

Parametric studies on the seismic performance of typical rural buildings in India

Sreenivas Sarma Paraitham

Sai Krishna Anudeep Paraitham

Abstract—India is divided in to four seismic zones ,viz.,zone II(moderate) to zone V (Very Severe). In each of these zones , rural areas exist and the rural buildings are unique in pattern to that particular zone . Many of these rural buildings are non-engineered and are always the ‘worst hit’ during devastating earthquakes . However, it is interesting to note that some of these buildings which follow traditional construction patterns and practices , popularly known as vernacular constructions , have withstood the power of earthquakes and are time tested

In this work , the results of a parametric study conducted on the seismic performance of typical rural houses of India , are presented . The study involved the analysis of representative numerical models of typical rural buildings of various geometries , materials and patterns . These representative models are the outcome of the several field investigations and review of the extensive standard literature available on construction practices adopted in rural housing In India .Based on the performance of these buildings in terms of their response parameters such as moments , shears , displacements , levels of satisfactory performance are drawn . An attempt is made to recommend alternative pattern/ geometry/ material that suits a particular zone of the country .

Keywords— Rural buildings , Vernacular Constructions , Seismic Performance , Parametric Studies

I. Introduction

India is one of the two major contributors for the world’s population. Over 70% of it’s population live in rural areas in about 140 million houses, most of which are non-engineered . Two-thirds of the country’s land (which is mostly rural) is disaster prone and 57% comes under seismic zone . Observations of seismic damages in rural houses during the past earthquakes reveal that some of these rural buildings are time tested and remain as examples of the strength of traditional practices. Such non-engineered buildings, which are the outcome of unique traditional and cultural practices of a locality, are often termed as ‘Vernacular Constructions’. They possess certain specific qualities that radically differentiate from other types of non-engineered constructions.

Over the years, studies in Indian context have focused on the

urban buildings and not paid due attention to rural buildings in spite of the fact that they constitute the majority of buildings . Recent earthquake of Bhuj(2001) proved beyond doubt that it is time to study the behavior of such time tested and long sustained rural buildings in order to understand why they are faring better in comparison to other non-engineered types. Furthermore, those vernacular buildings that were damaged during seismic activity, will also be giving us an opportunity to learn lessons. In any case, there is a strong need to conduct comprehensive studies on vernacular buildings and their behavior during seismic loads. Such studies enable the engineers to take maximum advantage of traditional materials, practices and architectural aspects.

In this work an attempt is made to gather comprehensive details about the vernacular buildings through extensive field studies and note various traditional materials, practices and architectural aspects among these buildings. Based on the performance of such buildings in the past earthquakes, guidelines are given in the Indian context, to help the engineer frame a network of compatible materials, practices and other architectural aspects that are appropriate and unique to a seismic zone.

Further, simple representative numerical models of the vernacular buildings in various seismic zones are analyzed on commercially available standard software (STAAD) and the parameters that influence the dynamic behavior of vernacular buildings are established. It is believed that such investigative studies on vernacular buildings will go a long way in helping the engineers understand the positive aspects of such vernacular traditions and evolve an appropriate technology for a capacity building in the country in future.

II. Methodology

As the objective of this work is to assess the influence of various parameters of the rural buildings on their seismic performance, it is felt appropriate to select the buildings for study, based on the seismic zones.

In these seismic zones, case studies of seismic damages to rural buildings are available in literature. At the same time, cases of some of the buildings with traditional practices, which could perform better and withstand earthquakes over the ages are also available. Representative buildings from among these villages were selected and visited for field investigations. It may be noted that among these buildings, varied practices pertaining to the construction materials, techniques and architectural aspects are in vogue. Thus there is a need to categorize and study these buildings according to these

Sreenivas Sarma Paraitham
Chaitanya Bharathi Institute of Technology, India

Sai Krishna Anudeep Paraitham
West Virginia University, USA

aspects. The field investigations therefore were so planned as to consider these aspects. Needless to say that, not all the buildings have withstood the earthquakes, among the vernacular constructions. Hence, the study is also intended to note the positive aspects of those vernacular constructions besides recording the reasons for seismic damages of other such buildings in various areas and finally culminating on “guide lines for appropriate technology” that gives useful recommendations for adapting to various situations.

