Experimental Study of Adobe Type Vernacular Structures Under Dynamic Loading

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Abstracts: The experimental analysis was carried out to understand the effect of earthquake resistant features on the behaviour and damage or failure pattern of adobe and concrete masonry structure under earthquake or dynamic force. To attain this objective two series of tests were performed: A material testing programme for reduced scaling of material and Shake table testing programme for dynamic testing on 6 reduced scale masonry house models (3 from adobe brick masonry and another 3 from concrete brick masonry). 3 models can distinguish as a simple reduced scale masonry structure with no extra or additional features, a similar masonry structure aided with horizontal RC (reinforced concrete) bands at sill, lintel and roof level as earthquake resistant feature and a similar masonry structure aided with horizontal RC (reinforced concrete) bands at sill, lintel and roof level and vertical Aluminium containment reinforcement as earthquake resistant features. After testing it is concluded that masonry structure aided with horizontal EQ (Earthquake). bands and vertical containment reinforcement shows more ductile behaviour which avoids life-threatening collapse of structure.

Keywords: Reduced Scaling of Material, Masonry Structure, Dynamic Force, Horizontal Bands, Dynamic Testing

1. INTRODUCTION

Vernacular housing is the traditional style in which a culture builds its homes. It can be defined as, “Materials, generally taken from the indigenous natural environment, and building techniques, either the result of slowly evolved processes or borrowed from the surrounding culture, are combined in response to the physical and social needs of the accommodation of a community; this combination generates architectural models, that is, building techniques, special designs, and aesthetic results that are natural responses to the historical– cultural experience and the ecological – and therefore sustainable – practices of the region, while at the same time responding to its economic realities [1].

As vernacular structures also referred as non-engineered structures are made from locally available materials, they can be more vulnerable to damage during earthquake, hence author has tried to study this kind of structures. According to the location, weather, material availability, etc. vernacular houses varying vastly, so focus of the study is made only for masonry type vernacular housing structures made from the adobe bricks and concrete bricks. Computational softwares are widely used for the purpose of analysis and design of the structures. Some softwares are also available to do performance based analysis of the structures. However, the output result could generally be varying due to different assumptions regarding boundary conditions, material properties, etc. made by software and analysist. Hence to check actual performance of the structure, experiments study is required and should be done by applying actual loads to the actual structure in laboratory.

Unfortunately, our structures and loadings on it are very large that experiments can’t be possible on them in a laboratory. To get experiments done within the laboratory structure and its dimensions has to be reduced to a particular scale. However, physical dimensions of the structure should reduce but inherent properties of materials should not change under scaling. However, for the material like concrete one cannot use same proportion of concrete mix for modelling purpose which intended to use for original prototype concrete mix because the scaling of constituent particles ultimately effect the primary properties like compressive strength, water absorption, flexure strength, modulus of elasticity, etc. Hence, effect of particle size reduction of concrete mix on the basic properties of concrete as a whole material should be understood.

Scaling Of Constituents

For reduced scaling purpose all constituents were approximately reduced to one fifth of their original dimensions. The size of coarse aggregate used in prototype concrete mix was approx. 19 mm (0.75 inch). The size of grit used in prototype concrete mix was approx. 12.7 mm (0.5 inch). Coarse aggregate and grit were used in ratio of 1:1 to form total portion of aggregate. The sand particles passing through the sieve of 4.75 mm were used in prototype concrete mix. OPC of grade 53 was used as cement for prototype concrete mix. Sand particles were sieved to get particles for reduced scaled concrete mix. The sand particles passing through the sieve of 4.75 mm and retained on the sieve of 1.18 mm were used as coarse aggregate in model concrete mix. The sand particles passing through the sieve of 1.18 mm and retained on the sieve of 600 µm were used as grit in model concrete mix.

