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# Dynamic deflection control of reinforced concrete frame under earthquake load with piezoelectric layer

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**ABSTRACT:** Piezoelectric materials are a type of smart materials that are of interest to many researchers in various engineering sciences due to their extraordinary properties such as converting mechanical energy into electrical energy and vice versa. In this article, the determination and control of the dynamic deformation of a one-span concrete frame with a piezoelectric layer coating on beams and columns under seismic load is discussed. In order to control the dynamic deformation of the concrete frame, a proportional-derivative controller has been used in such a way that a piezoelectric layer is considered as an actuator and a layer as a sensor. The governing equations for the beam and column components of concrete frame are obtained by using high-order shear theory, calculating energy relations, applying Hamilton's principle and considering the applied voltage on piezoelectric materials. In order to solve the dynamic coupled equations, the numerical method of differential quadrature method has been used and finally, with the help of Newmark method, the dynamic deformation of the concrete frame is calculated. After validating the results, the effect of various parameters such as voltage applied to the piezoelectric layer, piezoelectric type controller, thickness of the piezoelectric layer on dynamic deformation were investigated. Here, the optimal values of controller parameters, including proportionality coefficient and derivative coefficient, were obtained as 3.824 and 5.812, respectively. The results show that the use of the controller leads to a reduction of 72 and 65 percent of the lateral and vertical dynamic deflection of the frame, respectively.

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## 1- Introduction

Today, continuous mechanics models are widely used for mathematical modeling of structures. But in the field of mathematical modeling of concrete elements used in structures such as beams and columns, using the energy method based on the theory of elasticity, limited research has been done. In 2016, Jafarian Arani et al. [1] simulated the buckling of concrete beams reinforced with carbon nanotubes using Euler-Bernoulli and Timoshenko beam theories. Using the theory of the previous article, Safari Biloyi et al [2] analyzed the buckling of reinforced concrete columns with FRP layers. They concluded that the presence of FRP layer greatly reduces the buckling load. Arbabi et al. [3] in 2017 investigated the buckling of columns reinforced with silica nanoparticles under an electric field. In 2017, Zamaniyan et al. [4] investigated the effect of accumulation on the buckling behavior of concrete columns reinforced with silica nanoparticles. Mohammadian et al. [5] in 2017 analyzed the dynamic analysis of concrete beams reinforced with iron oxide nanoparticles under a magnetic field with the help of high-order hyperbolic theory. They concluded that the magnetic field reduces the dynamic deflection of the structure by about 54%.

In the previously mentioned research, the topic of the smart structure was not discussed. Nowadays, the use of smart materials in concrete structures and other structures is one of the new topics and ideas that many researchers are looking for. With the help of these materials, we can control the dynamic behavior of a structure and prevent its damage and fracture. Zhang and Kei [6] analyzed the vibrations, buckling, and bending of circular plates covered with piezoelectric layers. They used the numerical method of cubic differential method to solve the governing equations.

According to the search in the technical literature, the analysis and control of the dynamic response of concrete frames with piezoelectric layer as actuator and sensor under the effect of earthquake based on the energy method and using the numerical method of differential quadrature has not been done. Therefore, in this article, the dynamic response of the concrete frame covered with a smart layer is numerically analyzed to control the dynamic behavior of the structure under the effect of an earthquake. For this purpose, for the mathematical modeling of the structure, the shear deformation theory of the beam is used, and with the help of the energy method and Hamilton's principle, the governing equations are derived considering the piezo layer. Finally, using the

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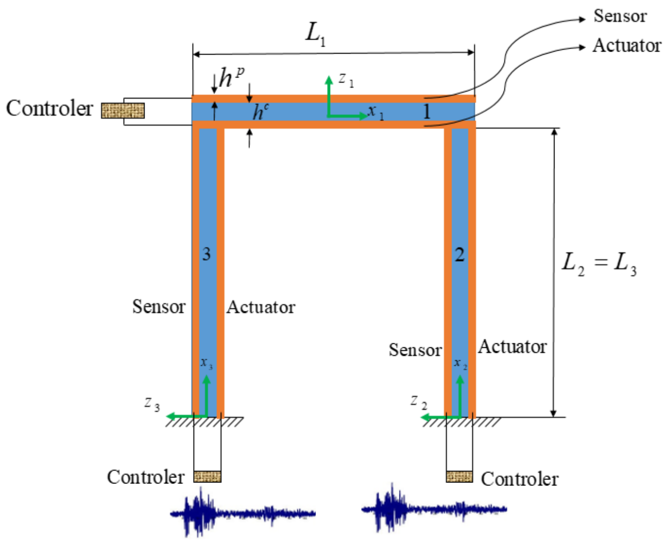


