Structural Analysis of Historical Constructions, New Delhi 2006
P.B. Lourenço, P. Roca, C. Modena, S. Agrawal (Eds.)

Analysis of the System of Construction in the Traditional Ahmedabad Houses: Query in Seismic Resistance

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ABSTRACT: Buildings in the old walled city of Ahmedabad are placed in dense street formation and have a specific manner of construction using brick and wood. Structural systems could be studied for earthquake resistance. These structures have survived several natural calamities that have extensively damaged many buildings in the new city. If indigenous techniques of building are not studied vital information about how to build here would be lost.

Idealized models of systemic behaviour (e.g. the Indian standards code) only partly explain the traditional construction of Ahmedabad. These models are based on scientific observations of contemporary materials and systems but fail in correctly assessing the vernacular. New models with alternative theoretical interpretations and 3D simulation techniques for analysis, may clarify the role of different materials and their construction systems within a structure.

The quest of this study is to find out whether these traditional structural systems provide a greater degree of resistance to earthquakes.

1 INTRODUCTION

Vernacular Architecture in walled city of Ahmedabad is an example of a typical construction, which is non-engineered construction and has evolved over a period of time in response to cultural, physical and environmental conditions.

Any non-engineered construction by definition is one, which occurs without any technical assistance. This construction is generally a result of traditions improved over a period of time. Often this kind of construction fails to respond to the natural calamities like earthquake, because of higher return periods of such calamities. In past earthquakes, it is a known experience of people in many parts of the world that vernacular structures have often shown better seismic resistance against the modern construction.

Effort in this paper is to analyze and discuss the seismic resistance of Ahmedabad pole houses, which have survived in past earthquakes so far. Modern buildings are designed for seismic resistance using the building design codes. The codes are based on the seismic zone of region, the seismic force is considered as a mainly lateral load, and structure is assumed elastic.

For non-engineered construction it is very difficult to model and analyze the structure as per the available codes, as these structures use materials and methods of construction that are difficult to analyze for behaviour, as properties of material used are not known. Furthermore, their behaviour may not be elastic because the nature of construction is composite.

Earlier codes were silent about the effect of configuration on the behavior of structures in earthquake, but recent codes have recognized the importance of configuration of structures under lateral loads. The paper presents the study of the configuration of the Ahmedabad pole house and its comparison with codal provisions.

Finally, the paper talks about the limitation of analytical methods for assessment of seismic resistance of vernacular structures using codal provisions. The assessment of such structures-needs a more holistic approach than present methods of modeling as per the Indain codes.

2 ANALYSIS BASED ON GENERAL PRINCIPLES OF BEHAVIOUR

Earthquake produces complex set of forces in a given structure. The response of the building in such situation is more like an object subjected to dynamic forces. The forces produced in structure will depend on seismicity of the area and response of the structure to these forces. The response of structure is highly dependent on configuration of building (the size and shape and its component) along with other factors.

The aspects of configuration, which are significant for the seismic resistance of building, are applied to the Ahmedabad pole houses and are compared with present codal provisions. The materials and construction techniques used for the pole houses is traditional and it offers certain advantages for making them earthquake resistant.

Figure 1 : Keyur Vadodaria School of Architecture, undergraduate Research thesis

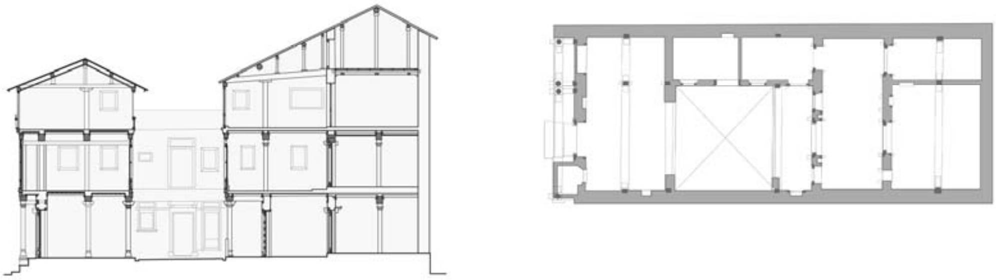
2.1 The cloister

Problems of adjacency

In walled city of Ahmedabad, the houses are elementary rectangular symmetrical units evolved linearly along the street to joined together to form blocks, Hence during earthquakes, when all houses shake according to their own natural period of vibration, hammering action between adjoining houses may take place.