The same ratio of 1:1 was used to form total aggregate from coarse aggregate and grit. The sand particles passing through the sieve of 600 µm were used as sand in model concrete mix. As cement is very finer material, its scaling would be insignificant hence same cement was used for model concrete mix which was used for prototype concrete mix. However, cement used for model concrete mix was sieved through 150 µm to avoid any lumps present in cement. [2,3,4]

Total 6 reduced scaled models of masonry structure were prepared at reduced scale of 1:5. Among those 3 models were prepared from scaled adobe bricks and remaining 3 were prepared from scaled concrete blocks. Detail plan and elevation is shown in Figure: 1.

All 3 adobe bricks models can distinguish as below;

A1: First model was a simple reduced scale adobe brick masonry structure with no extra or additional features as shown in figure: 2

A2: Second model was a similar reduced scale adobe brick masonry structure aided with horizontal RC (reinforced concrete) bands at sill, lintel and roof level as earthquake resistant feature as shown in figure:3

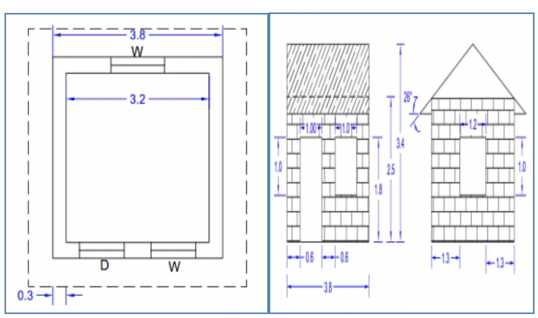
A3: Third model was a similar reduced scale adobe brick masonry structure aided with horizontal RC (reinforced concrete) bands at sill, lintel and roof level and vertical Aluminium containment reinforcement as earthquake resistant features as shown in figure:4

Similarly, all 3 concrete brick masonry models can distinguish as,

C1: First model was a simple reduced scale concrete brick masonry structure with no extra or additional features.

C2: Second model was a similar reduced scale concrete brick masonry structure aided with horizontal RC (reinforced concrete) bands at sill, lintel and roof level as earthquake resistant feature.

C3: third model was a similar reduced scale concrete brick masonry structure aided with horizontal RC (reinforced concrete) bands at sill, lintel and roof level and vertical aluminium containment reinforcement as earthquake resistant features.



Note: Scale used (1:5), All dimensions are in meter.
Figure 1: Plan and Elevation of prototype structure

