# Seismic Evaluation of Out-of-plane Performance of Masonry Walls Using Floor Response Spectrum

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**SUMMARY:**
This paper presents the results of the investigation on out-of-plane seismic behavior of non-structural masonry walls using floor response spectrum. Masonry walls collapse in the buildings has caused considerable casualties in the past earthquakes and hence, seismic design of such elements is important. Current codes provide design requirements for non-structural walls and also consider several parameters in prediction of the seismic demand forces such as thickness, height, location of the wall in the building and the building's period. The masonry walls are sensitive to both storey drift and acceleration and more over the out-of-plane behavior is affected by the type of connection at top. In this study, three conditions were considered for the top connection of the wall: 1) No restraint; 2) Horizontal translation restraint; and 3) Horizontal translation restraint and rotation restraint. In order to evaluate the out-of-plane performance of the masonry walls in the buildings, a number of hypothetical buildings with different height were modeled. Each storey included a wall and a bilinear link element was assigned by means of out-of-plane behavior. The behavior observed in wall tests in previous studies was used to define the properties of the inelastic link element. Nonlinear time history analysis was performed on the building models. A series of ground motion records were used for the analysis which were scaled to match an averaged spectral velocity from the Uniform Hazard Spectrum, with a probability of exceedance of 2% in 50 years, for a building located in a high risk zone with specific site class soil. The floor acceleration and displacement response spectra were then computed and seismic demand forces on the walls located in different stories for different buildings were calculated. As results, the inelastic response and out-of-plane performance of the walls was evaluated and the calculated demand forces were compared with the codes requirements.

*Keywords: Seismic evaluation, out-of-plane masonry walls, floor response spectrum.*

## 1. INTRODUCTION

Since the casualty of human being has a growing rate due to the collapse of non-structural components especially masonry walls, recently the engineers have drawn attention to the design of these walls. Referring to the building codes, there are various relations available for the wall's out-of-plane loads. The loads are depended to some of the loads parameters in the mentioned relations, such as the thickness and the height of the wall, its position in the structures level, the fundamental period of the structure and etc. however, because of the importance of the topic, it is requisite to investigate the competence and adequacy of these relations and study the nonlinear out-of-plane behavior of these walls. Thus, the authors have been motivated to study the behavior of these walls in the present study.

## 2. EXPERIMENTAL RESULTS

In order to achieve to a more reliable modeling approach for the out-of-plane behavior of masonry walls, the experimental results will be efficient. Herein, the results of walls with three kinds of boundary conditions which has been illustrated in Fig. 1, has been employed. The Force-Displacement behavior has been determined for these walls. Though, as the behavior of plastic hinges is defined by the Moment-Rotation diagram in analytical programs, the Force-Displacement diagram behavior has been converted to the Moment-Rotation behavior by the available relations of the material resistance.

The resulted graphs have been pointed out in Fig. 2.