2.2 The house

House consists of two bodies with a courtyard in-between and linked up by passage ways up above. As a general rule, the rear body is higher than the body looking onto the street. Roofs are pitched with the roofcrests running parallel to the street. The rear building is partly covered by a terrace for the collection of rainwater to be stored in the water tank (in the chowk) occupying part of the basement and the rest of the basement is used for storage purposes.



(a) (b)
Figure 2 : Ahmedabad Municipal Corporation- Heritage Department (R-1); (a) Long section; (b) Typical Plan

2.2.1 The Plan

Symmetry is a basic principle for earthquake resistance, as symmetrical buildings respond with regular displacements along height and almost negligible floor rotations due to insignificant torsional effects.

As a social belief in traditional construction, the door should never be located in the middle, as it causes an asymmetrical plan configuration. Symmetrical openings are preferable as per the IS code. The additional walls in the central part generate torsion and stress concentrations, creating eccentricity in plan.

The width depends upon site condition and proportionate measurements are worked out for the building span, the columns and openings. Columns are embedded within the wall at points where a beam is required to support the floor joists because a greater span is to be supported. This Structural integrity helps to distribute load among the structural elements, and their path of force transmission to the foundation are simple and effective.

As a response to site and family, need plan configuration changes throughout the city fabric. They possess an extreme height to depth ratio (aspect ratio). Large buildings impose unusually severe requirements on their diaphragms, and have large lateral spans, building up large forces to be resisted by shear walls or frames.

Ahmedabad houses have plan layout with the main parallel walls supported by cross walls at regular intervals in both directions and during earthquakes, these perpendicular walls act like shear walls. The general plan configuration follows complete masonary box system (boxes within one main rectangular box) with perpendicular shear walls. As it is not always followed it creates torsion due to variation in strength and stiffness.

2.2.1.1 Shape

Courtyards in the building weaken the diaphragm at most critical location diaphragms with abrupt discontinuities or variations in stiffness, including those having cut-out or open area greater than 50% of the gross enclosed diaphragm area, or changes in effective diaphragm stiffness of more than 50% from one story to the next, are not recommended by the IS codes.

The configuration can be described as concave because a line passing can connect two points within a figure across the figure's boundary. This is not good for earthquake resistance. However, the courtyard constructed with structure and material of its own helps it to act as a separate unit not transferring forces on to the diaphragms. The appropriate change in the nature of the diaphragms gives the building parts enough flexibility to move separately during earthquakes.