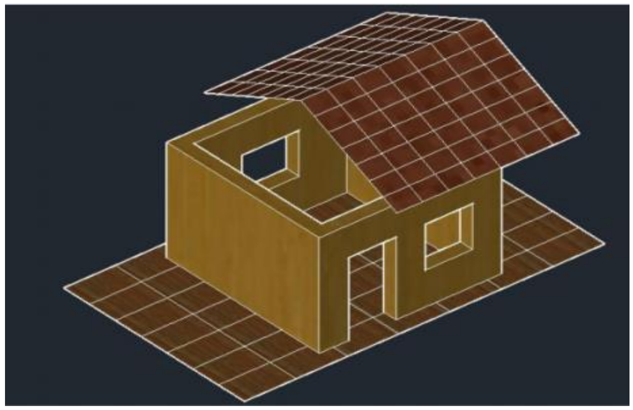


Figure 2: Pictorial presentation of model A1 and C1

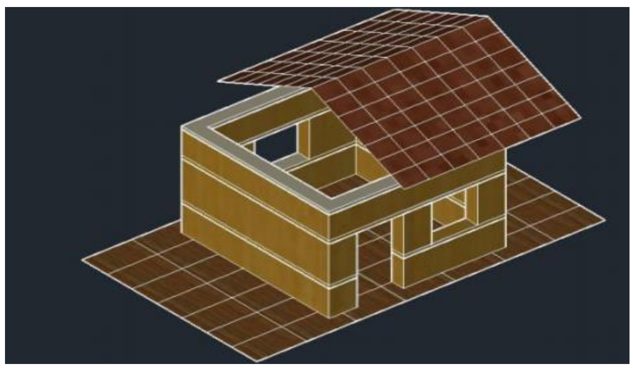


Figure 3: Pictorial presentation of model A2 and C2

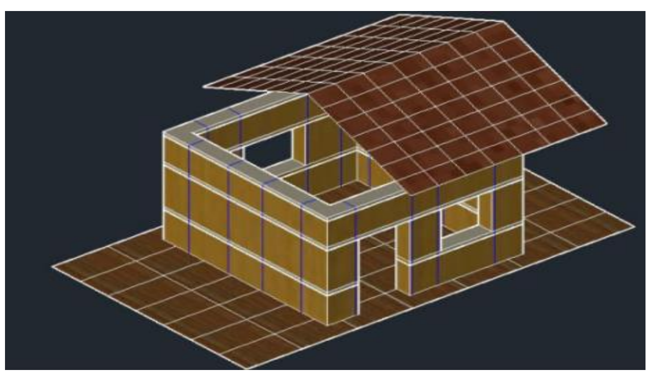


Figure 4: Pictorial presentation of model A3 and C3

Material and material proportion which are used for prototype structure may not show the same properties and characteristic at reduced scaled level.

TABLE 1: STIMULATION REQUIREMENT FOR MODELLED STRUCTURE

Physical Quantity	Relationship	Scale factor
Length (L)	SL = LP / LM	5.0
Stress, Strength (f)	Sf = fP / fM	1.0
Strain (ε)	Sε = εP / εM	1.0

Specific mass (ρ)	Sρ = ρP / ρM	1.0
Displacement (d)	Sd = dP / dM	5.0
Force (F)	SF = FP /FM = S 2 SƒL	25.0
Time (T)	ST = TP / TM	5.0
Frequency (ω)	Sω = ωP / ωM = 1/ ST	0.2
Velocity (v)	Sv = vP / vM	1.0
Acceleration (a)	Sa = aP / aM = Sƒ /(SL Sρ)	0.2

EXPERIMENTAL STUDY

Different materials were used for the preparation of all 6 scaled model [5]like adobe bricks, concrete bricks, Aluminium wire for containment reinforcement and steel wire for core reinforcement in Earthquake. bands. Same size of bricks which are used Conventionally is taken for both adobe and concrete bricks. Detail dimensions are shown in Table:2.

TABLE 2: BRICK SIZE SPECIFICATION

Brick Dimensions	Full Scaled (In CM)			Reduced (1:5) scaled (In CM)		
	L	B	H	L	B	H
Adobe Bricks	25	30	8	5	6	1.6
Concrete Bricks	40	20	15	8	4	3

The diameter of Aluminium wire considered for prototype structure was 4 mm. For simulation purpose diameter of Al wire considered for modelled structure was approximately 1 mm.

As per IS: 4326 (1993) [7]horizontal EQ. bands must have minimum thickness of 75 mm of concrete of grade not less than M15 with at least two bars of 8 mm diameter. A horizontal RC (Reinforced concrete) band having the thickness of 150 mm with two bars of 8 mm diameter was considered for prototype structures. While a horizontal RC (Reinforced concrete) band having the thickness of 30 mm with two G.I wire of 1.5 mm diameter was considered for modelled structures.

As per IS:2185 (part-1) - 2005[8] minimum avg. compressive strength of concrete should be 4 N/mm^2. Hence proportion of 1:5:10 is preferred for prototype concrete bricks and proportion of 1:2:4 is preferred for model concrete bricks.

TABLE 3: TEST RESULT OF PROTOTYPE CONCRETE MIX-1:5:10 AT 28 DAYS

Sr No	Wet weight	Water Absorption	Wet Density	Machine Reading	Wet Compressive Strength	Avg. Compressive Strength
	(gm)	(%)	gm/cm^3	kN	N/mm^2	N/mm^2
1	8670	6	2.569	163	7.2	6.24
2	8440	5	2.501	131	5.8	
3	8480	4	2.513	128	5.7	

TABLE 4: TEST RESULT OF MODELLED CONCRETE MIX-1:2:4 AT 28 DAYS

Sr No	Wet weight	Water Absorption	Wet Density	Machine Reading	Wet Compressive Strength	Avg. Compressive Strength
	(gm)	(%)	gm/cm^3	kN	N/mm^2	N/mm^2
1	7420	9	2.199	196	8.7	8.9
2	7490	8	2.219	212	9.4	
3	7550	7	2.237	191	8.5	

According Table: 2.1 from NZS:4298:1998 [9] required compressive strength for adobe brick material is 13.5 kg/cm². Test results from Table:6 shows that average compressive strength of adobe material cubes is 14.3 kg/cm², hence material is suitable for casting of adobe bricks.

