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## Seismic Vulnerability and Performance Level of confined brick walls

### Description/Abstract

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# Seismic Vulnerability and Performance Level of confined brick walls

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**Abstract:** There has been an increase on the interest of Engineers and designers to use designing methods based on displacement and behavior ( designing based on performance) Regarding to the importance of resisting structure design against dynamic loads such as earthquake , and inability to design according to prediction of nonlinear behavior element caused by nonlinear properties of constructional material .

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Different reasons such as environmental, economic, social, cultural and accessible constructional material have caused different kinds of constructional structures.

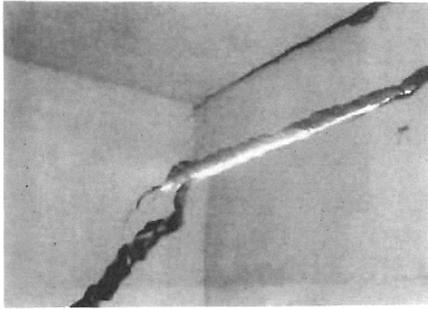
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**Key words:** performance level, masonry structures, Seismic Vulnerability , accelerator suitable with geology conditions

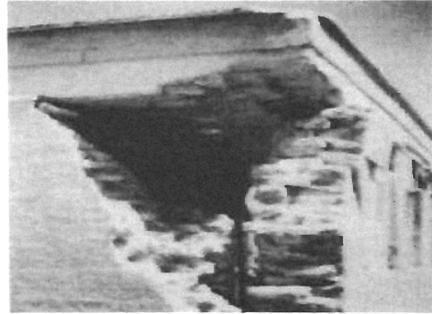
## INTRODUCTION

Studies on masonry buildings after earthquake shows that fragility of materials and non continuity of these buildings are main factor of destruction at the time of earthquake, There are similar damages occurred by earthquake on these structures Regarding to kind of construction of these structures. Some of these damages are horizontal cracks at the joint of ceiling and walls, indicated in Fig1. These cracks are caused due to unsuitability of connection between ceiling and walls .Also disconnection between walls at the joints and out surface collapse has been seen in most of masonry buildings at the time of earthquake Fig2, 3. As time passes along with research and experiments, using horizontal and vertical ties has been suggested to solve the problem. On the other hand, inertia force caused by earthquake on the building is divided on the structure elements in a way that a part by widthwise walls, a part by longitudinal walls and a part by ceiling are transferred. The proportion transferred from widthwise walls to ceiling and foundation and from ceiling to longitudinal walls. In fact, this mechanism defines the importance of longitudinal walls in transferring force caused by earthquake and the damage and destruction of

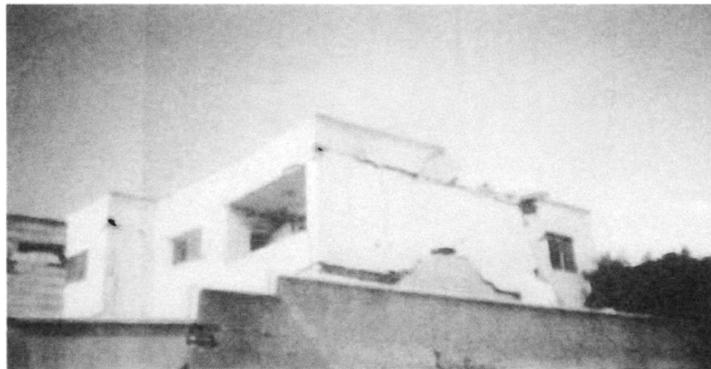
them can have a noticeable effect on vulnerability and destruction of the whole structure. [1]



**FIGURE 1.** Deep cracks between ceiling and walls



**FIGURE 2.** Discretion orthogonal walls



**FIGURE 3.** Out surface collapse of wall

In this study, destruction analysis method is introduced for confined brick wall and the effect of some parameters such as span length, numbers of span and number of floors on the destruction caused by earthquake. The common method to model of confined brick wall is taking equivalent diagonal member in to consideration. Park & Ang damage index and IDARC software has been used to analyze destruction. [2, 3]

## **MASONRY BRICK WALL**

Compressive stress-strain diagram of masonry brick constructional material is illustrated in fig4. This diagram is considered as a parabolic function till the maximum stress of  $f_m'$ , then with the increase of strain the value of stress is decreasing linearly and after that is a fixed value. Assumed model for coverage of strength of brick panel is illustrated in fig 5 that this coverage model shows compressive behavior.

