acceleration record. Taking into account of small, medium and strong earthquakes, the maximum peak value is correspondingly taken as 70, 200 and 400cm/s^2. Under the condition of rigid-foundations the input motion was simply controlled by regulating the value of actual motion proportionally. When the SSI effects are considered, the intensity of input motion determined by the acceleration peak value of the mass center of foundation which is unknown before the numerical analysis. For this reason the value adjustments of the input motion are needed in order to compare with the condition of rigid-foundation assumption.

Any measurements of earthquake response of structure can be easily calculated by solving the dynamic equation of the SSI system using Newmark-β method [6][7]

3. Active Pulse Control (APC) Of Structure Considering SSI Effects

The pulse generator is placed on the top of structure (see fig.1). The control arithmetic adopted is that the direction of the control force generated by the pulse generator is opposite to the relative displacement direction of the top structure and the amount of the control force is equal to the relative displacement of the top structure multiplied by the gain factor.

With the consideration of the SSI effects the earthquake response was analyzed in 27 combined cases on the basis of the small, medium and strong motion; rigid, hard and soft ground; and gain factor being taken respectively as 600, 800 and 1000kN/m. The value of relative displacement under the motion is illustrated in fig. 2 to 4. The illustrations also include results of earthquake response analysis for 9 combined cases of non-control facilities, so they can be compared with the results of the APC. The results show that the earthquake displacement of structure was reduced by the SSI effects, and the softer the ground, the smaller will be the earthquake response. In other words, the softer the ground, the greater will be the earthquake response of superstructure influenced by the SSI effects and the smaller will be the earthquake response of superstructure in comparison with the condition of rigid-foundations. The table 1 shows the maximum value of the APC force needed. In general, the result of active control is better when the gain factor K equals to 800kN/m. In comparison with the APC force under assumption of rigid-foundations, the SSI effects cause the use of less APC force, and the softer the ground, the smaller the control force needed. The APC force needed will become greater when the gain factor K is increased.

Since the amount of the control force is determined by the earthquake displacement response of structure in the APC mothed, thus there are two important meanings to consider the SSI effects during the structural aseismic design. Firstly, as the objective of active seismic control is to confine the earthquake response of superstructure to a certain extent and the SSI effects would lessen the earthquake displacement of structure, so the condition of displacement control will be satisfied automatically without the need of extra active seismic control facilities. Secondly, as the SSI effects greatly reduce the APC force needed, so the power for the APC system would be lowered enormously with which the cost could be cut down.

Table 1 Maximum Control Force Needed

		For APC (kN)			For AARC (kN)	
gain factor K (kN/m)		600	800	1000	4000	6000
small earthquake	rigid ground	32.0	39.4	53.8	65.2	94.8
	hard ground	20.0	24.6	34.3	53.2	78.6
	soft ground	14.8	18.2	23.9	49.6	71.4
medium earthquake	rigid ground	88.4	112.7	153.8	186.4	270.6
	hard ground	57.3	70.6	98.1	144.8	208.8
	soft ground	42.4	52.1	68.2	141.2	203.4
strong earthquake	rigid ground	174.7	215.5	268.1	334.8	499.8
	hard ground	114.5	141.0	196.0	296.4	426.6
	soft ground	83.6	102.6	132.6	280.8	399.6

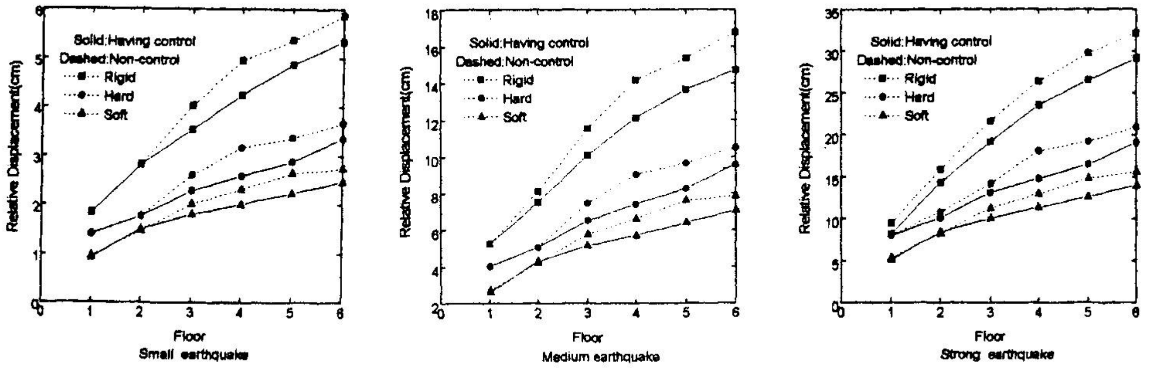


Fig.2 Comparison of relative displacement between non-control and APC for K=600 kN/m