TABLE 5: TEST RESULT OF ADOBE CUBE TESTING

Sr No	Length	Width	Thickness	Weight	Density	Dry Compressive Strength	Avg. Compressive Strength
	mm.	mm.	mm.	gm	gm/cm³	kg/cm²	kg/cm²
1	195	195	178	14550	2.15	12.6	14.3
2	195	195	174	14844	2.24	14.2	
3	195	195	175	14656	2.2	13.1	
4	195	195	180	14892	2.18	13.9	
5	195	195	175	14884	2.24	17.4	

Experiments are effective way to understand basic concept in structural dynamics and earthquake engineering. Earthquake simulator tables, or shake tables, are traditionally used for experimental research in earthquake engineering. These instruments are capable of reproducing the motion of the ground during an earthquake, allowing for testing of structures subjected to earthquakes [6]. Shake tables have been used at several universities for educating students about earthquake engineering and structural dynamics. The shake Table specifications are as following:

- Design Payload Approximately 200 kg
- Peak Acceleration 5g
- Operational Frequency Range 0–25 Hz
- Sliding Table Dimensions 3 ft x 5 ft
- Motor capacity 1 HP

Figure 5: Photograph of second shake table

Data collected from sixteen channel analyzer based on that base acceleration, applied frequency, acceleration at roof level of the model structure and displacement at the top of the structure were found out for each shaking. There are three different inputs frequency, displacement and No. of cycles to be provide to the shake table.

However, the input frequency is the frequency of the servo motor which empower the shake table unit may differ from the actual frequency applied at the base of the shake table where the prepared models to be rested. Hence, notation like 'F-D-C' is used to represent all the three input for shake table where 'F' stand for input frequency, 'D' stands for input displacement and 'C' stand for no. of cycles. For e.g. 1-2-3 shows 1 Hz frequency is applied for 2 mm displacement for 3 numbers of cycles.

TABLE 6: RESULTS BASED ON COLLECTED DATA FOR SHAKE TABLE TEST FOR MODEL A1

Shake	Applied Frequency (HZ)	Applied Acceleration (m/s^2)	Max. Acceleration at top (m/s^2)	Max. displacement at top (mm)
Shake-1 (1-15-5)	1.78	1.204	0.7945	0.947
Shake-2 (3-15-5)	1.375	4.026	2.48	2.644
Shake-3 (5-15-5)	2	8.24	4.45	9.55
Shake-4 (10-15-5)	2.875	24.55	16.93	15.33

Figure 6: Collapse occurs of model A1

TABLE 7: RESULTS BASED ON COLLECTED DATA FOR SHAKE TABLE TEST FOR MODEL A2

Shake	Applied Frequency (HZ)	Applied Acceleration (m/s^2)	Max. Acceleration at top (m/s^2)	Max. displacement at top (mm)
Shake-1 (1-15-5)	1.75	1.536	1.67	0.589
Shake-2 (3-15-5)	1.5	2.65	3	1.64
Shake-3 (5-15-5)	2	6.38	6.57	4
Shake-4 (7-15-5)	2.35	9.99	10.775	6.77
Shake-5 (10-15-5)	2.73	16.25	20.98	11.66
Shake-6 (10-20-5)	2.4	13.21	16.6	10.2
Shake-7 (10-30-10)	1.9	10.66	11.32	6.7318
Shake-8 (15-30-10)	2.4	21.07	23.113	16.19