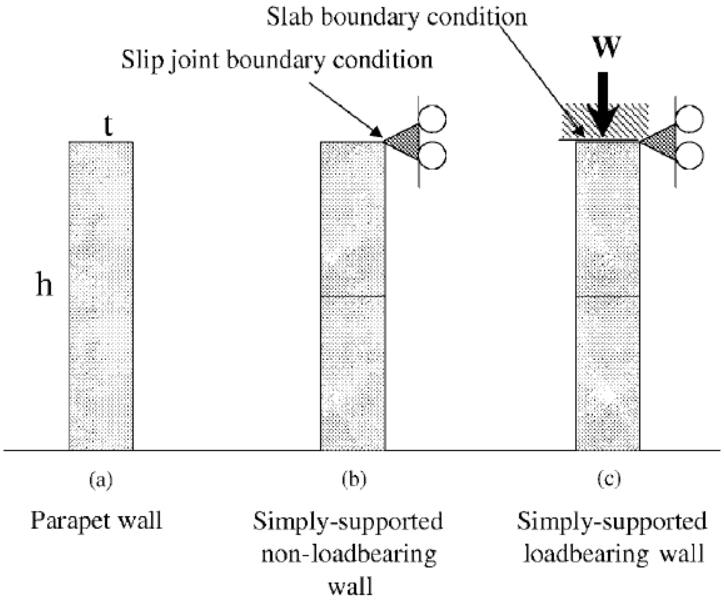
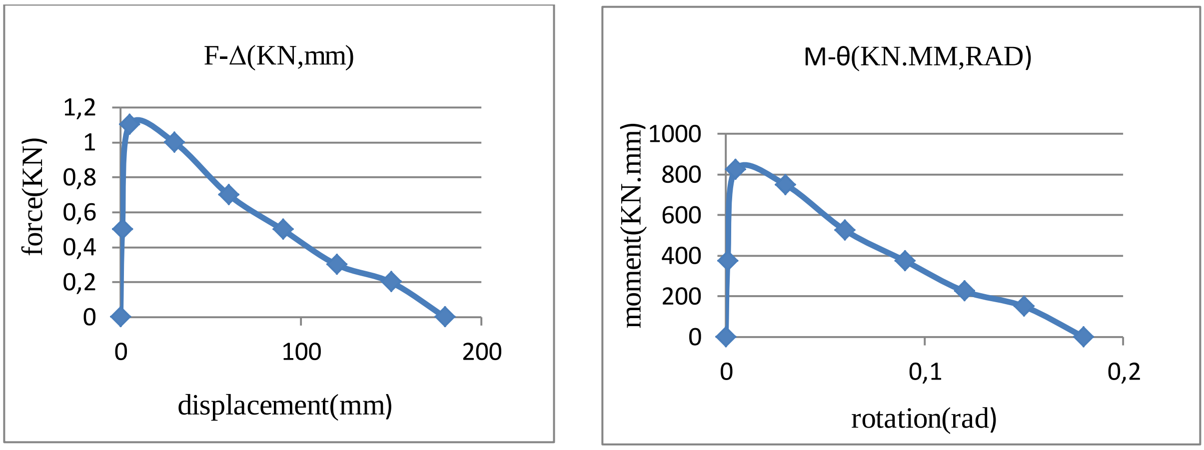



**Figure 1.** Unreinforced masonry wall support configurations




(a) (b)

**Figure 2.** Bending plastic hinge behavior diagram: a).Force-displacement; b) Moment-rotation

## 3. ANALYTICAL MODELING

The writers have made use of the Perform.3D program so that the walls behavior could be appropriately modeled in the structures frame. With the intention of attaining to comparable results, supposing the period of the main structure and taking the floor's acceleration spectrum into account, 4 common buildings with different number of floors, 5, 10, 15 and 20 floors, have been considered. In this regard, each frame has been analyzed separately from the main structure. However, the mass and stiffness of the segregated frame has been defined in such a way that leads to a reliable occupation of the frame. As it has been shown in Fig. 3, the wall has been modeled with a one-line element with geometrical properties of a wall with univalent width (3x1x0.19 meters). The nonlinear behavior of the wall is controlled by a plastic hinge in the middle of the wall using the mentioned properties. The model of the wall which has been offered here is the model (b) in Fig. 1. The mass of the wall has been determined according to the specific weight of the masonry walls and has been assigned by a lumped mass in the middle of the wall. It has to be mentioned that among various analysis, the nonlinear dynamic analysis have been executed for this structure, using the El-centro accelerogram. Besides, the maximum acceleration of the El-centro has been scaled according to the three earthquake levels, design base earthquake and the earthquake hazard level 1 and 2, and the analytical results are calculated for these levels.

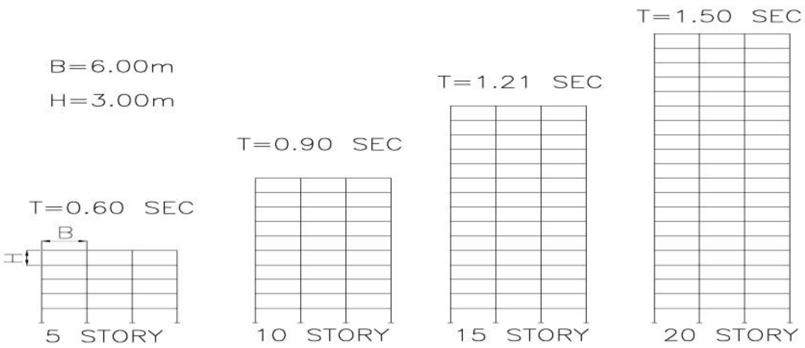
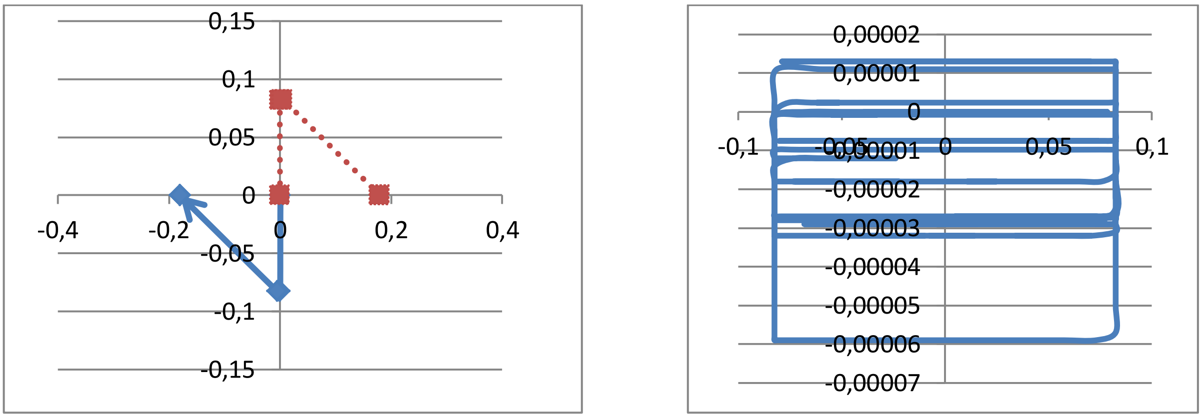



