PRESENTING A NEW APPROACH BASED ON INERTIA FORCES TO CONTROL THE VIBRATION OF STRUCTURES

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ABSTRACT

Vibration control is an effective way to improve safety and serviceability of structures. The concept of common active control systems is to constrain the vibration of structures by imposing additional damping or stiffness. This paper studies a basic idea of an active control system in which control forces are inertia forces that imposed by a set of pre-compressed springs connected to additional masses. Once drift of the system equals to a maximum pre-set level a lever pull the trigger of springs and the mass that connected to them shot into the opposite direction. This action forced the system to move backward and thereby decrease the drift of the structure. A computer program in MATLAB programming was developed to evaluate the response of the structure under simultaneous effects of the earthquake excitation and due to the shooting of the masses. A linear single degree of freedom (SDOF) system that equipped with aforementioned system was studied under the record of various earthquakes. By changing the dynamic parameters of system and additional mass such as mass, stiffness and damping ratio and computing the response of the structure the optimum proportion between floor mass and additional mass or stiffness ratio can evaluated. Because of simplicity and less expense of this technique comparison to other control system this method could be used in wide range of common structures and also can be applied as a supplement system in structures that already have a more sophisticated control system.

Keywords: vibration control, dynamic of structures.

1. INTRODUCTION

In this study a structure that its vibration must be controlled is modeled by a linear single degree of freedom (SDOF) system with the controlling device system of a new proposal installed in it and detailed time history analyses are carried out. Consequently the response of the structure was reduced by the means of additional controlling mass that shot into opposite directions when

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subjected to moderate earthquakes and as a result of that the performance of the structure was improved.

Although the above concept apply to a SDOF system that reasonable for several group of structures such as airport tower, elevated reservoirs and so on that instinct characteristic of those is SDOF ,but this idea can be developed for other categories of structure and buildings either.

2. STRUCTURAL MODEL

The 2D model of structure with mentioned controlling system is shown in Figure 1 schematically. Where Kst and Ksp are stiffness of the structure and springs and Mst and Msp are mass of the structure and springs respectively. As seen in the figure additional controlling system with pre compressed springs are connected to the both side of the pillar. The pillar linked to a system that consists of a set of sensors and data loggers monitoring the lateral displacement or drift of structure during a seismic event.

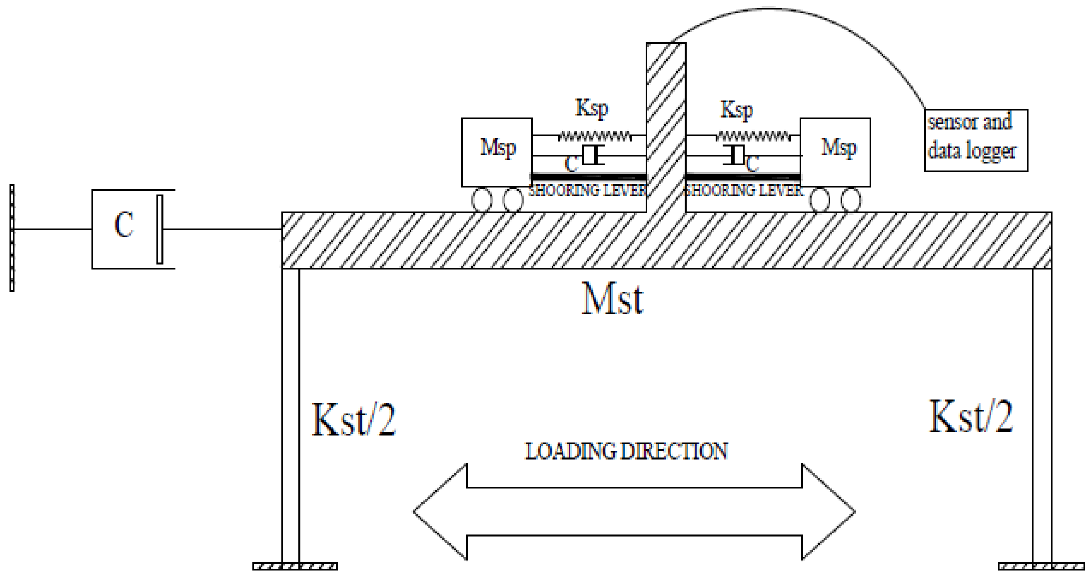


Figure 1: Structural model.