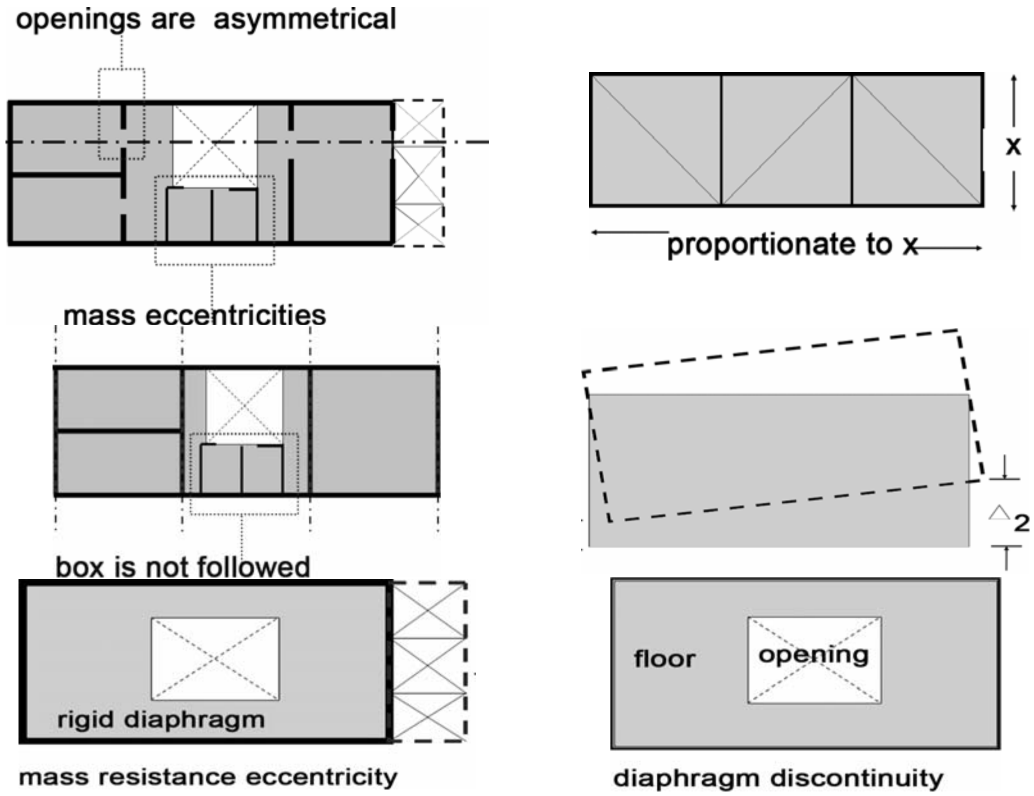


Figure 3 : Implications of the shape of the construction

2.2.2 The Section

Structural symmetry in section is very important as an earthquake resistance principle. Because a building possessing symmetrical conditions responds with regular displacements along height and almost negligible floor rotations due to insignificant torsional effects, in consequence their deformation pattern is well distributed among the structural elements.

Ahmedabad houses have all walls matching their respective floor layout at every level, which helps the gravitational and horizontal load transmission easily to the foundation.

For earthquake resistant design, it is important that center of mass and center of rigidity of building is nearly coincident. If it is not so, the distance between center of mass and center of rigidity will cause torsion in the building. Center of mass and center of rigidity of Ahmedabad buildings nearly coincide with each other. Ahmedabad houses are narrow, deep, consist of two bodies with courtyard in between, and linked up by passageways, The general rule in making of these units is that the rear body is higher than the body looking on to the street.

Stress concentration at the notch, generated due to different periods of vibration for different parts of building, generates high diaphragm forces to transfer at the setback. “Timber and other organic materials are vulnerable to fungi and decay. Traditional methods of building with highly effective construction details, like overextending its roof eaves, protect these vulnerable materials against moisture, rain and humidity.

However, over extending of roof eaves may cause overturning of roof structure”. “Projection in buildings helps as the floor joists, which extended through the wall to supports the balconies, were more successful at stabilizing the walls than were wooden joists terminating in pockets and makes conjunction with brick wall to hold”.