**Figure 3.** Test frames in analysis

## 4. EVALUATION OF THE MODEL

As the obtained numerical study has to be authentic results, the accuracy of the abovementioned modeling has to be perfectly confirmed. The results have been evaluated by two one degree of freedom models. These models have been created and analyzed in the SAP.v14 program. In which, the stiffness and mass of the main members have been supposed unlimited and those of the wall have been exactly modeled. A plastic hinge, according to the results of the experimental model, has been defined at the middle of the wall to define the nonlinear behavior of the wall. The wall has been analyzed with nonlinear static and dynamic analyses and the results have been shown in Figs. 4. The modeling of the wall element has been verified in view of the plastic hinge results.

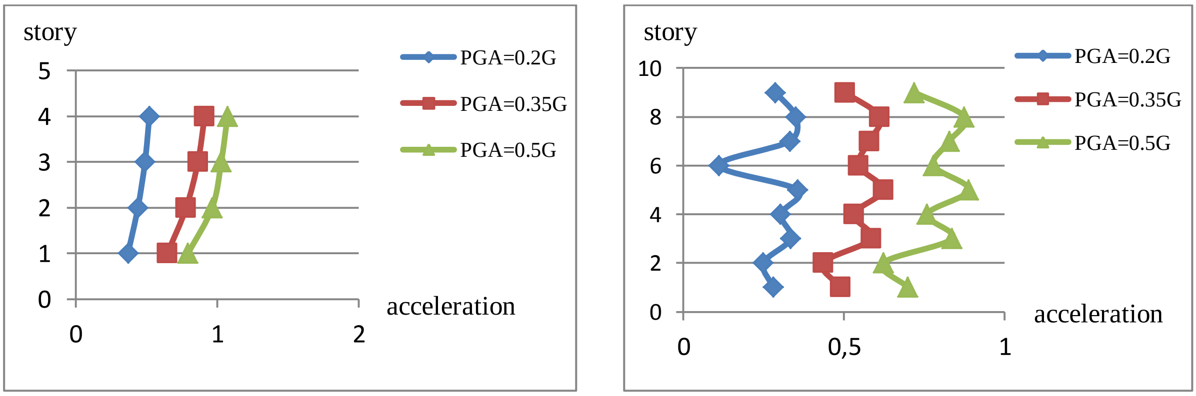



(a) (b)

**Figure 4.** Force–displacement relationships of rigid URM walls (Simply Supported Wall): a) Pushover test-hinge results; b) Nonlinear time history test-hinge results