Figure 7: Sliding can be seen in Model A2

TABLE 8: RESULTS BASED ON COLLECTED DATA FOR SHAKE TABLE TEST FOR MODEL A3

	Applied Frequency	Applied Acceleration	Max. Acceleration at top	Max. displacement at top
Shake	**(HZ)**	**(m/s2)**	**(m/s2)**	**(mm)**
Shake-1 (1-15-5)	1.75	1.029	1.032	0.947
Shake-2 (3-15-5)	1.375	4.097	4.08	1.638
Shake-3 (5-15-5)	2	4.766	4.81	2.528
Shake-4 (7-15-5)	2.375	18.25	18.79	12.894
Shake-5 (10-15-5)	2.75	17.96	18.93	14.02
Shake-6 (10-30-5)	2	11.37	11.59	8.586
Shake-7 (15-15-5)	3.25	17.43	39.86	23.558
Shake-8 (15-15-10)	3.25	28.02	34.22	21.952

Figure 8: Failure of wall Junction and upper horizontal EQ.

TABLE 9: RESULTS BASED ON COLLECTED DATA FOR SHAKE TABLE TEST FOR MODEL C1

Shake	Applied Frequency (HZ)	Applied Acceleration (m/s2)	Max. Acceleration at top (m/s2)	Max. displacement at top (mm)
Shake-1 (1-15-5)	1.75	1.035	1.587	0.051
Shake-2 (3-15-5)	1.5	4.27	6.9112	1.003
Shake-3 (5-15-5)	2	6.42	9.5	2.82
Shake-4 (7-15-5)	2.35	16.34	14.72	4.88
Shake-5 (10-15-5)	2.75	20.31	19.13	6.83
Shake-6 (10-30-5)	1.95	9.9	18.91	6.56
Shake-7 (15-15-5)	3.35	24.58	26.321	9.2
Shake-8 (15-15-10)	3.27	27.74	46.454	9.51
Shake-9 (20-15-5)	3.7	30.73	72.06	26.26

Figure 9: Diagonal cracks developed near window at Shake-9 in model-C1

TABLE 10: RESULTS BASED ON COLLECTED DATA FOR SHAKE TABLE TEST FOR MODEL C2

Shake	Applied Frequency (HZ)	Applied Acceleration (m/s2)	Max. Acceleration at top (m/s2)	Max. displacement at top (mm)
Shake-1 (1-15-5)	1.78	1.675	1.9517	0.094
Shake-2 (3-15-5)	1.57	6.322	5.82	1.003
Shake-3 (5-15-5)	2	8.81	10.636	4.17
Shake-4 (7-15-5)	2.35	15.25	15.2496	7.79
Shake-5 (10-15-10)	2.73	16.55	18.617	8.41
Shake-6 (15-15-10)	3.35	34.44	24.85	9.21
Shake-7 (15-30-10)	2.45	23.38	27.72	10.206
Shake-8 (20-15-10)	3.78	49.88	30.07	11.18
Shake-9 (20-30-10)	2.75	30.58	37.625	17.76

Figure 10: Collapse of Model C2

TABLE 11: RESULTS BASED ON COLLECTED DATA FOR SHAKE TABLE TEST FOR MODEL

	Applied Frequency	Applied Acceleration	Max. Acceleration at top	Max. displacement at top
Shake	**(HZ)**	**(m/s2)**	**(m/s2)**	**(mm)**
Shake-1 (1-15-10)	1.25	1.83	1.7337	3
Shake-2 (5-15-10)	2	8.94	7.63	3.57
Shake-3 (7-15-10)	2.375	14.57	14.506	4.79
Shake-4 (10-15-10)	2.75	20.95	20.95	8.02
Shake-5 (15-15-10)	3.375	30.87	28.59	9.51
Shake-6 (20-15-10)	3.75	26.47	38.681	10.24
Shake-7 (25-15-10)	4.125	52.3	64.856	14.474
Shake-8 (25-20-10)	3.625	37.35	242.562	24.8475

Figure 11: lintel and sill level EQ. bands broke after shake-9 in model C3

Capacity curve for all 6 models in the form of Base shear coefficient (BSC) vs. Drift ratio is to be plotted. Drift ratio is the ratio of the top lateral displacement to the height of the structure and is expressed in percentage drift. Base shear is calculated by multiplying the maximum response acceleration at the top of the structure with the storey mass, while storey mass can be taken as the sum of the mass of roof and half of the mass of the walls.

