# Seismic Performance Evaluation of In-Filled RC Frame Structure with and Without Separator Medium between Walls and Frame Components

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**ABSTRACT:** In normal practice masonry infill walls are provided in the structures and are not considered in the design phase of the structure. This negligence may lead to undesirable stresses like short-column effect, torsion, scissor cracks at beam column connection and P-Delta effect in the structure during lateral loads. This paper present shake table test on 1/4th reduced scale model of RC-frame with and without separation medium (Styrofoam) between frame and walls. Similitude requirement and Artificial Mass Simulation are taking into account during Model design. The RC frame was designed and detailed as special moment resisting frame (SMRF) for seismic zone 3 and Soil type B (Sb) of Building Code of Pakistan. The results of shake table test have shown that the model with separator medium between the infill wall and the frame component was vulnerable to damage caused by lateral vibration as compare to the model with no separator medium between the wall, beam and column of the frame structure.

**Key words:** Shake Table Test, SMRMasonry Infill Wall, RC Structure, Artificial mass simulation

## 1. INTRODUCTION

Like other countries in Pakistan, frame construction is the trending practice both in residential and commercial type of structure [1]. Almost everywhere, the curtain walls are provided at the locations depending upon the structural usage, which is economical as well as easy to manipulate for privacy, thermal insulation and sound barrier purposes [2].

Usually the Reinforced concrete (RC) frame structures with masonry infill walls have been broadly constructed for commercial, industrial and multistory residential uses in seismically active regions. Masonry infill normally consists of bricks or concrete blocks fabricated between beams and columns of a reinforced concrete frame. The masonry infill panels are usually not regarded in the plan procedure and treated as a non-structural components (do not take structure load). Nevertheless, the presence of masonry infill partitions has an extensive influence on the seismic response of a rigid concrete frame building, increasing structural strength and stiffness (relative to a bare frame) [3]

Properly designed infill partitions can increase the average strength, lateral resistance and energy dissipation of the structure. An infill wall reduces the lateral deflections and bending moments in the frame, thereby decreasing the likelihood of collapse. Hence, accounting for the infill walls in the evaluation and design leads to slender frame members, lowering the normal cost of the structural system. The total base shear experienced by a building during a lateral load such as earthquake is dependent on its time period. The seismic force distribution in structural elements is dependent on the stiffness and mass of the component along the building height [4].

After the devastating 2005 Pakistan earthquake, investigations have shown that the interaction between the infill walls and the frame components should be taken into consideration while designing a structure [5].

The structural contribution of infill wall results into stiffer structure in in-plan lateral loads, thereby reducing the story drifts (lateral displacement at floor level). This property of the in-plan infill walls performance makes the structural design realistic to a greater extent to consider infill walls as a structural element in the earthquake resistant design of structures to study and analyze the response behavior of the building. Results from previous research have shown that the presence of infill reduces the lateral deflection and increases the global strength of the structure. The deflection at story level decreases due to the presence of masonry infill walls in frame but the story drift of the soft story is significantly large and that may lead to P-Delta effect. These effects normally not found significant in bare frame model [6].

This is why the contribution of masonry in concrete structures is of great importance, although strongly depending on the ground motion characteristics, especially for frames which has been designed without considering the seismic forces and region effects [7].

The infill walls may restrain the movement of frame during strong shaking and causing damage to columns. However the damage to columns may be prevented if there are some elastic medium between frame and walls. The elastic medium may be rubber, soft plastic material and Styrofoam. The elastic effect of elastic material may prevent the damage to frame [8].

The objective of this paper is to study the energy dissipation and strength of both models that is in one case the infill wall is directly attached to the beam and column of the frame structure and the other there is some separation between the components of the frame and the infill wall.

## 2. EXPERIMENTAL SETUP

Keeping in mind the restriction of earthquake laboratory facility i.e. load, velocity, acceleration and displacement capacity of working shake table, a reduce model of (¼)th scale has been used.