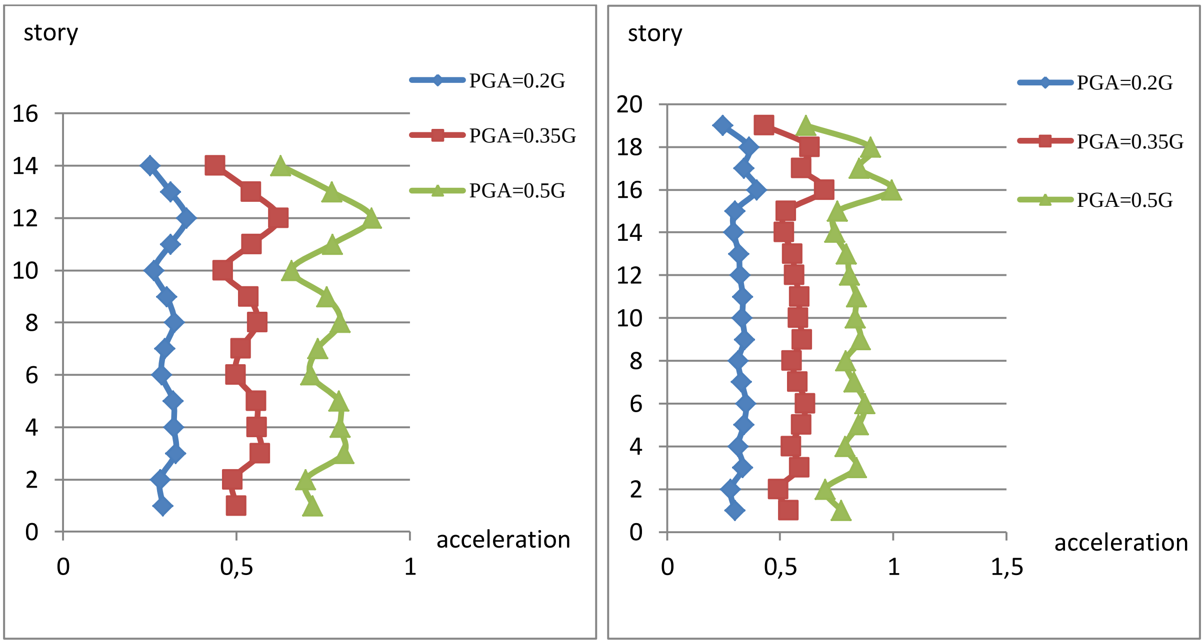
## 5. NONLINEAR ANALYSIS RESULTS

The nonlinear dynamic analysis of the structures has been performed in viewing of the aforesaid situations. Figs. 5, 6 and 7 illustrate the results of the wall's displacement and the mass acceleration in each story and the acceleration spectrum of the floors, relatively. The lateral force, applied to the wall could be calculated by the wall's acceleration results and finally compared with those of the building codes. By knowing the fact that the wall's thickness is 19 cm and on the other hand the wall's force resistance has been determined up to 19 cm of lateral displacement form experimental results and it will collapse for further displacements, it could be obtained from the displacement results that which walls would be destructed in which levels.



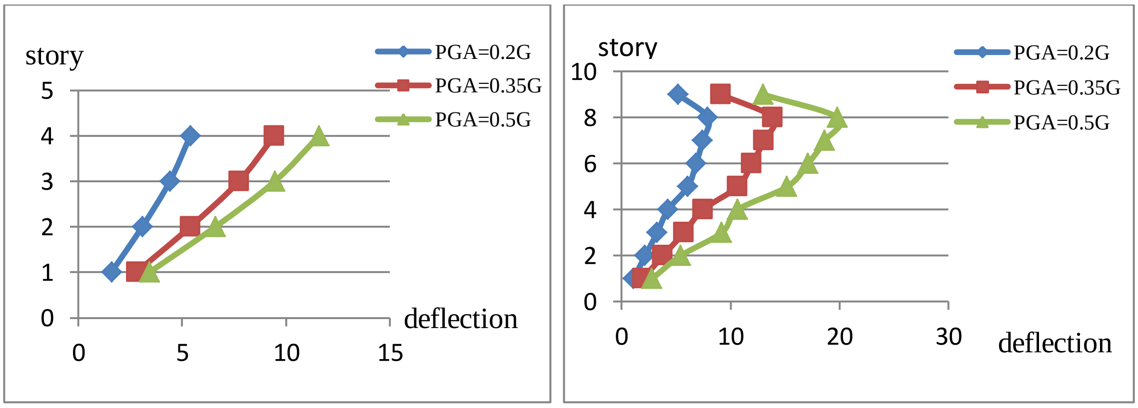

(a) (b)

**Figure 5.** Acceleration in each story : a) Story acceleration in five story building; b) Story acceleration in ten story building