Cyclic force-displacement diagram for compressive situation is shown in fig 6. Resulted formulas for coverage are presented according to studies done by Sanezhad and Houbez. [4]

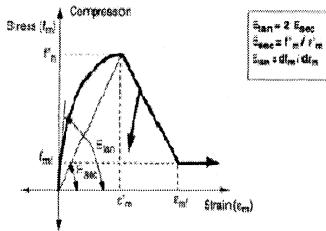


FIGURE 4. Stress-strain behavior of brick materials

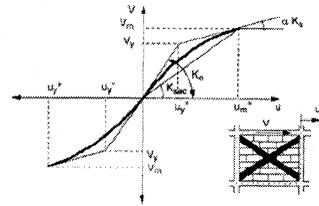


FIGURE 5 brick panel strength coverage

With taking a confined brick wall in fig 7 in to consideration, maximum lateral force  $V_m$  and the relevant displacement  $U_m$  are as following; [4]

$$V_m \leq A_d f_m' \cos \theta \leq \frac{vtl'}{(1-0.45 \tan \theta) \cos \theta} \leq \frac{0.83(Mpd)tl'}{\cos \theta} \quad (1)$$

$$U_m = \frac{\varepsilon_m' L_d}{\cos \theta} \quad (2)$$

Where  $t$  is the thickness of wall,  $f_m'$  is prism strength of masonry materials;  $\varepsilon_m'$  is relevant strain,  $V$  is basic shear resistance or tenacity of masonry,  $A_d$ ,  $L_d$  are area and equivalent length of diagonal member respectively. [5]

$$A_d = (1 - \alpha_c) \alpha_c t h' \frac{\sigma_c}{f_c} + \alpha_b t l' \frac{\tau_b}{f_c} \leq \frac{0.5 h' f_a}{f_c \cos \theta} \quad (3)$$

$$L_d = \sqrt{(1 + \alpha_c)^2 h'^2 + L^2} \quad (4)$$

The values of  $\alpha_c$ ,  $\alpha_b$ ,  $\tau_b$ ,  $f_a$ ,  $f_c$  are related to geometry and the characteristics of confined material and wall (infill frame). Allowable stress  $f_a$  is resulted from the Equations following;

$$f_c = 0.6 \times \phi \times f_m' \quad f_a = f_c \left[ 1 - \left( \frac{L_{cef}}{40 t} \right) \right], \quad \phi = 0.65 \quad (5)$$

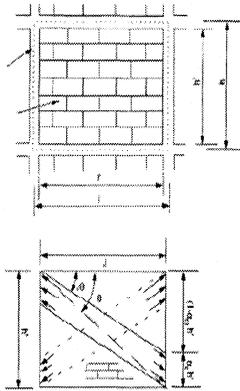


FIGURE 6. brick panel and equivalent compressive member

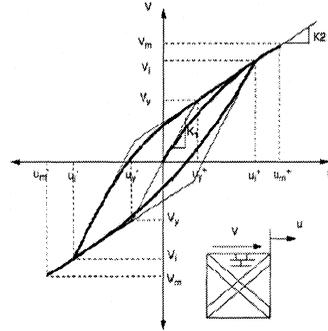


FIGURE 7 VAN-Bouk model for Cyclic response of brick panel

Uniform contact stresses at the time of fracture at the joint of vertical ties with wall  $\sigma_{c0}$  and horizontal ties with brick wall  $\sigma_{b0}$  based on Tereska hexagonal gauges yielding is as following ;

$$\sigma_{c0} = \frac{f_c}{\sqrt{1 + 3\mu_f^2 r^4}} \quad \sigma_{b0} = \frac{f_c}{\sqrt{1 + 3\mu_f^2}} \quad (6)$$

Where  $r$  is height of wall to length of wall ratio and  $\mu_f$  is friction factor of wall with ties .In one dimensional force-displacement diagram, maximum force of  $V_m$  And the relevant displacement  $U_m$  , initial stiffness  $K_0$  and. stiffness of ultra yielding to initial stiffness ratio  $\alpha$  are considered. The initial stiffness  $K_0$  can be estimated as following;

$$k_0 = \frac{V_y}{U_y} \quad (7)$$

Lateral yielding force and the relevant displacement in brick panel are as following;

$$V_y = \frac{V_m - \alpha K_0 U_m}{1 - \alpha} \quad (8)$$

$$U_y = \frac{V_m - \alpha K_0 U_m}{K_0 (1 - \alpha)} \quad (9)$$

For  $\alpha$  the value 0.1 is suggested.