A. Details of Villages Visited

The following villages were visited as a part of the field study, to identify and observe the patterns of vernacular constructions
 Zone 2: Thummalasugur, Tandur

Zone 3: Bhadrachalam , Dhummugudem, Sitaram puram, Regula palli, Gangolu, Charla, Berugulapadu, Chinna nallaballi, Pedda nalla balli, Sita nagaram, Venkatapuram, Parnashala, Panchavati, Chandrupatla, Kochi.

Zone 4: Shimla , manali

Zone 5: Bhuj, Anjar , Bachau ,Rapar and Gandhidham.

Zone 2: Tummallasugur

Zone 2 consists of many rural areas but for the case study adobe type of buildings, a village named Tummallasugur has been chosen. The typical adobe buildings here are consists of thicker mud walls plastered with mud. The roof laid is also made of mud type.

Tandur: The houses visited in zone 2 were mostly in areas where limestone deposits were in abundance. In view of this local wealth, Villagers over the years traditionally used “Shahbad stone construction patterns” in their housing .It can be seen that even the compound walls of the houses are in “shabad stones”. Further the roofs of these houses are typically in sloping pattern, loaded with shabad Stones. In this type of building style right from base to the roof Shabad stones are used and for plastering work Mud is used.

Zone 3: Bhadrachalam and other villages

The lower hazard zone is confined to indian shield in the south. The places that were visited are villages in and around Bhadrachalam and some the rural areas in kerala. Most of the rural buildings around Bhadrachalam were thatched huts and thatched roofing is predominant in some cases clay tiles were used for the roof covering and most of the beams and columns were built using seasoned wood or timber, the compound walls were mostly made up of locally available timber, and in some cases masonry walls. The raw material used for thatching was dried leaves from Toddy tree.

Kochi:

The Rural houses opted for the case studies were Laurie Baker houses. The houses were built of bricks with lime mortar used in between two brick blocks. Cement plastering was not done to these houses. These houses absorb less heat.

Zone 4 :Shimla

Shimla is in zone IV (High Damage Risk zone)as per the Earthquake hazard zoning of India. Weak construction techniques and increasing population pose a serious threat to this area. As the construction activity takes place mostly on

hilly slopes, for majority of the houses the columns are raised at different heights and every wall is inserted with lintel bands for better earth quake resistance. Most of the structures here are built using Reinforced Cement Concrete.

Another type of typical building which had a Shear wall built of stone masonry on one side and all the other three sides were made of brick masonry. The roof is covered with galvanized iron corrugated sheets with skeleton structure made of wood under it.

Zone 5: Bhuj and other nearby villages were severely hit by the January 26th, 2001 earthquake. While in Bhuj both RCC framed structures (New city) and masonry buildings (old Bhuj) existed together, traditional adobe houses and masonry buildings were common in nearby villages like anjaar, bachav and Rapar. It is interesting to note that the traditional ‘bhanga’ houses (which are typical in Gujarat) survived the earthquake in 2001.

III. Analysis of the representative models

Building materials that are representative of the typical pattern predominantly followed in each zone are prepared in STAAD and are analyzed in this work. In preparing the models, care is taken to account for the nature of construction involved and also the construction practice adapted, to the extent possible.

A. Models for Zone 2

Referring to the buildings visited in zone 2 as in Fig. 1(a) and Fig. 1(b), the skeletal model shown in Fig. 2(a) was adopted.



Fig. 1: (a) Stone Wall Houses; (b) Sloping Roof Top

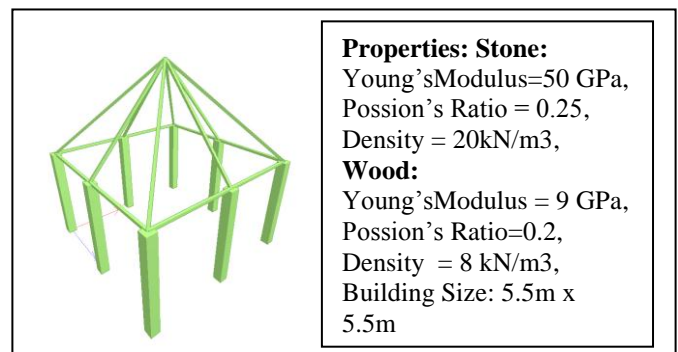


Fig. 2 (a) STAAD Model for Zone; 2 (b) Properties

B. Models for Zone 3



Fig. 3 (a) Skeletal Wooden Frame; (b) Thatched Roof

C. Models for Zone 4 & Zone 5:



Fig. 4 (a) Zone 5 building; (b) STAAD Model

Properties:

Mud: Young's Modulus = 0.5 GPa, Poisson's Ratio = 0.4, Density = 17.3 kN/m³

Wood: Young's Modulus = 9 GPa, Poisson's Ratio = 0.2, Density = 8 kN/m³

IV. Parameters considered

A. Material Practices

Three materials were chosen to be representative of the field studies viz., Mud, Wood, Stone models. These materials were analyzed for various zones using STAAD.