The role of shooting levers (solid black rods in figure 1) is for pulling the trigger of the springs and shooting the masses. Until that moment the lateral drift during earthquake is less than a preset value the shooting lever is locked with the masses carrying forces and structure and masses act as a SDOF system as soon as the sensors realizing that the drift value in each direction is getting to the threshold drift they command to the right or lever that self unlock and causing to eject mass on the opposite direction this reaction forces cause the system to move backward and thereby decrease the drift of the structure. After this action the system state from SDOF shifts to the two degree of freedom system and after eject the other spring we have a system with 3 degree of freedom and all of this may be occurred during earthquake. It must be mentioned that damping ratio for the control system assumed equal to the structure's value.

3. ANALYTICAL MODELS AND FORMULATION

Because we have three possible phases during analytical process so we have one model for each state (Single, Two or Three degrees of freedom). Analytical model for the structure is shown in Figure 2 in which part (a) represents the SDOF phase and parts (b) and (c) are showing multi degrees of freedom phases.

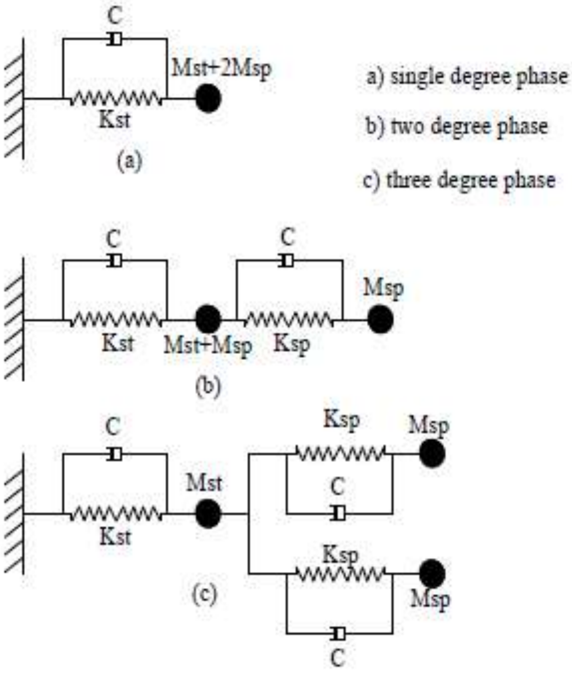


Figure 2: Analytical models.

The general form of the equation of notion in a structure subjected to seismic excitation at foundation level is

$$\underline{M}\,\underline{\ddot{u}}(t) + \underline{c}\,\underline{\dot{u}}(t) + \underline{k}\,\underline{u}(t) = -\underline{M}\,\underline{r}\,\underline{\ddot{u}_g}(t) \tag{1}$$

Matrix elements in equation (1) all known in literature and we don't need the explanation if taking:

$$\underline{u} = \underline{\emptyset} \times \underline{Y} \tag{2}$$

Then we get to the following equations:

$$\underline{\emptyset}^T \underline{M}\,\underline{\emptyset}\;\underline{\ddot{Y}}(t) + \underline{\emptyset}^T \underline{C}\,\underline{\emptyset}\,\underline{\dot{Y}}(t) + \underline{\emptyset}^T \underline{K}\,\underline{\emptyset}\,\underline{Y}(t) = -\underline{\emptyset}^T \underline{M}\,\underline{\ddot{u}_g}(t)$$

$$\underline{\widetilde{M}}\,\underline{\ddot{Y}}(t) + \underline{\tilde{C}}\,\underline{\dot{Y}}(t) + \underline{\widetilde{K}Y}(t) = \underline{\tilde{P}}(t)$$

$$\ddot{Y}_j(t) + 2\varepsilon_j\omega_j\dot{Y}_j(t) + \omega_j^2 Y_j(t) = \gamma_j\ddot{u}_g(t) \tag{5}$$