## PERFORMANCE LEVEL AND ACCEPTANC CRITERIA

Different codes for performance based design have similar interpretations. The goal of seismic design of buildings is defined for different kinds separately and the selection of performance of structure is on the employer decision so the designer should take it for safety in to consideration.

Performance level is showing some boundary conditions where the acceptable value and amount of damage of a building because of an earthquake is defined. These boundary conditions are described by physical damage in the structure and the life danger for residents inside the building and the amount of serviceability of structure after the earthquake. A building consists of complicated elements and members which many of these elements have an independent performance than other elements, so for designing level, different kinds of elements performance should be considered.

Elements of a structure have 4 main performance levels as following;

1. Immediat occupancy performance level
2. Life safety performance level
3. Collapese prevention performance level
4. Not considered performance level

to study a structure performance ; result of analysis must be compared with some boundary values of performance where these boundary values are categorized in 2 parts of general acceptable criteria of a building and acceptable criteria of elements. And if the result of each analysis be more than the acceptable criteria then performance level is not accepted.

The general acceptance criteria of building as following;

**Resistance against of lateral load:** According to ATC 40 the lateral resistance of structure at performance point should not decrease more than 20 percent of ultimate resistance [7] and according to FEMA-273 base shear at performance point should not be less than 80 percent of base shear at limit yielding. [8]

**Lateral displacement;** Lateral displacement is controlled by relative lateral displacement conception. So the allowable limits for relative lateral displacement and inelastic lateral displacement are as table (1). [7]

TABEL 1. allowable relative displacements in different performance levels

Immediate occupancy	Damage control	Life safety	Collapse prevention	
0.01	0.01-0.02	0.02	0.33 Vi/Pi	relative lateral displacement
0.005	0.005-0.015	unlimited	unlimited	inelastic relative lateral displacement

## DAMAGE INDAX

Cyclic smooth Model is used for cyclic panel modeling. This model includes the effects of stiffness deterioration, resistance deterioration, and slip. Introduced Cyclic

model here is based on Van-bouk model. [5, 6] Force-displacement relationship for cyclic model is as following;

$$V_i = V_y [\alpha \mu_i + (1 - \alpha) Z_i] \quad (10)$$

Where  $V_i, V_y$  Are yielding force and instantaneous force respectively and  $\mu_i$  is uniform displacement.

$$\mu_i = \frac{u_i}{u_y} \quad (11)$$

The subscript i is applied to define instantaneous values,  $\mu_y$  yielding displacement,  $\alpha$  is stiffness of ultra yielding to initial stiffness ratio and  $Z_i$  is cyclic component.

To describing the damage value quantitatively, suitable damage index for brick wall is used. The reduce coefficient relationship of  $S_\beta$  and damage index is as following;

$$S_\beta = 1 - DI \quad (12)$$

Used damage index is a function of resulted ductility and wasted cyclic energy.

$$DI = \frac{\mu_{\max}^p - 1}{\mu_c - 1} \times \frac{1}{\left(1 - 0.25 S_{p1} \int \left(\frac{V}{V_y}\right) \frac{d\mu}{(\mu_c - 1)}\right)^{S_{p2}}} \quad (13)$$

Where  $\mu_{\max}^p$  is maximum ductility at response history,  $\mu_c$  capacity of the ductility of brick wall and  $S_{p1}, S_{p2}$  are parameters of strength deterioration rate.

## CONSIDERD WALLS

Walls of a building, with 3 and 5 meters span and the height of 3 meters in one floor and 2 floor buildings have been analyzed by nonlinear dynamic analysis.

In theses walls section and bars of ties are considered according to the Standard code 2800 of Iran. It is noted that load bearing surface of wall is 4 meters. Also, the used records related to Mexicosity, Northridge, Bam, Naghan, and Tabas earthquake are with maximum accelerator of 0.3g. To ease the work, tied walls have abbreviated like nS\_mP\_L where n is number of floors, m number of span, L is length of span and S,P are abbreviation form of story and panel respectively.