Only geometric scaling has been done by reducing linear dimension of prototype structure and also the diameter of reinforcement bars was scaled down, keeping the modulus of elasticity of steel (Es) as well as strength remain same in prototype as well as in model (Simple Model) structure. Due to same strength in model as well as in prototype and requirement imposed by similitude laws the density should be increased up by 4 times, which is an unfeasible task. So, this limitation can be overcome by adding artificially extra mass at each level uniformly spread on the slab floor.

Ten physical quantities are being measured in this physical phenomena. It can be possible to represent the same phenomena with product of seven physical quantities, using Buckingham's PI-theorem (Buckingham 1914) [9]. So in this case, three basic quantities is required .For this, E, ρ and l can be used as function of dimensionless products as reproduced in Equation 1 and Equation 2 and same for both prototype and model specimen.

$$\frac{\sigma}{E} = f\left(\frac{r}{l}, \frac{t}{l}, \sqrt{\frac{e}{\rho}}, \frac{\alpha}{g}, \frac{gl\rho}{E}, \frac{\sigma_0}{E}, \frac{r_0}{l}\right)$$

Equation (1)

$$\pi_r = \left\{\left(\frac{\sigma}{E}\right)_r, \left(\frac{r}{l}\right)_r, \left(\frac{t}{l}\sqrt{\frac{E}{\rho}}\right)_r, \left(\frac{a}{g}\right)_r, \left(\frac{gl\rho}{E}\right)_r, \left(\frac{\sigma_0}{E}\right)_r, \left(\frac{r_0}{l}\right)_r\right\} = 1$$

Equation (2)

The scale factors used in this study are reduced by using

**Table 1: Scales Factors**

| Physical Quantities | Relationship | Scale factor |
|---|---|---|
| Length | $S_L=l_p/l_m$ | 4 |
| Stress, Strength | $S_f=f_p/f_m$ | 1 |
| Strain | $S_\epsilon=\epsilon_p/\epsilon_m$ | 1 |
| Specific Mass | $S_\rho=\rho_p/\rho_m$ | 1 |
| Displacement(d) | $S_d=d_p/d_m=S_l$ | 4 |
| Force (F) | $S_F=F_p/F_m=S_{l2}S_f$ | 16 |
| Time (t) | $S_t=t_p/t_m=S_l\sqrt{(S_\epsilon S_\rho/S_f)}$ | 4 |
| Frequency (f) | $S_\Omega=\Omega_p/\Omega_m=1/S_t$ | 0.25 |
| Velocity (v) | $S_v=v_p/v_m=\sqrt{(S_\epsilon S_\rho/S_f)}$ | 1 |
| Acceleration (a) | $S_a=a_p/a_m=S_f/S_lS_\rho$ | 0.25 |

The material properties used while constructing the test models are given in the following table.

**Table 2: Material properties**

| Material Properties | | |
|---|---|---|
| Material | Property | Consider Values |
| Concrete | Concrete Compressive Strength, fc' | 3000 psi |
| | Concrete Modulus Of Elasticity, Ec | 3122018 psi |
| | Weight per unit volume | 150 pcf |
| Steel | Steel type | Grade 60, ASTM A615 |
| | Reinforcement Yield Strength, fy | 60,000 Psi |
| | Steel Modulus Of Elasticity, Est | 29000000 Psi |
| Zone | Zone | 3 |
| Soil Type | Soil Type | Sb |

The fineness modulus of the fine aggregate used in the model was found by sieve analysis at concrete lab and was 2.56 which is in between 2 and 2.8. The specific gravity of fine aggregate found in concrete lab was 2.56.

A well graded course aggregate was used in the model which was 3/8 inches maximum size and down.

Concrete Mix ratio for 2000 psi strength with max size of aggregates 3/8" down are 1:2.55:2.16 (w/c ratio 0.68) were used in model preparation.

For rigid attachment of model specimen to shake table RC footing were firmly attached through threaded rods. The size of footing were 9 feet's length 5 feet's wide and 0.4167 feet's thick, reinforced with #4 deform bars spaced 5 inches c/c.

The size of columns and beams section in model structure were 3 in x 3 inches, and 3 in x4.5 inches, respectively. While slab thickness was 1.5 inches.

## 2.1 Reinforcement Detailing

The Following Reinforcement Detailing Will be used in this study as Special Moment Resisting Frame.