Equation (5) is famous equation for j th mode of vibration with the solution of it for all modes and then combination of them by equation (2) we could reach to the matrix u vector that means the displacement of all degrees of freedom. Solution of (5) by Duhamel integration is

Where:$u(t) = \frac{1}{m\omega_d}\int_0^t p(\tau)\exp(-\varepsilon\omega(t-\tau) sin\omega_d(t-\tau)d\tau = A(t)sin\omega_d t - B(t)cos\omega_d t$

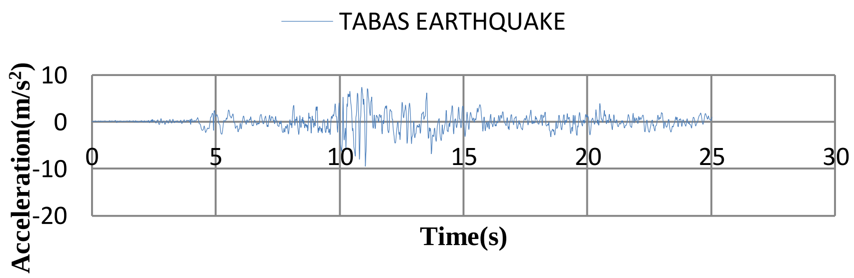
$$A(t) = \frac{1}{m\omega_d}\int_0^t p(\tau)\,\frac{e^{\varepsilon\,\omega\tau}}{e^{\varepsilon\,\omega t}}\cos\omega_d\,\tau d\tau\,, B(t) = \frac{1}{m\omega_d}\int_0^t p(\tau)\frac{e^{\varepsilon\,\omega}}{e^{\varepsilon\,\omega t}} sin\omega_d\tau d\tau$$

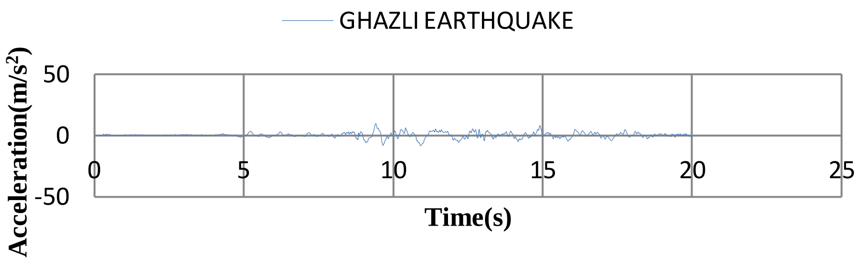
As we know there is no closed form solution for above equation so we used the numerical solution by linear interpolating of forces (acceleration) to obtain the response of the system.

From where that we have three possible phases during analytical process so we need a special program to take into account this problem and could switch between one to three degrees of freedom automatically during analysis. A computer program in MATLAB programming was developed to evaluate the response of the structure under simultaneous effects of the earthquake excitation and due to the shooting of the masses with the capability to apply that said effect.

4. GROUND MOTION

For input record we used three different acceleration time histories of the TABAS, NAGHAN and GHAZLI earthquakes that represented in the books of earthquake engineering as famous and tangible examples for student. Acceleration time histories of said records showed in Figure 3.