## EFFECT OF SPAN LENGHT

To study the effect of span length, walls with the span of 3, 4, and 5 meters for mentioned earthquakes have been analyzed by nonlinear dynamic analysis and the results are based on total relative displacement of roof as following ;( table2)

**TABEL 2.** total relative displacement of roof

	<b>Bam l</b>	<b>Bam T</b>	<b>Naghan</b>	<b>Tabas</b>	<b>Northridge</b>	<b>Mexicosity</b>
1S-1P-3	0.0036	0.0035	0.0033	0.0054	0.0043	0.0038
1S-1P-4	0.0034	0.0033	0.0029	0.0042	0.0039	0.0035
1S-1P-5	0.0031	0.003	0.0024	0.0039	0.0034	0.0031

Results shows that in all earthquakes along with the increased of span length, total relative displacement of roof is decreasing. Increase of span length increases the stiffness of wall which is a factor to decrease the displacement.

## EFFECT OF NUMBERS OF SPANS AND FLOORS

To study the effect of number of spans and number of floors, tied walls of 3,4,5 meters of one and two spans in one and two floors have been analyzed by nonlinear dynamic analysis. Results are as following ;( table3)

**TABEL 2.** total relative displacement of roof

	<b>Bam L</b>	<b>Bam T</b>	<b>Naghan</b>	<b>Tabas</b>	<b>Northridge</b>	<b>Mexicosity</b>
1S-2P-3	0.0033	0.0028	0.0025	0.0041	0.0038	0.0035
1S-2P-4	0.003	0.0025	0.0022	0.0037	0.0034	0.0033
1S-2P-5	0.0029	0.0022	0.0019	0.0034	0.0031	0.0030
2S-1P-3	0.0240	0.0215	0.0216	0.0260	0.0261	0.0153
2S-1P-4	0.0189	0.0185	0.0171	0.0227	0.0241	0.0123
2S-1P-5	0.0173	0.0145	0.0127	0.0189	0.0225	0.0103
2S-2P-3	0.0230	0.0202	0.0187	0.0242	0.0205	0.0130
2S-2P-4	0.0182	0.0188	0.0145	0.0189	0.0193	0.0110
2S-2P-5	0.0158	0.0154	0.0112	0.0163	0.0148	0.0099

Results shows that increase in number of spans causes decrease in total relative displacement which is influenced by increase of stiffness but increase in number of floors will cause increase in total displacement of roof.

Amount of damage index on analyzed wall is as following ;( table4)

**TABEL 4.** damage index value for walls

	<b>Bam I</b>	<b>Bam T</b>	<b>Naghan</b>	<b>Tabas</b>	<b>Northridge</b>	<b>Mexicosity</b>
1S-1P-3	0.280	0.245	0.259	0.208	0.234	0.264
1S-1P-4	0.219	0.139	0.179	0.228	0.250	0.242
1S-1P-5	0.037	0.041	0.280	0.051	0.043	0.048
1S-2P-3	0.119	0.221	0.090	0.188	0.186	0.243
1S-2P-4	0.112	0.200	0.011	0.121	0.163	0.121
1S-2P-5	0.010	0.009	0.009	0.010	0.131	0.010
2S-1P-3	0.155	0.167	0.179	0.195	0.157	0.193
2S-1P-4	0.145	0.120	0.160	0.165	0.137	0.112
2S-1P-5	0.090	0.088	0.147	0.115	0.167	0.091
2S-2P-3	0.195	0.261	0.266	0.289	0.400	0.155
2S-2P-4	0.181	0.163	0.219	0.223	0.366	0.147
2S-2P-5	0.148	0.140	0.162	0.154	0.171	0.112

After study on destruction index resulted from analysis and comparison with Park-Ang damage index values, we can say that 5 meters walls, One span one floor, and 2 spans 2 floors and 5 meters walls of 2 spans one floor has got a damage index of less than 0.1 where it is located in repairable level, but on other walls the damage index is located in unrepairable area and any of analyzed walls is not located in collapse level;

## RESULT

After study the results of analysis , we can say that in 1S-1P-3,1S-1P-4,1S-1P-5,1S-2P-3,1S-2P-4 and 1S-2P-5 the total relative displacement of roof is less than 0.01, and according to table 1, have got Performance level of 1, but the walls of 2S-1P-4, 2S-1P-3 for Tabas , Northridge earthquakes and also 2S-1P-3 wall for Bam and Naghan earthquakes is located between safety limit and collapse prevention whereas walls 2S-2P-4, 2S-2P-5, 2S-1P-5 and in some earthquakes the 2S-1P-4 wall have got the total relative displacement between 0.01 and 0.02 which have got limited destruction performance level.

Comparing the resulted damage index with Park-Ang shows that 1S-1P-5, 1S-2P-5 and 2S-2P-5 walls were repairable after the earthquake and the other walls were unrepeatabe.

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