B. Construction practices

During the field study various construction practices were observed. They include sloping roof and flat roof, supported on a skeletal frame work of wooden/stone/mud pillar or directly supported on mud/masonry walls. The former type is named as Type-A while the later as Type-B. Apart from these practices various locations of openings were also seen. Hence two locations of the opening (corner and middle of the wall) were considered for the study.

C. Architectural practices

Under these, 3 different plans as observed in the field were chosen. They are circular, rectangular and L-shaped (shown in fig. 5 a - c)



Fig. 5 (a) L-Shaped Houses; (b) Circular Houses



Fig. 5 (c) Rectangular Building

V. Results and Discussion

A. Bending Moments

(i) Absolute Values: For Type-A models absolute maximum bending moment occurred in an L-shaped house built in stone, for seismic zone-5. This (15.369kN-m) was 3 times the value (5.086kN-m) obtained for Type-B model for stone structure. Again, this maximum value is 20 times the lowest value (0.75 kN-m) that occurred for wooden building of circular cross shape in zone-2.

(ii) Influence of Material: For a Chosen Shape of building and seismic zone, Moments are maximum in stone buildings and minimum in wooden buildings. The incremental increase in moments from wooden to mud buildings is about 1.2 times while the same from mud houses to stone houses is 5.5 times.

(iii) Influence of construction practices: Houses with Type-B practice have in general developed lesser moment, than those with Type-A practice. However, the difference is marginal. Square and L-shaped buildings were found to be more sensitive to the location of the opening, while in circular buildings the impact of location of the building was marginal.

(iv) Influence of Architectural (geometric) aspects: Among the three shapes of buildings compared, L-shaped building has in general developed maximum moments for all the seismic zones, and for all the materials. Circular Buildings performed much better than the other two. The incremental increase in maximum moments from circular to square is about 2 times while the same for square to L-shape was found to be 1.5 times.

B. Shears

(i) Absolute values: The absolute maximum shear was found to be in L-shaped house built in stone, for seismic zone 5. This was found to be about 1.2 times the value obtained for type-B model, for the same case. Again, maximum value is 13 times the minimum value, produced in wooden buildings in zone 2.

Table 1 : Response of Type 'A' Buildings

S. No	Model code	My kNm	Mz kNm	Fy kN	Dx mm	Dy mm
1	SM2	0.997	2.187	2.596	45.66	5.544
2	SM3	0.99	2.196	2.612	69.96	5.54
3	SM4	1.013	2.207	2.634	102	5.54
4	SM5	1.046	2.89	2.667	150	5.54
5	SS2	11.03	12.167	4.62	1.015	0.914
6	SS3	11.03	12.848	4.848	1.076	0.914
7	SS4	11.03	13.575	5.151	1.158	0.914
8	SS5	11.03	15.121	5.606	1.28	0.914
9	SW2	1.145	2.033	0.574	6.347	2.442
10	SW3	1.147	2.034	2.467	8.689	2.442
11	SW4	1.149	2.036	2.469	11.813	2.442
12	SW5	1.153	2.039	2.472	16.499	2.442
13	CM2	0.354	0.909	1.956	31.217	1.275
14	CM3	0.419	1.08	2.09	49.185	1.277
15	CM4	0.502	1.563	2.269	73.143	1.28
16	CM5	0.628	2.227	2.537	109	1.285
17	CS2	0.843	1.966	2.397	1.68	0.014
18	CS3	0.843	3.001	2.399	2.6	0.014
19	CS4	0.843	4.381	2.402	3.8	0.014
20	CS5	0.843	6.452	2.419	5.79	0.017
21	CW2	0.53	0.78	1.814	16	1.136
22	CW3	0.472	1.031	1.964	39.162	1.371
23	CW4	0.472	1.03	1.964	39.162	1.271
24	CW5	0.553	1.452	2.093	58.271	1.571
25	LM2	1.203	1.872	2.658	79.449	25.24
26	LM3	1.205	2.134	2.723	99.003	25.462
27	LM4	1.209	2.552	2.81	125.07	25.756
28	LM5	1.215	3.291	2.94	164.181	26.196
29	LS2	11.26	12.546	4.652	1.062	0.947
30	LS3	11.263	13.198	4.87	1.12	0.947
31	LS4	11.267	14.066	5.16	1.198	0.947
32	LS5	11.273	15.369	5.595	1.314	1.905
33	LW2	1.237	2.102	2.928	570.35	103.15
34	LW3	1.237	2.107	2.935	800.57	103.989
35	LW4	1.238	2.114	2.944	1107.3	105.11
36	LW5	1.239	2.215	2.957	1567.98	106.77