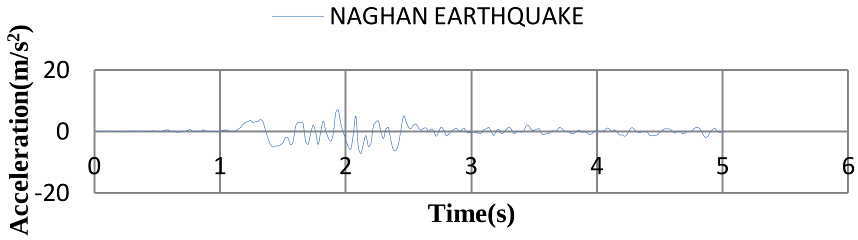


Figure 3: Time history of recorc(time-acceleraton).

5. NUMERICAL RESULTS AND SOME DISCUUSION

The response of the structure can be assesses after applying the aforementioned MATLAB program for dynamic analysis of the structure subjected to the said earthquake and calculating output for 0.02s time steps. By changing the dynamic parameters of system and additional mass such as mass, stiffness and damping ratio and computing the response of the structure the optimum proportion between floor mass and additional mass or stiffness ratio can evaluated. Figures 4 to 6 show maximum drift versus mass proportion of control system and the structure with different stiffness ratios.

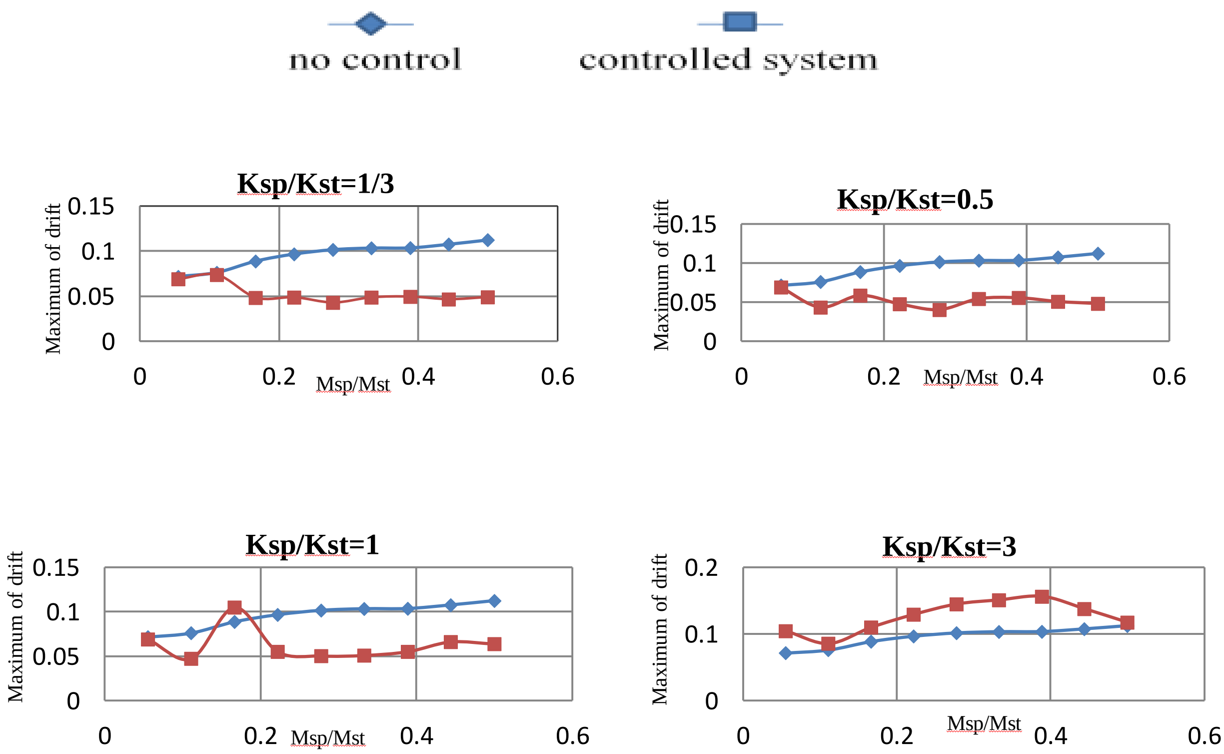


Figure 4: Maximum drift vs mass ratio for NAGHAN Eq.