Prototype structure have columns size 12" x 12" reinforced with 4 #6 and #3 @ 3" c/c up to 20" from each joint and #3 @ 4" c/c in elsewhere. Beams dimension were 12" wide and 18" deep including slab, while slab thickness is 6". The beams are reinforced with 2#6 bars (top & bottom), and #3 @4" c/c from joint to 36" and #3 @7" c/c were used as shear reinforcement.

To ensure rigid connection of model with shake table a rigid foundation pad has been designed and constructed. But rigid foundation was available in the department of Civil Engineering, University of Engineering and Technology Peshawar. The drilling are done to anchor the bars in the Pad with the help of Epoxy as shown in figure below.

**Figure 1:** Foundation pad

After fixing the column main bars to the concrete base using epoxy the model was erected further until completion.

## 2.2 Mounting on Shake Table:

After the successful completion of model construction and curing for 28 days the model was white washed using two coats.

The dimension of shake table is 5 feet's x 5 feet's with pay load capacity of 4 tons.so keeping in mind the model structure is designed so to meet the above constrain. The model will be anchored with steel bolts to the shake table using grid of holes provided in shake table as shown in the figure below.

**Figure 2:** Shake Table mounting of completed model

In these two models one have direct connections of walls with the components of frame that is beams and columns. While the other one has Styrofoam between the walls and the frame components. For protecting the out of plan falling of wall with Styrofoam we provided some support to the walls.

### 2.3 Instrumentation Plan:

The Following Instrumentation were installed on model structure in direction of in plane as well as out of plane.

1.. Total five accelerometers were used, two on each floor and one on foundation pad (these five accelerometers were placed in plan to direction of motion).
2.. Accelerometers at the shake table to record the input time history.
3.. Displacement Transducer at each floor level (in plan) to measure the response displacement history.
4.. Displacement Transducer at foundation pad to record the ground displacement time history.

**Figure 3:** Instrumentation plan

### 3. Work Plan for Shake Table Test:

After successful mounting of the model, a supper imposed dead load of 600kg was placed on each model as shown in the above figure.

The acceleration time history of North Ridge Earthquake was used along East, West (NR1) and North, South (NR2).

The time step was taken as 0.00250 second.

The frequency content was applied in stepwise manner as increased from 0%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%.

### 4. TEST RESULTS:

For Earthquake Record NR1 (Northridge NS):

- First of all self-check is made for compatibility of input frequency from control room and output frequency at shake table.
- At 5% of NRI – no cracks appear in both models
- At 10% of NR1- again no cracks in both models
- At 20% of NR1 – same result.
- At 30% of NR1 – same as above.
- At 40% of NR1 – same result.
- At 50 % of NR1 – again no cracks in both models.
- At 60% of NR1 – no cracks.
- At 70% of NR1 – few small hair-like cracks (hardly visible) in model having separation medium between frame and walls but no cracks in other model.

**Figure 4:** Cracks at 80% of NR1 (Styrofoam model)

After complete run of NR1 the infill wall was completely detached from the frame components and was supported by the steel hooks and minor cracks were there at the widow jams in model of normal configuration as shown in the figure below.

**Figure 6:** *Cracks at 100% of NR2*

## 5. DATA ANALYSIS:

- By using software EXCEL, SEISMOSIGNAL and DADiSP.
- We convert the data which is in 'volts' form into the form of 'g' by dividing sensitivity constants using EXCEL.
- Then we import data in the form of 'g' into DADiSP.
- We draw PSD in DADiSP.
- Then by using SEISMOSIGNAL we find time time-history of accelerometers and response acceleration graphs.

## 6. CONCLUSION:

After performing shake table test we observed the model having separation medium (Styrofoam) between frame and walls was more vulnerable to damage and large cracks appeared on that model. This is due to improper connectivity between walls and frame. Since walls resist the lateral earthquake forces and in our case two walls of model having separation material were damaged. The center of rigidity may disturbed and not coincide with the center of mass. Due to this torsion is created and it largely cause damaging in buildings.

However the damages on frame may be reduced by providing proper elastic separation medium and proper connectivity between frame and walls.

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