**Fig. 1. Schematic of the concrete frame covered with piezoelectric layers as actuator and sensor**

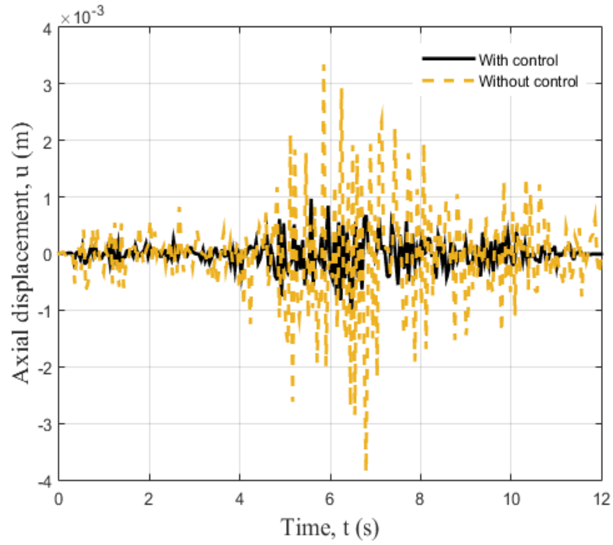


**Fig.2. Effect of controller on the lateral dynamic deflection of concrete frame under earthquake**

numerical solution, the lateral and vertical dynamic deflection of the system is calculated and the effect of parameters such as the presence and location of the piezoelectric layer, the thickness of the piezoelectric layer, the voltage applied to the piezoelectric layer, the controlling effect of the piezoelectric layer and the boundary conditions on the seismic response of the frame is investigated.

## 2- Mathematical modeling

The schematic configuration of the concrete frame with the piezoelectric controller is shown in figure (1). This figure shows a concrete frame with a span including the length of the beam $L_1$, the length of the columns $L_2 = L_3$, the thickness of the concrete $h_c$ and the thickness of the piezoelectric layers $h_p$. The beams and columns of the concrete frame are covered with two piezoelectric layers, one of which acts as an actuator and the other as a sensor. The output signal from the sensor enters into the proportional-derivative controller (PD) and after modifying the signal by the actuator, it enters the structure. Beam coordinate axes are shown with $x_1$ and $z_1$ in the longitudinal and thickness directions respectively, and column coordinate axes are shown with $x_2$, $x_3$, and $z_2$, $z_3$ in the longitudinal and thickness directions respectively. The frame is located on the supports with various boundary conditions and is under seismic load.

## 3- Discussion and Result

Lateral and vertical dynamic deflections according to the acceleration time history of the Bam earthquake are shown in figures (2) and (3) for the states with and without controllers, respectively. It is worth mentioning that because there is no steady state error in the dynamic analysis of the structure, the presence of integral gains not only does not improve the dynamic response of the system but also slows down the

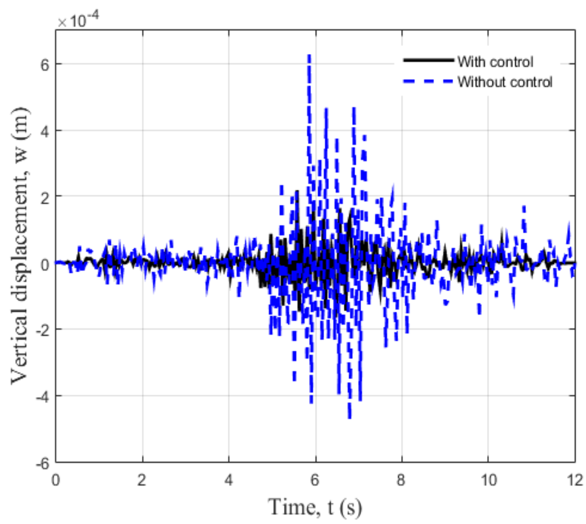


**Fig. 3. Effect of the controller on the vertical dynamic deflection of the concrete frame under earthquake**

response. Therefore, a proportional-derivative controller is used in this article. For this purpose, the optimal values of the controlling parameters, including proportionality coefficient ($G_d$) and derivative coefficient ($G_v$), were obtained as 3.824 and 5.812, respectively.

## 4- Conclusions

In this article, the dynamic analysis and control of the concrete frame covered with piezoelectric layer on beam and columns under seismic load was discussed. In order to control the concrete frame, a proportional-derivative controller was used in such a way that one piezoelectric layer was considered as the actuator and the other as the sensor. To derive the governing equations of the concrete frame with piezoelectric layer, first, the frame was mathematically modeled with the help of high-order hyperbolic shear deformation theory and energy method, and finally, to couple the obtained equations for the beam and columns, from the continuity boundary conditions at the points connecting beams to columns was used. In order to numerically solve the dynamic coupled equations, for the first time, the differential quadrature method along with the Newmark method was used. The advantage of this method is the high accuracy of the results along with the high speed of its calculation. The results show that for the number of grid points 15, the dynamic deflection obtained from the differential quadrature method converges. Also, if a piezoelectric controller is used, the deflection range will be greatly reduced and the damping time of the system will be shorter. Among other main results of this research, we can mention the significant effect of external voltage on the dynamic deflection of the frame, so that by applying a negative external voltage to the piezoelectric layer, the dynamic deflection will decrease and vice versa.

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