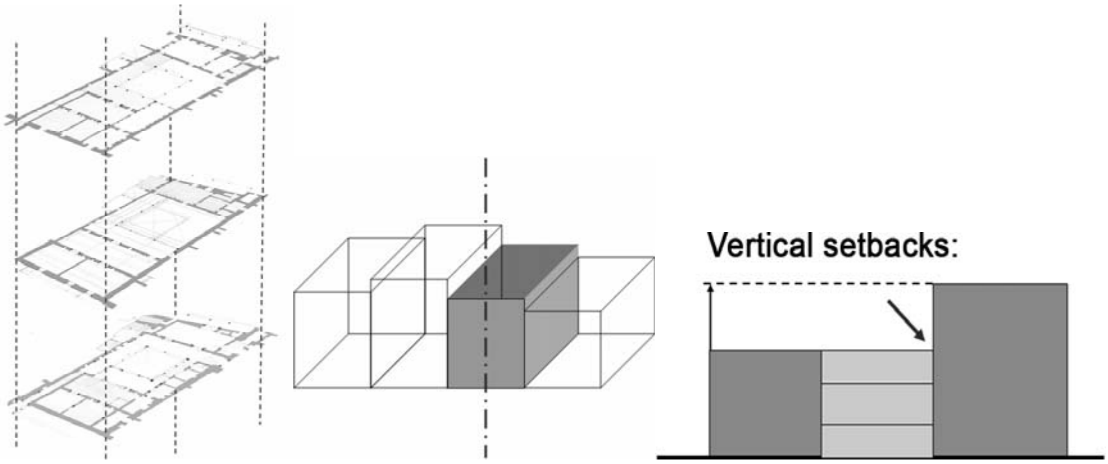


Figure 4 : Characterization of possible sections

2.2.3 Materials

Materials used for construction are light: because earthquake forces are, proportionate with the weight of the structure. Elastic properties of materials allow uniform deformation and absorb more energy during the earthquake. If the energy affecting the structure during the earthquake is equal to this energy area of the structure, the structure will have no damage. The ductile material deforms more, have more power of absorbing energy. Materials used should have the capacity to resist tensile forces, as the horizontal ground shaking is very likely to induce net tensile stresses.

Wood: "Timber structures have a well-deserved reputation for high resistance to earthquakes. Particularly the high strength-to-weight ratio of timber and also its enhanced strength under short-term loading and the ductility. Timber is organic materials and their cellulose fiber makes them highly effective to undertake tensile stresses."

Brick:

The large flat brick, which was used in Ahmedabad, are helpful, because these bricks when placed evenly over each other on well-made surfaces produce stability against overturning. The bonding materials used for brick work was made of mixture of

mud and cow-dung or lime which was adequate bonding material for large sized bricks. The weak mortar perhaps allowed a certain degree of movement and plasticity in total wall.

Stone:

In traditional houses of Ahmedabad stone is used to make base for column or posts and door-frames; "so that under earthquake moions, the posts are effectively pin-connected at the top and bottom and the structure can rock to and fro somewhat This has the advantage of substantially reducingthe lateral forces, effectively isolating the structure from the high amplitude high frequency motions".

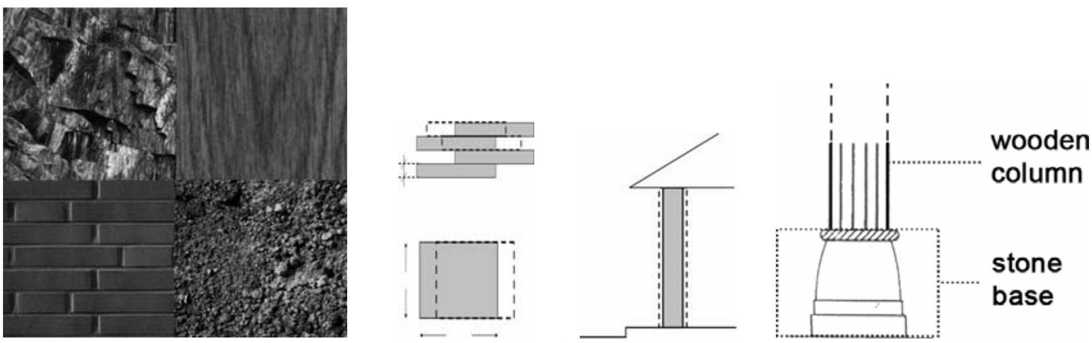


Figure 5 : Materials's tipologies

2.2.4 Composite construction: Configuration

In traditional construction system of Gujarat, wood work in the presence of brick wall and

bonding timber placed in the wall divides the wall horizontally at intervals reducing wall's effective height, which ties up with attached columns, door and window frames to form a kind of a cage which holds the house together.