Table 2: Response of Type 'B' Buildings

S.No	Code	My kNm	Mz kNm	Fy kN	Dx mm	Dy mm
1	CMC2	0.07	1.022	1.389	2.453	0.752
2	CMC3	0.1	1.024	1.39	3.838	0.824
3	CMC4	0.14	1.025	1.392	5.685	1.057
4	CMC5	0.2	1.028	1.713	8.456	1.406
5	CSC2	0.002	1.762	2.408	0.446	0.004
6	CSC3	0.004	1.762	2.408	0.714	0.005
7	CSC4	0.006	1.764	2.408	1.024	0.006
8	CSC5	0.008	1.764	2.408	1.606	0.007
9	CMM2	0.07	1.022	1.388	2.427	0.75
10	CMM3	0.1	1.203	1.388	2.427	0.75
11	CMM4	0.14	1.024	1.391	5.601	0.84
12	CMM5	0.2	1.026	1.542	8.32	1.229
13	CSM2	0.002	1.762	2.408	0.444	0.003
14	CSM3	0.004	1.762	2.408	0.71	0.007
15	CSM4	0.005	1.763	2.408	1.064	0.005
16	CSM5	0.008	1.764	2.408	1.596	0.007
17	LMM2	0.146	0.673	1.455	5.685	3.057
18	LMM3	0.22	0.684	1.461	7.777	3.41
19	LMM4	0.319	0.698	1.469	10.587	3.879
20	LMM5	0.468	0.719	1.481	14.828	4.584
21	LSM2	0.012	0.888	2.042	0.082	0.048
22	LSM3	0.012	0.888	2.049	0.125	0.049
23	LSM4	0.013	0.889	2.049	0.182	0.051
24	LSM5	0.014	0.889	2	0.267	0.01
25	LMC2	0.149	0.674	1.462	5.645	2.914
26	LMC3	0.223	0.685	1.467	7.767	3.277
27	LMC4	0.322	0.701	1.476	10.597	3.761
28	LMC5	0.471	0.724	1.489	14.842	4.487
29	LSC2	0.012	0.888	2.042	0.082	0.048
30	LSC3	0.012	0.888	2.044	0.108	0.049
31	LSC4	0.013	0.889	2.046	0.181	0.051
32	LSC5	0.014	0.889	2.049	0.267	0.053
33	SMC2	0.174	3.454	3.902	8.08	3.943
34	SMC3	0.188	3.465	3.902	10.93	3.343
35	SMC4	0.208	3.465	3.902	14.74	4.312
36	SMC5	0.238	3.465	3.902	20.4	5.016
37	SSC2	0.174	3.454	4	8.088	3.697
38	SSC3	0.188	3.456	3.9	10.939	3.943
39	SSC4	0.208	3.46	3.902	14.742	4.312
40	SSC5	0.238	3.56	3.902	20.445	5.016
41	SMM2	0.175	3.45	3.9	7.785	2.802
42	SMM3	0.19	3.454	3.901	10.73	3.058
43	SMM4	0.209	3.46	3.902	14.66	3.46
44	SMM5	0.239	3.468	3.904	20.55	4.064

(ii) Influence of Material: Wooden buildings were found to be producing less amount of shear when compared to the other two. This increment of shear from wood to mud was found to be very minimal where as from mud to stone was found to be around 2 times the value.

(iii) Influence of construction practices: Houses with Type-B practice were observed to be producing 33% lesser shear. Walls opening were found to be giving better results when the openings were placed at middle of the wall.