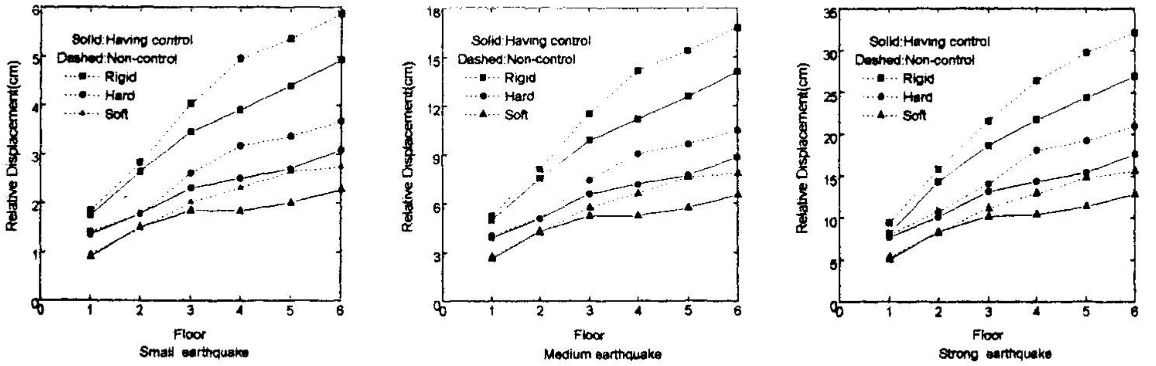


Fig.3 Comparison of relative displacement between non-control and APC for K=800 kN/m

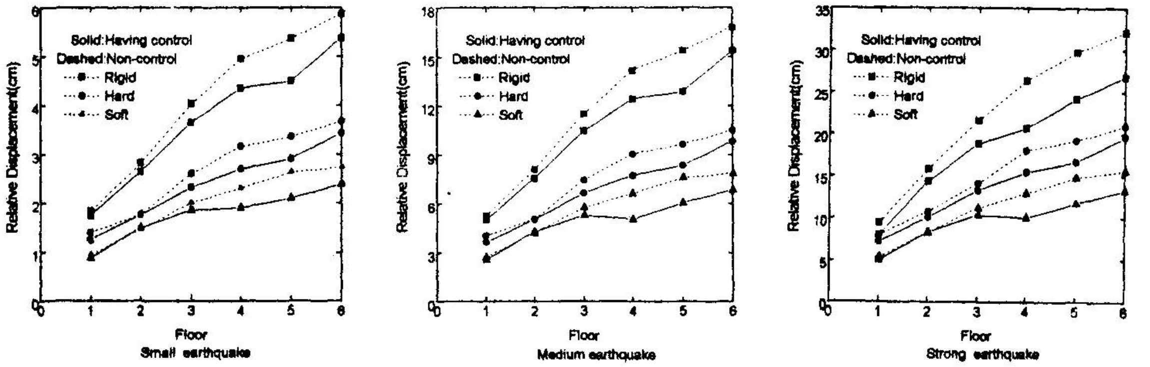


Fig.4 Comparison of relative displacement between non-control and APC for K=1000 kN/m

4. Active Anchor Rope Control (AARC) Considering the SSI Effects

Fig. 1(b) shows the computational model for the AARC. The control force was generated by a servosystem pulling the anchor rope and the amount of the control force equaled to the storey displacement of bottom structure multiplied by the gain factor K. The direction of the control force was determined by the following method: if the displacement of superstructure moves to left, then $F_2 = 0$; if it moves to right, then $F_1 = 0$.

Fig. 5 and 6 show that there are 18 combined cases of storey displacement with the consideration of input motions as the small, medium and strong one; the ground condition as the rigid, hard and soft ground; and the gain factor K taken as 4000 and 6000kN/m. In order to compare with the cases of non-control facilities, the storey displacement of non-control facilities was also given in the figures. Table 1 shows the AARC force needed and the storey displacement of structure lessened by the SSI effects, and the softer the ground, the greater will be the influence caused by the SSI effects. The SSI effects decreased the efficiency of AARC of structure, and the softer the ground, the greater will be the extent decreased. But the SSI effects affected on AARC was limited under the condition of hard ground. That the SSI effects can decrease much control force means the cost could be reduced.