Timber used at openings as lintels, sill and niches, helped to give the masonry work a visual sense of order and clear manner of construction. The joints among elements and components have enough strength and ductility to either resist the forces holding the elements together or deforming to limit the transmitted forces.

The technique of timber bonding used in conjunction with brickwork. At intervals of about, 120c.m horizontal timbers were placed in such a way so that one set was at the level of door and window lintels, another mid-way between two and one at the floor ceiling level that helps building withstand in earthquake forces. Because of the existence of the timber studs and column, which subdivided the brick walls into small panels, the loss of portions or all of several panels did not lead progressively to the destruction of the rest of the wall.

"Heavier walls help to apply compression to brickwork in lower level, and the resultant of horizontal forces are taken care by thick walls. Top parapet with brickwork also helps to hold roof in place

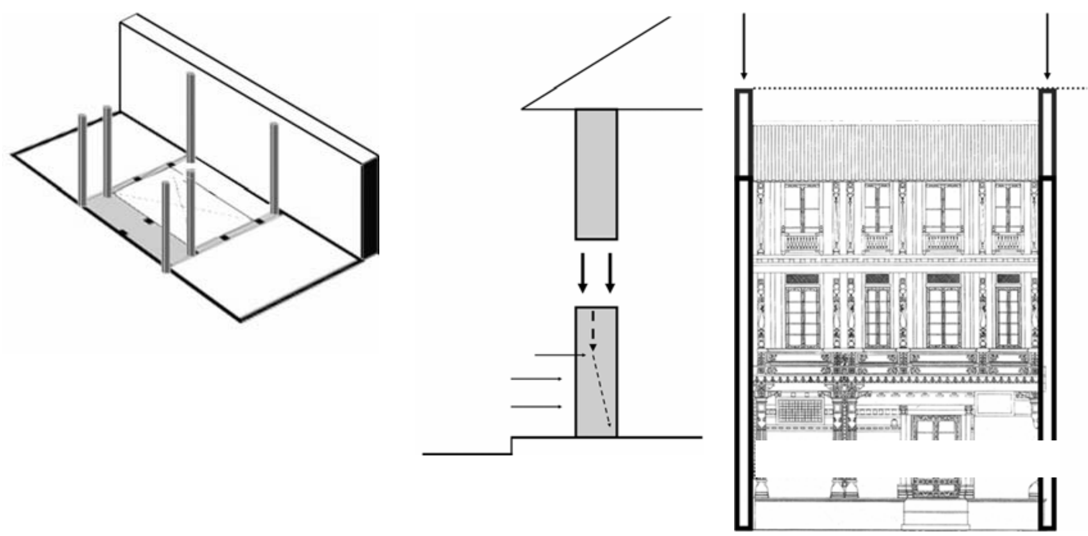


Figure 6 : Different types of configurations

2.2.5 Lightness

Lightness in building acquires special relevance in the context of earthquake resistance, as the acceleration induced due to inertia forces are in direct proportion to the masses of the buildings and its contents. Furthermore, in the event of partial or complete collapse, the consequence of a heavy construction falling upon its occupants dramatically increases the chance of serious injury or death.

Techniques:

(a) Lighter mass at top and heavier mass at bottom by using appropriate materials: Composite structure in which both wood and brick perform together in a manner in which timber becomes reinforcement to brick work makes the wall ductile during earthquake. Proportion of wood reinforcement increases as the wall goes up and increases the strength of wall. First floor facade made only by using wood, to reduce load on the first floor.

(b) Reducing wall thickness: the first floor thickness of the wall is less than the ground floor wall thickness, which makes the structure lighter on top and well balanced in effect of horizontal forces.