(iv) Influence of Architectural Aspects: Among the three shapes of the buildings chosen the Circular building was found to be performing well. The Maximum shear value in circular buildings was found to be 20% lesser than in square buildings. Where as, for square buildings it was found to be 15% lesser than that for L-shaped buildings.

C. Deflections

(i) Absolute Values: The Absolute maximum nodal deflection was found to be for the L-shaped wooden skeletal framed building which was around 1567.98mm in zone 5. The least was found for circular stone building. This value is as low as 1.68mm.

- (ii) Influence of Materials: For the same shape and zone, the values of deflections in mud buildings were found to be more than other two materials. The ratio of highest deflection to least for same shape and zone was found to be 18 times more.
- (iii) Influences of Construction Practices: For all shapes and materials the location of the openings in the walls did not make much difference in the context of deflections produced.
- (iv) Influence of architectural aspects: For the same material and zone, in general, the deflections were found maximum in L-Shaped buildings when compared to the other two shapes. The incremental increase of the deflections between circular and square was found to be 1.5 times where as from square to L-Section was found to be about 2 times.

D. Proposed Building

Based on the results obtained from the analysis of all representative building models, it is seen that wood houses of circular and square shapes are performing better in all the seismic zones. Hence it is proposed to have a house with wooden roof and exclusive wooden wall system or wood reinforced mud system for supporting walls. Wood can be locally available variety. For example, it can be bamboo where it is abundantly available or it can be cedar wood in zone-4 where forests are rich in cedar.

E. Guidelines for evolving seismically better performing rural buildings

- (a) Extensive field studies must be made to identify and establish the traditional practices in rural housing that are time tested and have sustained the severe earthquakes in the past.
- (b) A database must be created of the locally available materials, their abundance, properties, aspects of economy and also the availability of skilled personnel to work with those materials.
- (c) Preparation of building models is depicting different plan forms, areas to suit the needs and also the relevant literature in simple form revealing the fabrication of the house and important aspects to be followed.
- (d) Fabrication, testing and standardisation of building modules which are portable and can be easily assembled or disassembled, promoting ease and quickness of construction.
- (e) Preparation of zone wise guidelines for the adoption of these practices and organizing training camps and awareness programs.

Conclusions

Based on the limited numerical study conducted in this work, the following general and specific conclusions could be drawn

General

- (i) L-shaped / Square shaped buildings were found to be more sensitive to the location of the opening while in circular buildings the impact was marginal
- (ii) Vernacular buildings are found distributed across the country in various seismic zones, some of which remained as time tested withstanding even dreadful earthquakes. The

positive aspects of such traditional practices can be compiled, tested and manifested to evolve an appropriate technology that leads to safer seismic resistant construction in rural India .

- (iii) Building constructions in wood with circular plans show superior seismic performance and hence can be encouraged.

Specific

- (i) In all the seismic zones, for all the three chosen plans, wooden buildings are performing better, followed by mud and stone buildings. The maximum bending moments in these buildings are increasing by 1.5 times (from wood to mud) and 5.5 times (from mud to stone) respectively. Similarly maximum shear are increasing by 1.1 times (from wood to mud) and 2.1 times (from mud to stone) respectively. The maximum deflections are also increasing by 1.1 times (from wood to mud) and 12.5 times (from mud to stone) respectively.
 - (ii) For a chosen seismic zone and material (say wood), the circular buildings are performing better. The maximum bending moment in these buildings are increasing by 2 times (from circular to square) and 1.1 (from square to L-shape) respectively. Similarly maximum shear are increasing by 1.25 times (from circular to square) and 1.2 times (from square to L-shape) respectively. The maximum deflections are also increasing by 1.8 times (from circular to square) and 40 times more (from square to L-shape) respectively.
 - (iii) The proposed building which is totally in bamboo and circular in plan is showing extremely better performance than all the models considered from the field study.
- In this model, the moments are reduced by more than ten times, shear by 3 times while deflections are incomparably minimal.

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About Author (s):



1. **Sreenivas Sarma Paraitham** is currently a Professor and Head of the Department of Civil Engineering at CBIT, Hyderabad, India. He has over 30 years of teaching experience.
2. **Sai Krishna Anudeep Paraitham** is currently a Graduate student in Structural Engineering at WVU, USA and an Alumnus of CBIT, Hyderabad, India.