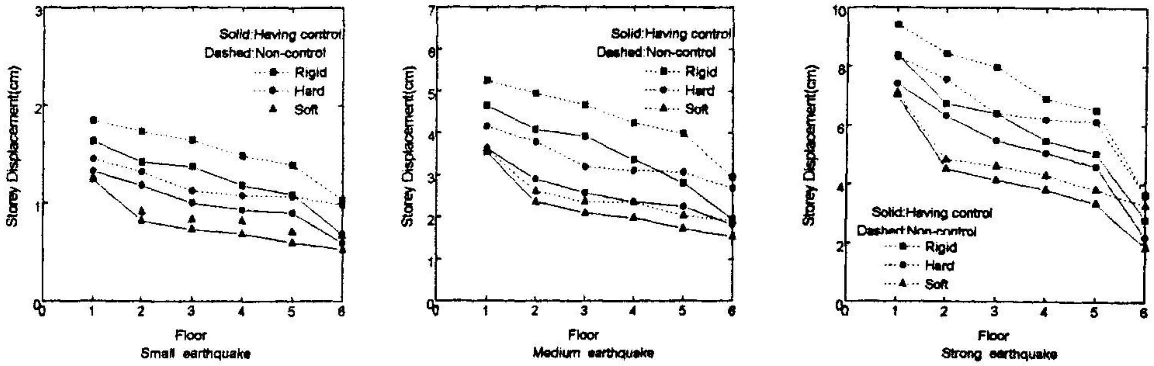


Fig.5 Comparison of storey displacement between non-control and AARC for K=4000 kN/m

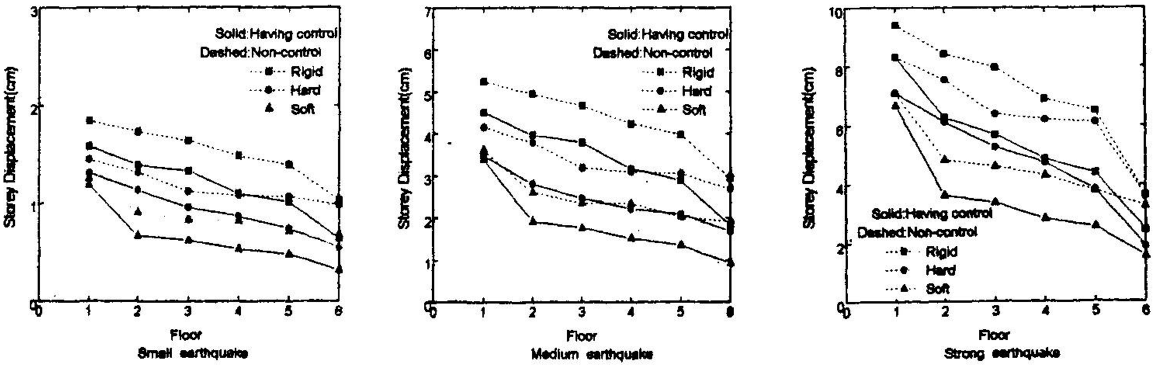


Fig.6 Comparison of storey displacement between non-control and AARC for K=6000 kN/m

5. Conclusion

The active seismic control of inelastic structure under considerations of the SSI effects has been first time analyzed by using the two-dimensional finite element method. After the investigation of the active aseismic control of structure effected by the SSI effects in detail. the conclusion can be reached as follows.

Firstly, since the purpose of active control is to control the earthquake response of structure within a safe extent and for multistorey shear frame structure the SSI effects would significantly decrease the earthquake response of structure, so the actual earthquake displacement of structure would be automatically contented with the purposed degree on rigid-foundation assumption without setting up active seismic control facilities if the SSI effects are to be considered during the structural aseismic design.

Secondly. comparing the two control methods, namely APC and AARC, the APC method needs less control force thån the other and its result is quite contented with any type of ground by just regulating the gain factor K to an appropriate value. The result of the AARC on soft ground, however, is not so good, even taking no effect at all. In other words, for multistorey frame structure the earthquake displacement on top storey is controlled in a relatively effective way.

Third. the SSI effects reduce greatly the control force needed for the APC of structure and on hard and soft ground it would be reduced by 1/3 and 1/2 on the frame structure mentioned above, thus, the power consumption is decreased and the cost then could be cut down.

The research is based on specific structure and input earthquake motion, and the ground condition is relatively simple, therefore, it is a initiative and further research is needed.

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