(c) Increasing openings on the top floor: The wall thickness on the floors above can be maintained the same as the ones below if there are more number of openings as they reduce the dead load on the walls below. However, as per IS codes mass irregularity in subsequent floors that creating weaker stories is a major problem. As per IS code Is one in which the storey lateral strength is less than 80% of that in the lower storey.

Mass irregularity**:** Increasing openings on top floors for achieving lightness as building goes up is an issue as it seriously degrades the capacity of the point of maximum force transfer.Opening area may then exceed only 30% of total wall area. The irregularity need not be considered in case of roofs.

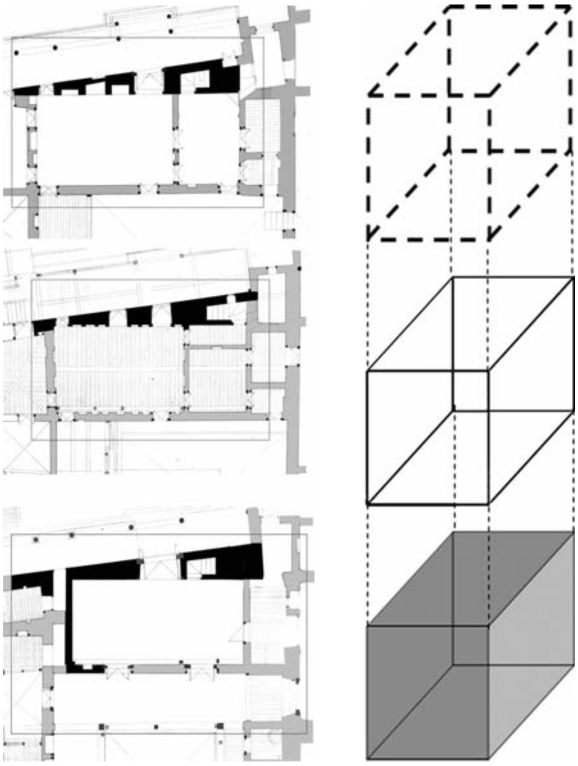


Figure 7 : Implications of the mass distributions

2.2.6 Openings

Great care has taken in design of openings since jambs of openings are the critical section of a wall panel during earthquake. Traditional houses in Ahmedabad have two complete frames of timber (tied to each other) around the openings to strengthen it against lateral force.

Openings in any storey of Ahmedabad houses have their top at the same level so that a continuous wooden band provided over them, including the lintels throughout the building. In most frames there is a large wooden sill made of thick planks. The depth of the sill is equal to the wall thickness and its width area wider than the opening, so that it projected into the wall and hold fast, All the various vertical posts were now tongued into the sill and an important member called todlo sits on the top of them and on top of that sits the lintel. Wooden lintel ties the whole door and its parts with the wall and takes the load coming from the wall above, and transfers it to the door and the wall below.

Opening on upper floor coincide with lower level openings for easy load transfer, keeping intact the capacity of the point of maximum force transfer in the event of earthquake.

Stone base: Posts that make the vertical frame for the entrance and the door made out of stone. It protected in such a way that does not deteriorated due to rainwater. The threshold is made of stone. With 1” to 2” higher than the floor level, this height helps to keep insects and rainwater out of house

Main structural parallel wall have some storage niches and less of openings that take care of the strength of the wall. Opening area does not exceed then 30% of total wall area

Regarding the dimensions, the common rule is that the height of the door should be twice its width. Locations of openings are carefully controlled keeping all windows at least away from corners so as not to weaken them.