For comparison each structure without control system but with the same mass and stiffness also subjected to analyses.

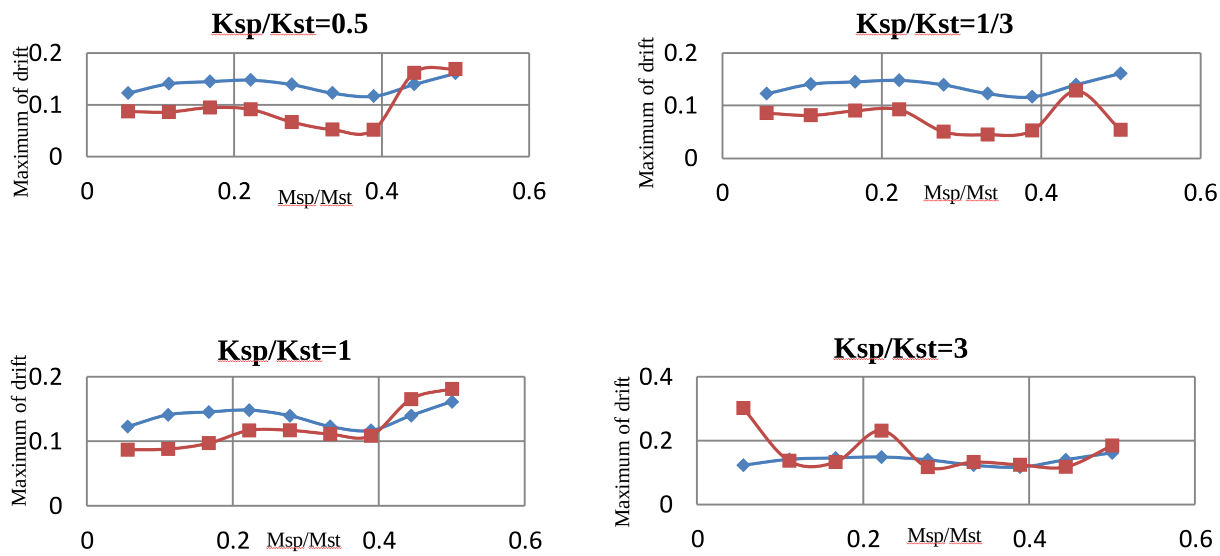


Figure 5: Maximum drift vs mass ratio for TABAS Eq.