CONCLUSIONS

Percentage decrement in strength of concrete with respect to prototype concrete mix is at the peak when the percentage volume of cement used of total volume of concrete mix is nearly 6%. After the percentage volume of cement is nearly 14% the decrement in strength of concrete is nearly constant.

Figure 12: BSC vs. Drift ratio (%) curves for Model masonry structures A1, A2 and A3

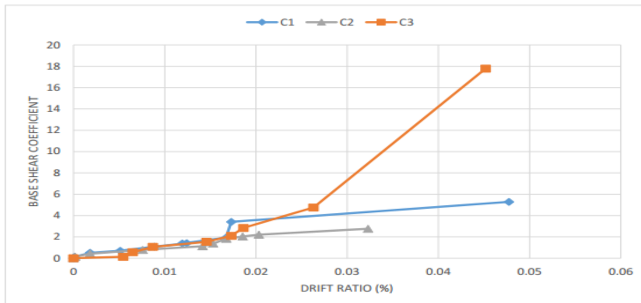
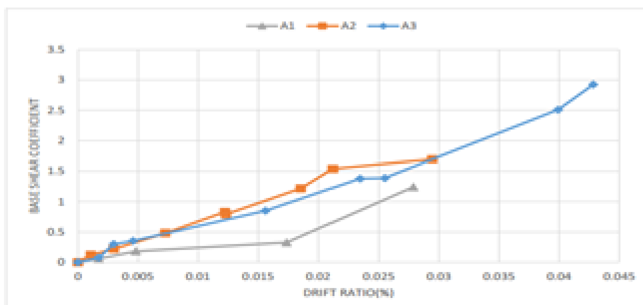


Figure 13: BSC vs. Drift ratio (%) curves for Model masonry structures C1, C2 and C3



From the above graphs following observations are made,

Inclusion of Horizontal earthquake resistant Bands in masonry structure provide better resistant to earthquake compared to the simple masonry structure but lower drift ratio for higher BSC indicates lower deformability to applied force which tends to brittle or sudden failure of the structure (seen during shake table testing of model A2), hence inclusion of only horizontal EQ. bands as earthquake resistant feature is not recommended.

In the structure aided with only Horizontal EQ. bands, with every level of Horizontal EQ. bands material discontinuity introduced in the structure from where initiation of cracks and damage started which ultimately led portion of masonry above band level to slide and collapse occurs.

- Seismic resistance of model A3 is significantly larger than the other models A1 and A2.
- Both A1 and A2 models reach their ultimate capacity at drift ratio (%) around 0.028, however BSC corresponding to model A2 is slightly higher than the BSC corresponding to model A3.
- Capacity curve for model for model A2 and A3 is nearly equal up to the drift ratio of 0.015.
- Model A2 shows higher values of BSC than Model A3 for corresponding drift ratio up to 0.028 after that Model A2 Fails.

- For Drift ratio of 0.01 to 0.03, less deformation or damage and cracks observed in model A2 for same amount of acceleration than model A3. After that Model A2 fails which shows brittle behaviour of the structure.

- Capacity curve of model A1 shows competitively lesser values of BSC for corresponding drift ratio compared to other two models A2 and A3. Which shows very low energy absorption for model A1.

- Seismic resistance of model C3 is much larger than Model A3

- Model A3 shows higher drift ratio of 0.043 compared to 0.032 drift ratio of Model C2 for nearly equivalent BSC, which shows higher deformability of model A3 tends to ductile failure compared to model C2 having lower deformability tends to brittle failure of the structure.

- Model C3 shows much higher BSC of nearly 18 compared to Approx. 3.0 BSC of Model A3 for nearly equivalent Drift ratio, which shows for the same amount of deformation in structure Model C3 Absorb very large amount of energy compared to Model A3.

- All concrete brick masonry models except model C2 performed higher than the Adobe brick masonry model A3.

- Model C1 shows highest deformability by achieving maximum drift ratio of 0.048 among all other models.

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