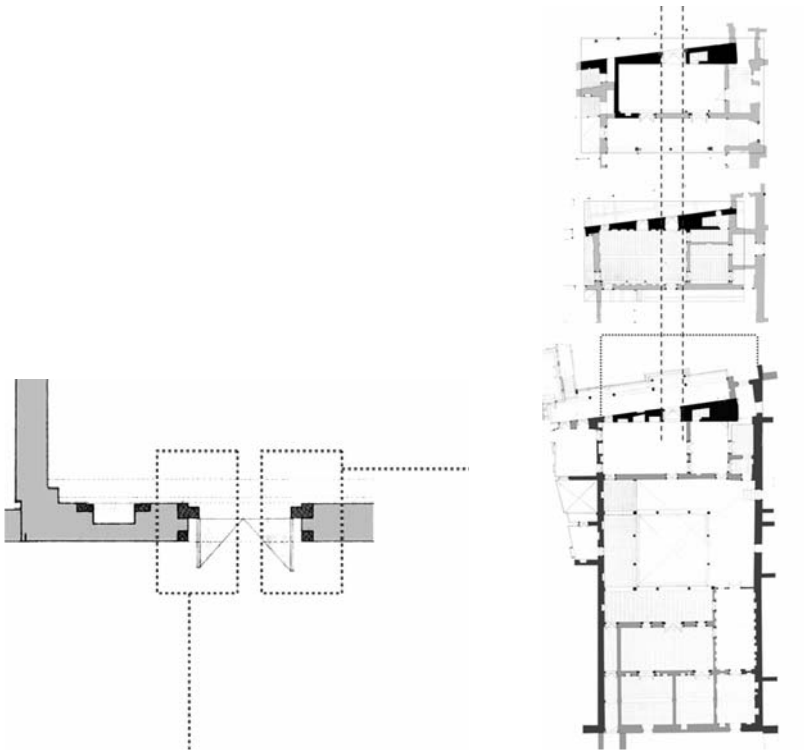


Figure 8 : Effect of the openings

2.3 Comparison

Table 1 : Comparison between traditional and contemporary materials and constructions' technologies

	Traditional	Contemporary
Configuration	Plastic, Damageable	Stiff, Rigid
Material	Circumstantial behaviour Deformation	Uniform behaviour Measurable assessment
Construction Technology	Qualitative experience based assessment Durability contextual parameters Performance based Easily repairable	Universal parameters Non maintenance Durability Required complex process

3 LIMITATION OF ANALYTICAL METHODS

The modern method of analysis fails to determine the seismic adequacy of traditional buildings. From comparison table one can see the different approach that is followed for traditional and modern building construction. The difficulty with analytical methods is as follows.

1. Analysis of structure using scientific methods needs formulation of an idealized model capable of being analyzed along the known mathematical relationships.
2. Codes and engineering methods are designed to ensure predictable behaviour and therefore advocate simple and regular configuration closer to the idealized models. However, historical structures achieve non-predictable but definite firmness; such structures, because of their complexity and irregularity make it difficult to predict, and analyze behaviour.

3. The method fails to take into account contradictory, complex or unqualifyable characteristics of the combined action of wood and brick.

Ultimately, the main difficulty is that most analytical methods are based on the assumption that the structure is elastic. These fail to take into account the higher order of deformability and energy dissipation of traditional construction. The response of inelastic structures will be different from that of elastic structure and the seismic forces attracted are lower in the former than in the latter.

4 CONCLUSIONS

The Ahmedabad pole houses qualify as earthquake-resistant by satisfying some codal provisions, but at the same time they fail to satisfy other requirements in the codes. The major hurdle is the method of analysis to be followed for seismic evaluation of the structure. This is not a problem which, requires a great deal of manpower or infrastructure. On the contrary, while traditional computer programs fail to deliver the answers, a comprehensive study of such structures and their peculiar characteristics of context, configuration, the use of materials and the documentation of the same is the need of the hour. Leaving aside the impracticalities of the computer generated methods and codes that are limited, a complete study, such as the case in hand, the pole house of Ahmedabad is of vital importance for the improvement of the general understanding of the structural behaviour of the buildings, especially during the extreme conditions of an earthquake.

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