SOCIO-CLIMATICALLY RESPONSIVE ARCHITECTURE FOR EARTHQUAKE PRONE AREAS
AN ANALYTICAL STUDY OF BHONGAS OF KUTCH REGION

Dr. Lizmol Mathew¹, Mr. Arun.M.P²

ABSTRACT

The earthquake, which struck Gujarat State in India on 26th January 2001 with an intensity of 6.9 to 7.9 on the Richter scale, caused a large-scale destruction of life and property in the State. While the majority of the buildings in the region succumbed to the seismic forces, some of the few structures that suffered minimum damage were the simple traditional ‘Bhongas’. Most of the consequent rehabilitation housing provided were abandoned by the inhabitants who found them to be socio-culturally and climatically unsuitable. Hence they returned to their traditional ‘Bhongas. The paper presents the findings of an enquiry into the seismic performance of Bhongas and presents an innovative method to increase their earthquake resistance. The improved Bhongas with greater seismic resistance can offer alternatives to contextually inappropriate rehabilitation housing while enabling the inhabitants to retain the centuries old traditional dwelling forms with their architectural and socio cultural values.

1. INTRODUCTION

Earthquakes are one of the most disastrous natural phenomenon that affect human beings. The devastation caused by earthquakes on living beings and buildings is immense. The earthquake, which struck Gujarat State in India on 26th January 2001, had an intensity ranging from 6.9 to 7.9 on the Richter scale. The worst affected was the district of Kutch, with the epicenter being 20 km northeast of Bhuj, Rann of Kutch, located at 23.6° N latitude and 69.8° E longitude. The Rann of Kutch has experienced above normal levels of microseismicity throughout the past 200 years. Though the 56 earthquakes that struck the region had magnitudes ranging from three to four, around seven quakes in the recent past had magnitudes of five and above.

The 2001 earthquake killed nearly 20,086 people in the State while around 11,000 deaths were reported from Kutch district alone. Around 3.0 lakh houses both engineered and non-engineered were estimated to be destroyed in the State, while nearly 1 million houses suffered partial damage and destruction. Bhuj, Bharda, Anjar and Rapar talukas of Kutch were the worst affected with almost all housing reduced to rubble.

2. KUTCH

2.1 The Socio-Economic Context:

Kutch is an arid, sparsely populated area under economic and social stress due to its history of droughts, epidemics and earthquakes. It accounts for less than 2 percent of the State’s industrial employment with most of its population dependent on traditional forms of agricultural practice. It also has a large percentage of socially and economically marginalized communities dependent on small land holdings, cattle and diary production, craft works, salt mining and remittances from seasonal migrations to urban areas. Kutch has a very rich craft tradition, which forms the livelihood for about 40,000 people. The earthquake shattered this livelihood base and also this rich craft resource.

¹ National Institute of Technology Calicut, India, Department of Architecture, lizmol@nitc.ac.in
² National Institute of Technology Calicut, India, Department of Architecture, amp812004@yahoo.co.in
2.2 Post Earthquake Rehabilitation measures:

The government and many NGOs took up the rehabilitation programme as a joint venture. The programme consisted of relocation of villages, full adoption of village by public-private partnership and owner-driven construction. Solutions offered ranged from temporary shelters of tarpaulins and tents, to permanent shelters of concrete blocks with tin sheet roofs. But most of the rehabilitation programmes were not very successful. The strong location-specific bonds, social stratification and polarization practiced among the communities, misuse of compensation money offered in owner-driven housing, and the contractor-driven approach which isolated the locals in ‘adopted’ villages were the major reasons for the same. The rehabilitated settlements with their gridiron patterns, as opposed to the traditional meandering streets with hierarchical open spaces and housing clusters of distinct typologies were not socio-culturally acceptable to the people. In addition, the climatic incompatibility of concrete coupled with its heavy demand on water for construction in an arid area with acute water shortage accentuated the issue. Further, the use of new alien materials and technology prevented the internalization of the new technical know-how among the local communities. All these reasons resulted in the non-acceptance of these socio-culturally and climatically incompatible alien structures. It was found that the inhabitants abandoned them or used them for storage while preferring to live in temporary shelters. It is interesting to note that among the few structures that survived the earthquake is the traditional ‘Bhonga’, which is circular in plan and made of wattle and daub mud construction.

2.3 The Architecture of ‘Bhonga’

The ‘Bhonga’ is the traditional housing typology of the Kutch region. It is a structure circular in plan with a conical roof. A single family occupies it but often ‘Bhongas’ present themselves as clusters, housing the different families of a joint family set up. A ‘Bhonga’ generally has only three openings, namely one door and two small windows. A typical plan of the Bhonga is shown below.
The typical Bhonga has an inner diameter of 3 to 6 meters with the cylindrical thick walls of banni mud providing thermal insulation in the harsh desert climate. Traditional roofs consist of lightweight thatching of local wood like babul and extremely ductile materials such as bamboo and straw. Often the single joist provided over the span in one direction is not directly supported on the cylindrical walls, but is supported on two wooden vertical posts outside the Bhonga. This improves seismic resistance of the inertia force generated in the roof. Since Bhongas do not have a foundation, the walls which extend 30 cms below the ground function as the foundation. Traditional construction, which is often carried out only using the skills of a mason and few unskilled labourers, can easily be completed within a period of 30 days.

It was observed that in the 2001 earthquake very few Bhongas experienced significant damage in the epicentral region. The damage which occurred has been mainly attributed to poor quality of the construction materials or improper maintenance of the structure. The failure of light weight roofed Bhongas also caused very few injuries to the occupants due to the type of collapse. Hence an attempt is being made here to improve the seismic performance of the Bhonga so as to offer a socio culturally and climatically appropriate alternative for housing the inhabitants of Kutch.