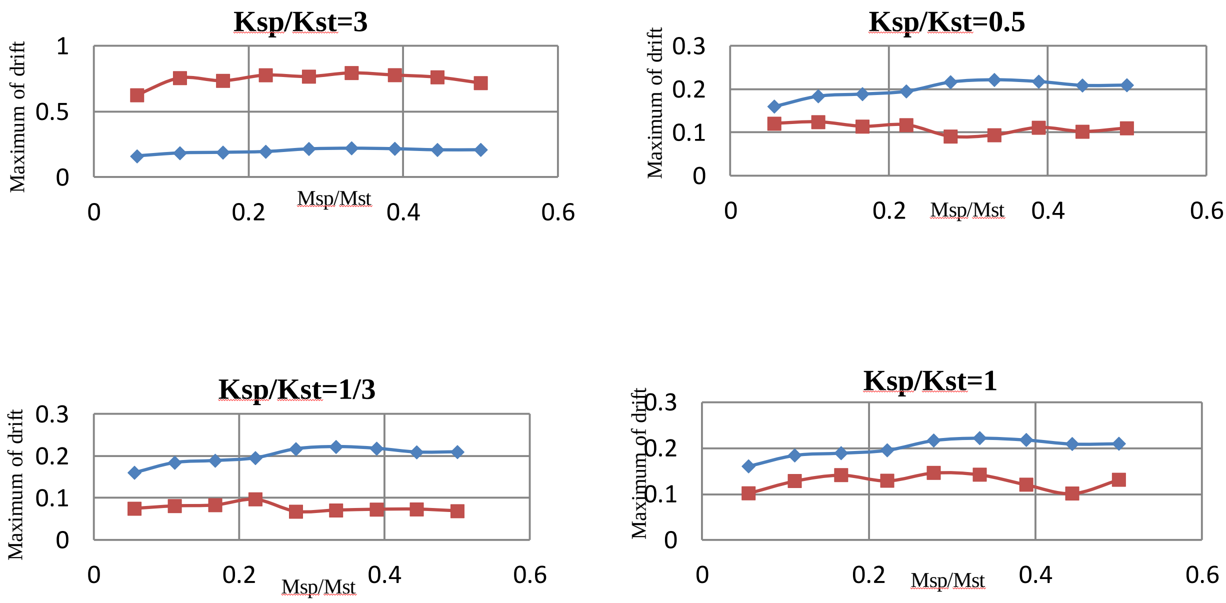


Figure 6: Maximum drift vs mass ratio for GHAZLI Eq.

As we see in the Figures the mass ratio variation is from 0.05 to 0.5 and stiffness proportions of each set of analyses are 0.5, 0.67, 1 and 3. From the graphs it’s observed that for the stiffness ratios of 0.5 and 0.67 the drift ratios of the controlled structure under all three cases of record almost be less than uncontrolled system when mass ratios are in between 0.05 to 0.5. Also from figures it's understandable that for stiffness ratio equals to 3 in all three cases of records the maximum drift of controlled system always be more than same values in the uncontrolled system and finally for the stiffness ratio equals to 1 the drift of controlled system in GHAZLI and NAGHAN earthquakes always be less than uncontrolled system except one case in NAGHAN earthquake when the mass ratio is 0.15.

The other thing from the graphs is that in the structure with the stiffness ratios of 0.5 and 0.67 if the mass ratio is in the range of 0.25 to 0.40 the minimum drift occur in entire cases of the records. In other words the optimum state for minimizing the response of the structure in our three cases of the records occur when the ratio of the masses is something in between 0.25 to 0.4 and the stiffness ratio has to be in the range of 0.5 to 0.67 simultaneously.

Thus it seems that this technique acted and the existence of the said controlling system caused to limiting vibration and reduction the response of the structure albeit in the condition that the dynamic properties of the system adopted in a suitable and effective manner.

We studied simplest models since this article as stated before is merely going to the theoretical explanation of a new idea that in which inertia reacting forces restricting the response of the system. So although this method in the present format applicable to some narrow band of the structures but further complimentary studies should be done to be generalized and more developed so that be applicable to wide variety of structures and buildings.

For example in the study it’s assumed that the shooting lever releases the masses one time and no more so the all of potential energy saved in springs be released one time and if in the middle of the earthquake the response of the structure passing through the pre set value again, the system already released its energy have no means resisting to increase the drift. But if the system set up be in a format that releasing the masses occurs in a gradual manner and shooting lever let the masses be free step by step when displacement goes on to its high value this problem can be solved and structure can be controlled in that direction for several times during one event.

Finally because of simplicity and less expense of this technique comparison to other control system this method could be used in wide range of conventional structures and also can be applied as a supplement system in structures that already have a more sophisticated control system.

6. CONCLUSIONS

A new approach for active control system were presented that in which control forces are inertia reaction forces that imposed by a set of pre-compressed springs connected to additional masses. Then by means of a computer program that specially developed for this study the response of structures with control system subjected to three selective records of earthquakes calculated and the results compared to the equal system without the system of control. By changing the dynamic parameters of system and additional masses such as mass, stiffness and computing the response of the structure it found out that for a specific proportion between floor mass and additional mass or stiffness ratio the response of structure could be least possible. It obvious that this is first step and complimentary studies should be done to encounter other structural aspects such as 3d modeling, non classical damped, non linearity and so on to better developments applicable and optimization of the method.

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