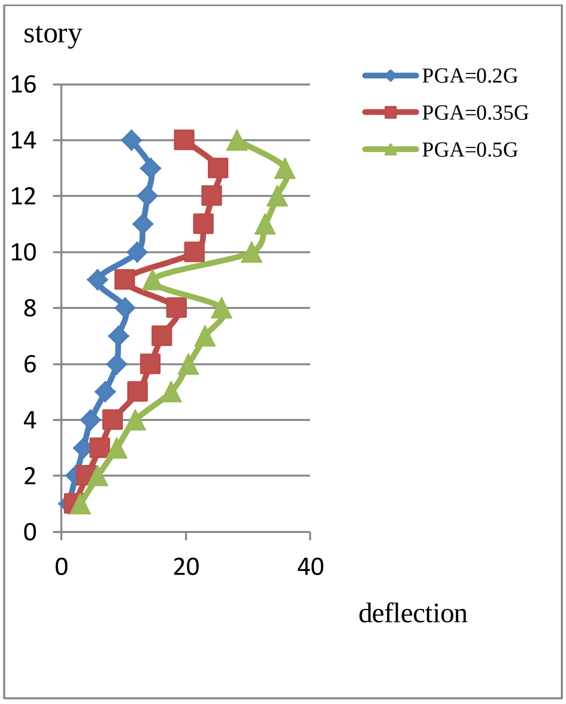

(a )　　　　　　　　　　　　　　　　　　　　(b)

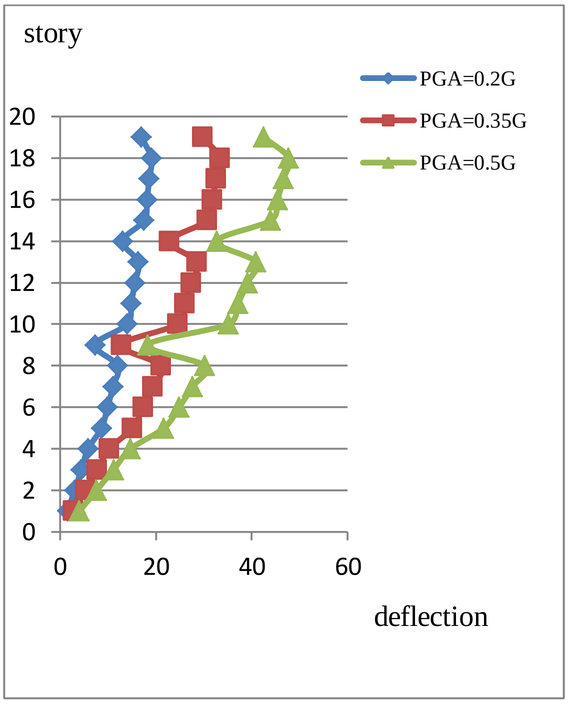
**Figure 6.** Acceleration in each story: a) Story acceleration in fifteen story building; b) Story acceleration in twenty story building




(a)　　　　　　　　　　　　　　　　　　　　(b)

**Figure 7.** Story response spectrum: a) Story deflection in five story building; b) Story deflection in ten story building




(a) (b)

**Figure 8.** Story response spectrum: a) Story deflection in fifteen story building; b) Story deflection in twenty story building

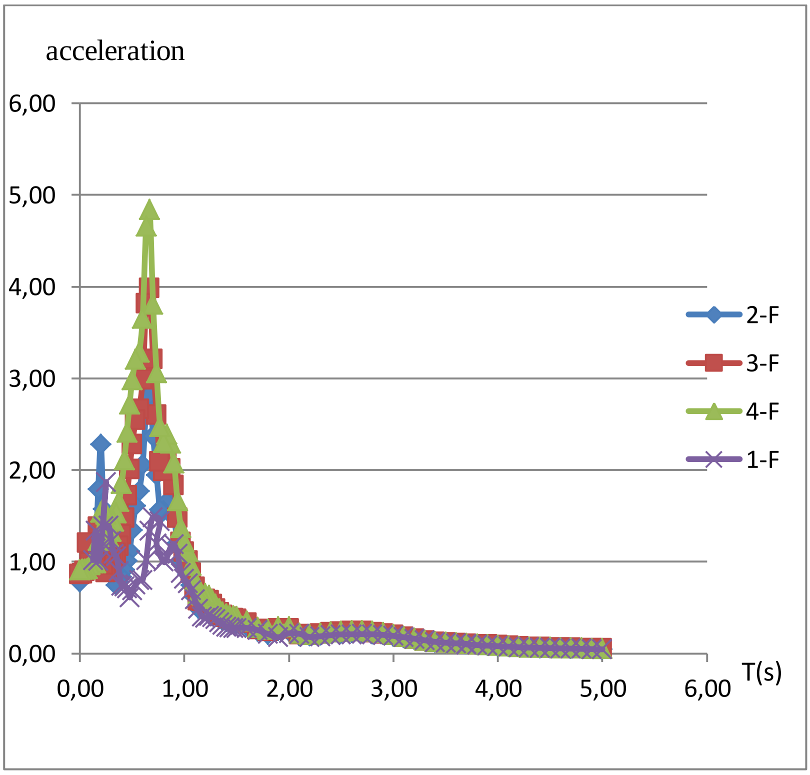



**Figure 9.** Story response spectrum

## 6. APPLIED LOADS TO MASONRY WALLS IN STANDARDS

In order to evaluate the analytical results, they have been compared with those obtained from relations of three well-known building codes: UBC, NEHRP2003 and the Iranian earthquake standard. The results of the methods have been illustrated in a graph in Fig. 10.

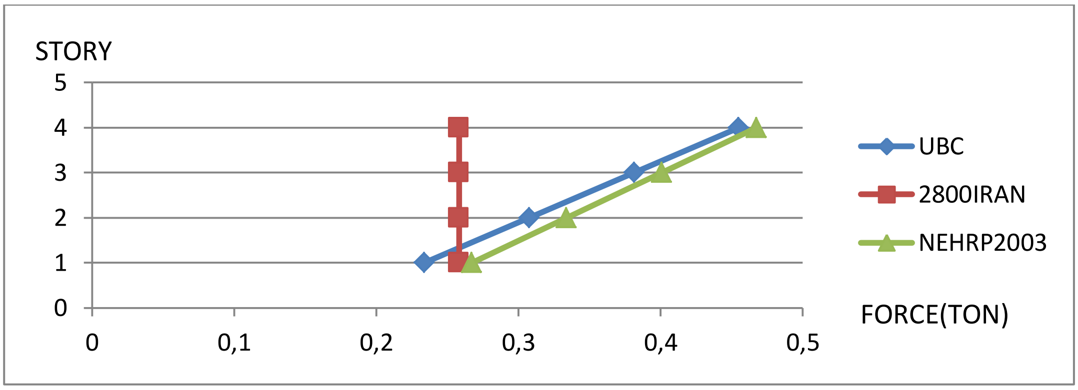



**Figure 10.** Loads to Masonry Walls in Standards

## 7. COMPARISON OF THE LOADS TO THE MASONRY WALLS ACCORDING TO THE STANDARDS AND ANALYTICAL RESULTS

The applied load to the wall could be obtained by multiplying the mass acceleration of each floor to the mass of the wall per its length. This load has been compared with the values determined by the Standards and the results of this comparison for 5 story building have been offered in a graph in Fig. 11.

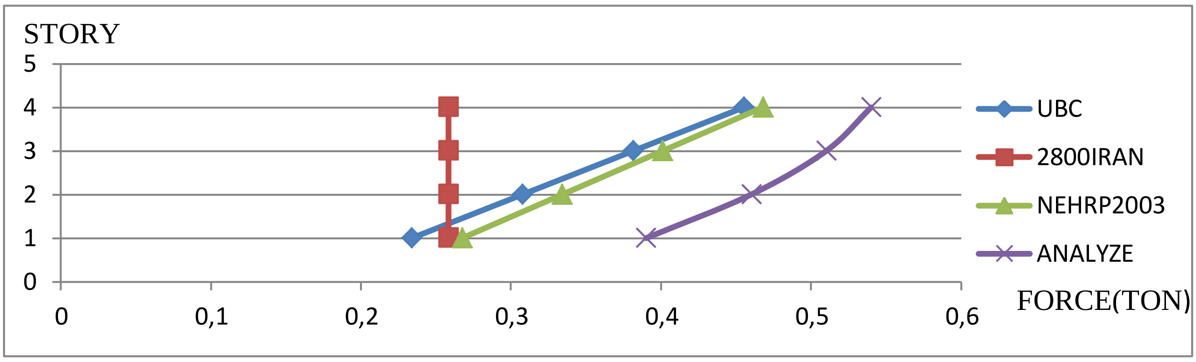



**Figure 11**. Loads to masonry walls in standards and analyze

## 8. CONCLUSIONS

According to the attained results it is obvious that the loads determined from the standards are much smaller than the loads obtained from nonlinear dynamic analysis. However, these results are due to just one accelerogram and the final results have been presented for only 5 story building. Hence, by the increscent of the accelerograms and the structures under investigation, a force superposition could be obtained which will adjust the resulted loads.

As a result, the significant fact is the lack of the standard's relation which it has to be precisely taken into consideration. Another point is the large displacement of the walls at the top stories of the towers which it also has to be carefully intentioned.

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