3. THE ANALYTICAL STUDY

A comparative analytical study of a reinforced and un-reinforced Bhonga is carried out using SAP 2000.

3.1 Assumptions in Analysis:
1. All joints are rigid.
2. Plate elements are assumed to have membrane action.
3. Roof load for un-reinforced Bhonga is neglected.
4. Roof load for reinforced Bhonga is concentrated at the rafter level.
3.2 Model Description of Un-reinforced Bhonga:

For modeling the un-reinforced Bhonga the in built cylinder template of SAP 2000 is used and its action is idealized as a thin shell. The material properties defined were of sensitive clay. Model was subjected to UBC 97 Response spectrum. A response spectrum analysis was carried out. The epicenter distance was considered to be 20KM away as per the data furnished by Gujarat Government. The section of the exact un-deformed analytical model is as shown below.

![Fig. 1](image)

The properties of the clay attributed to the model are as below:

1. Unit weight of clay : 20 kN/m³
2. Modulus of Elasticity attributed : 2000 kN/m²
3. Poisson’s Ratio : 0.4
4. Height of the model : 2.5m
5. Radius : 3m

The foundation was modeled as a hinged base since Bhongas do not have specialized foundations. Selection of the cylinder template is justified under the ground that the conventional Bhongas were monolithic constructions of clay. The entire analytical model was divided into 16 circumferential divisions and 4 vertical divisions along the height.

3.3 Model Description of Reinforced Bhonga:

For modeling the reinforced Bhonga, frame element and the plate element option of the SAP2000 is used. The plan and the 3D analysis model is shown below.
PLAN
Fig. 2
The plan consists of eight columns. Along the height the model has been divided into four divisions using tie beams as detailed below. For analytical simplicity the Bhonga has been idealized as an octagon. In the roof two rafter beams as described below are placed in the perpendicular direction imparting an interlocking effect. The junction is modeled as a rigid joint.

The properties attributed to the elements are as listed below:

1. **Rafter Beam:**
   - Section: 300mm x 600mm
   - Material: *Babul* wood

2. **Tie Beam:**
   - Section: 300mm x 500mm
   - Material: *Babul* wood

3. **Wall Element:**
   - Thickness: 250mm
   - Material: Clay

The properties attributed to clay in reinforced model are same as that attributed in un-reinforced model. Here also the foundation is modeled as hinged base. The model is also subjected to UBC 97 Response spectrum.
3.4 Response Spectrum Analysis:

Response spectrum analysis is done using mode superposition. Modes are calculated using Eigen vector analysis. UBC 97 Spectrum is used for the analysis and the spectrum is shown below.

![Graph](image)

Fig.4

3.5 Loads Considered In Analysis:

The loads considered include dead load of the structure and the earthquake load obtained from UBC 97 spectrum. A combination loading is defined as 1.5(DL+ EL). The result of the modal analysis carried out using SAP 2000 is given below.

4. RESULTS AND DISCUSSIONS:

4.1 (a)Mode Shapes:

The mode shapes for both un-reinforced as well as reinforced Bhonga is as shown below. The shadow profile in ash color shows the un-deformed shape of the structure and the color model profile shows the deformed shape of the structure. Figures 5 to 7 are of un-reinforced Bhonga and Figures 8 to 10 are of reinforced Bhonga.
Mode 1 Unreinforced *Bhonga*
Fig.5

Mode 2 Unreinforced *Bhonga*
Fig.6
Mode 3 Unreinforced *Bhonga*

Fig. 7

Mode 1 Reinforced *Bhonga*

Fig. 8
From the animated pictures it becomes clear that in the first mode of vibration the deformation of the wall of the reinforced *Bhonga* is negligible compared to the un-reinforced. This strengthens the concept that earth quake resistance can be increased through increase in the stiffness of the structure.
4.2 (b) Modal Periods:
The modal period of vibration for both un-reinforced and reinforced Bhonga is tabulated below.

**Modal Period for Unreinforced Bhonga**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.87</td>
</tr>
<tr>
<td>2</td>
<td>0.74</td>
</tr>
<tr>
<td>3</td>
<td>0.64</td>
</tr>
</tbody>
</table>

**Modal Period for Reinforced Bhonga**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.05</td>
</tr>
<tr>
<td>2</td>
<td>0.013</td>
</tr>
<tr>
<td>3</td>
<td>0.008</td>
</tr>
</tbody>
</table>

The period of vibration for mode 1 of un-reinforced Bhonga is 0.87 seconds. On the other hand, it is observed that the period of vibration for mode 1 of the reinforced Bhonga has been substantially reduced to 0.05 seconds. This reinforces the concept that increase in stiffness reduces the deformation and consequently decreases the time period of the structure. It is observed that such reinforcement brings about a sizeable reduction in the time period of the structure by 94%. It can be observed that this reduction in the period of vibration pushes the structure away from the destructive frequency range of earthquake.

5. CONCLUDING REMARKS:

The results of the analysis reveal that reinforcing the mud walls of the Bhonga with babul wood significantly enhances its earthquake resistance. The consequent increase in the stiffness results in a substantial reduction in the modal period. The deformation in the elements of the structure is reduced to a negligible extent. The reinforced Bhonga while offering high seismic resistance retains traditional architectural form, and hence will present a more socio-culturally and climatically acceptable solution to the post earthquake housing scenario.

The current analytical study is being extended to detail out the feasibility of the same from the structural and economic point of view and its execution in the local context.

References: