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LEARNING EARTHQUAKE RESISTANT ARCHITECTURE: FIRST HAND

V.R.Shah[1] and Muktirajsinhji Chauhan[2]

ABSTRACT

Traditionally the seismic performance of buildings has been regarded as the primary responsibility of a structural engineer. The recent research however has shown that the role of an architect is equally and sometimes more critical for seismic performance of the building in terms of the basic design decisions. To inculcate this in the students, lessons from a real site of earthquake-affected housing is a rare opportunity.

This paper describes the results of a second year design studio conducted at Faculty of Architecture; CEPT University, India after a high magnitude earthquake struck the region where the University is located. The studio began with a survey of damaged houses in the village of Kalyanpur located close to the epicenter. After documenting the pattern of damage at the house and village level, the students analyzed the structural shortcomings of the layouts and the structural system. In addition, they studied the local materials and technology, climate and lifestyle.

The class was divided in three groups with each one focusing on a cluster generally representing the different social groups in the village to prepare layouts for reconstruction of the dwellings and clusters for each social group. Besides taking widely different design approaches to deal with seismic loads in the context of Kalyanpur, all three groups also responded to the lack of basic amenities and other issues common to village life in India. The paper also touches upon teaching structural design and seismic aspects to the students of architecture at the University.

The Context

Fig.1 Streets of Kutch

[1] Professor at the Faculty of Architecture, CEPT University, Ahmedabad. Email:profvrshah@ gmail.com
[2] Assistant Professor at the Faculty of Architecture, CEPT University, Ahmedabad. Email:muktiraj@cept.ac.in

[3]January 26 every year marks the day India adopted a republican democratic constitution and is celebrated by National flag hosting, pageantry and such appropriate events. It is also a public holiday. This time of the year also marks the middle of an academic session of the second semester in a calendar year at the Faculty when students find themselves burning the mid-might oil for the mid-semester design reviews.

January 26, 2001 was no different a day until 8.36 AM when Ahmedabad was shaken for almost a minute fall out of the earthquake measuring Mw7.7 (1) on Richter scale with an epicenter 238 km north west of Ahmedabad. While the news of collapse of several buildings in the city was immediately known, those of us studying and teaching at the Faculty spent the day slowly realizing the devastation caused across the region and the epicenter in bits and pieces, and it was 2-3 days more when the pattern, scale and nature of the total devastation became clearer.

If not the first, among the first lessons we learn was that earthquakes do not kill people, buildings kill them. Suddenly we become conscious of the nature of damage to a building, its shape, form, size, height, materials of construction, structural system from a whole new point of view as compared to simply transferring the load vertically from the terrace to the sub-soil.

As an institution, we searched for ways in which to participate not only in the relief efforts but most importantly, to ensure that in any such future event, buildings designed by us perform better and what that should mean in terms of the education and practice of architecture.

To that goal, it was decided at the Faculty to participate in the relief work as volunteers, to help the public authorities in assessing and certifying the damages to the buildings for financial and technical assistance etc.

And we also decided that we carve out a period of 8 weeks from the rest of the semester and undertake a design project in and around the epicenter to get a firsthand experience of the impact of an earthquake on people's lives, their habitat and prepare design proposals with the added parameter of earthquake resistance with greater concern.

By then one of our colleagues, Snehal Nagarsheth, had been approached by a private donor to rehabilitate the village of Kalyanpur, a rural community of about 125 dwellings close to the epicenter, and we chose the settlement to locate our design project.

Structure and Architecture[3]

The art and science of building well was at one time an integrated system of knowledge in the field. Aesthetic and structural considerations were complementary to each other. The sense of form, the understanding of stability and the order that emerged were thought of simultaneously by the Master Builder, and were complementary, not contradictory. However, in more recent history, the professions of architect and engineer have evolved as specializations, each with its own area of focus, its own methods, and its own values.

Architect's role was defined increasingly in terms of creating a formally and visually

[3] This section is based on Chhaya and Shah (2001)

unique design. In the extreme cases, this led to neglect of the integral sense of built order. The architect saw himself as an artist free from restraints especially in areas where the building scrutiny and approval processes are lax or lacking. Among architects, greater importance was given to the creation of a striking and unusual appearance of a building.

On the other hand, the engineer's role was seen to be that of ensuring that a demonstrable and certifiable level of safety and stability was ensured. The engineer saw himself as the harbinger of technology, with continuous development of methods to "solve" any requirement with sufficient application of material and technological innovation.

In both the professions, education evolved along similar lines to train professionals in the image that each profession had built for itself.

This extreme specialization has had many consequences, including:

i) An alienation of the profession from the societal and economic realities. Both professions have created their own internal value systems that are not consonant with the larger context. Hence, fulfilling highest absolute standards of strength and stability are not seen as attainable given the scarcity of material and financial resources across large sections of our society. At a more fundamental level, the issue of "what level of safety is necessary" is never even discussed.

ii) Splitting of the "professional" and the "informal" systems of knowledge and operation. The traditional and grass-roots methods are completely marginalized and devalued by the codes of practices of the professions. Both systems are in conflict and unable to operate effectively in a synergistic way.

iii) Most importantly, this leads to a corruption and degradation of both professions and informal modes of work as they try to superficially fulfill unattainable goals

Stand Point:

Our above observations have led us to conclude that:

The sense of safety, stability, and material order should be an integral and inseparable part of architectural design thinking.

The specialization into architectural and structural considerations needs to be seen in the holistic framework of a well made built form.

Earthquake safety must be seen as integral to the design process as part of arriving at built order. Traditions and thumb rules should be seen in consonance with advanced analytical methods. The study of traditionally evolved patterns is as necessary as the theoretically grounded analytical methods.

Therefore we advocate an integrated teaching of structure, including earthquake safety in the curriculum of architecture program. We also believe that an interactive teaching method with

the participation of engineer and architect is necessary.

Seismic considerations in architecture

Based on above we believe that designing for seismic consideration is a responsibility to be shared jointly by the engineer and the architect and must begin with the first, conceptual decisions on any project.

As observed by well known structural engineer Henry Degenkolb, " If we have a poor configuration to start with all the structural expert can do is to provide a band-aid to improve a poor solution as best as he/she can. Conversely if we start off with good configuration and framing system even a poor engineer cannot harm its ultimate performance too much."

It would be useful here to understand how the structural design courses are taught at our Faculty. The inclusion of course content on seismic aspects is taken as extension of what is taught in structures courses in general and emphasizing it in the studios. For seismic aspects, the course content can conveniently be divided into basic understanding of seismic load generation because of earthquake, the effects on buildings and their response and finally structural systems to resist lateral loads.

Teaching of structures in architecture

The structures courses at the Faculty are divided into three parts. In the first part, an understanding of structures is developed using various teaching aids like slides, model testing, self studies for various systems and materials where ever possible in consonance with studio and other courses. It is restricted to teaching only qualitative aspects of structural behavior and the basic concepts.

The understanding developed in the first part is enhanced by using the analytical and quantitative methods in the second part. Here, the contextualization of various aspects of structure's studies is also done to enhance the architectural design skills. The integration of this is done with relevant teaching in studios.

The third part dwells into aspects of structural and constructional detailing integral to the design process. This is detailed in the table below.

Table 1. Different stages of teaching of structures courses

Stage and Key issues and Methods	**FOUNDATION STAGE** ←→ Tapping intuitive understanding systematizing through Observation Experience and Experiment MODELS, SKETCHING	**CONSOLIDATION STAGE** ←→ Application Knowledge based selection and Evaluation Logical Evaluation and Detail Development ANALYTICAL PROCEDURES PRECEDENT & INNOVATION	
Year	I	II	III
General Intent applicable to design studio & other courses	Basic understanding of space and form. Scale, Dimensions. Abstract Relationships. Development of skills	Relationship of functions Impact of Context Design Methods	Aspects of integration of design dimensions Design resolution Details
Structures Courses	Qualitative Understanding of Behavior FUNDAMENTALS OF STRUCTURE	Principles of behavior in relation to systems and materials STATICS & STRENGTH OF MATERIALS ADVANCED STRUCTURAL ANAYSIS	Specific system characteristics and details DESIGN OF CONCRETE STRUCTURES SURFACE STRUCTURES.
Seismic Aspects	Elementary Seismology Impact of lateral loads on behavior of various systems. Aspects of behavior: Choice of Configuration	Seismic Design Principles Building Forms and Configurations. Site Planning	Structural Detailing Aspects for Seismic Design. Earthquake Resistant Structural and Constructional Details

Studio IV at Faculty of Architecture

For the design exercises to be set under each studio, the curriculum at our Faculty has assigned a focus and emphasis for each of the semesters. Studio IV scheduled in the fourth semester is aimed at understanding and exploring cultural dimensions of space and culture as a determinant of design. Secondary emphasis is on the role of climate and materials and technology in determining the design. To best highlight the impact and relationship of "culture" and people, studio IV projects always set the task of designing a small residential project of about 25-30 dwellings on a site measuring about one ha.

Studies by scholars such as Amos Rapoport generally form the basis of understanding the "culture" of a community. Since culture would have multiple meanings in modern times some of which may be universal and some specific, the exercise has always identified a distinct group of people, "community" as the target group which will be occupying the residences. Over the last few years, the selection of the target community has been based on distinct occupational, regional or religious identity which sets them apart as a specific group of people. For example, these groups have ranged from urban based cowherds, Muslims, artists, senior citizens, professionals and academicians. The selection of site in the urban fabric would be determined by their presence historically in a given quarter of the city or places of work. For a few years, advantage was also taken of the field studies of traditional dwellings and focus across India which the studio IV students undertake just before the semester begins. In all condition, a visit to existing dwellings of the target community and observation and meeting with members to understand their lifestyle and activity-space relationship would be studied. This will be recorded on a diurnal basis as well as across the seasons.

For the above purpose, the general framework such as some critical factors by Amos Rapport would be contextualized and elaborated jointly as a class before the field work commences. Over several cycles, the study of target community based on the research by Amos Rapoport has proved to be very useful. Specifically, mention may be made of what he calls five critical dimensions of Socio-cultural Factors which have been listed as Some Basic Needs, Family, Position of Women, Privacy, and Social Intercourse (page 46).The goal finally is to arrive at a set of checklist for fieldwork and guidelines for the layout of the cluster and design of individual dwellings. These juxtaposed with the area brief becomes a common starting point for the project by the class. The guidelines are by no means seen as an end, but starting point for a performance based design development interpreted individually by each student within a larger framework.

Studio IV: Seismic Resistance Housing at Kalyanpur

Earthquakes are unfortunate and tragic events for mankind but if they are taken as an opportunity for learning, they offer valuable lessons for future. For architects and engineers, they specially offer useful lessons to understand the behavior of structures subjected to seismic loads.

In January 2001, with almost 20,000 dead and several hundred thousand injured, fear of diseases, urgent need of medicines, water, food, and temporary shelter around us, there was also the realization of the failure by regulatory authorities, architects, and engineers to better fulfill

their duties. This only made us more conscious of the need to learn and perform our professional duties right for the future. Reworking the semester schedule, a design studio was planned for a total duration of eight weeks. Of which one week was to be spent at Kalyanpur where almost all the houses were affected heavily. Students were asked to study fully collapsed, partially collapsed, damaged structures and the few which survived. The study was based on the visual inspection of the buildings. The data to be collected consisted of plan configuration, materials, and construction techniques along with crack pattern.

Travelling just about four weeks after the earthquake, the journey to the epicenter was an eye opener as to what an earthquake can do. Whole towns and villages lay flat, most of them just a vast layer of rubble some two or three meters thick which had been cleared along the existing street pattern to allow access. On reaching Kalyanpur, we were housed in an assortment of places, generally tents in yards around some of the new community buildings which had better withstood the impact owing to use of RCC.

After a general walk around the village, the class was divided in three groups and three different streets were chosen for documentation of the damage to the houses. The three locations were chosen to include different social groups in the village and implicitly, three economic groups. That we believed would offer a variety in the dwelling size and may be type. Students prepared detailed measured drawings of selected streets with dwellings on both sides as a cluster and more detailed drawings of some of the houses in the cluster. For some of the houses, the students documented the crack pattern to study the correlation of crack pattern and house form which helped them to understand the basics of behavior of structures subjected to seismic forces.

After coming back to the Faculty, we continued the groups formed in the field and decided to do the design exercise as a group work. Along with developing design guidelines following Rapoport's framework of socio-cultural factors, the students had opportunities to attend lectures and workshops on designing for seismic loads. Kalyanpur is located in the most sever seismic zone as per Indian Seismic Zone classification and students were made aware of what this meant. A more detailed study of the climate of the region was undertaken and what passive responses can be built in the design was discussed.

Importance was also placed on studying the materials and techniques of construction employed in the existing housing to understand what lacunae played a role in the seismic resistance. As an example mention can be made of the local method of wall construction which lacked any interlocking bonding making it very vulnerable to collapse when shaken in an earthquake. The cracking and failure pattern was analyzed to understand how plan configuration and mass distribution played a role in the damage and how these could be modified to better resist twisting and turning due to multiple wave patterns generated in an earthquake. This helped them to understand how to use the local materials, how to modify the plan configuration and mass distribution to achieve symmetry in plan and in third dimension.

The Projects

General

We believe that the impact of the field experiences had made the students far more concerned and committed to this exercise than a normal studio brief. They did rise to the challenges of the exercise and, with the inputs they received back at the Faculty, produced a set of design proposals which are truly innovative with each group taking a unique and strong position on how to respond to seismic loads.

Walking through the streets, they had become aware of the quality of the street spaces and the social role that streets play in an otherwise strongly knitted community of a village. They also became aware of the drinking water, cooking fuel, fodder, and sanitation issues which were lacking or completely missing in the village. Each group responded to some of these areas and this was observed in their inclusion of, for example, a smokeless chulha, which is an improved wood burning, stove that directs the smoke away from the person cooking.

One of the groups was strongly committed to providing extra wide streets as an additional measure where people could safely wait out the next time a trembler comes along. Another group focused on water harvesting methods in their proposals. For us, all such ideas pointed to a much deeper sensitization of the students beyond the professional call of designing for safety from earthquakes.

Group 1 Proposal

This group was strongly influenced by the lifestyle of the residents which resulted in clearly defined zones in the house layout and the belief that traditional close-knit pattern of clustering that allows the significant resistance to the lateral loads in earthquakes.

The major lacunae identified by them was in the manner of constructing a wall at Kalyanpur which traditionally was built as two separate thin stone walls with rubble filled in between. This meant that the wall did not behave as one unit but three separate planes which quickly fell apart. They therefore proposed proper coursed masonry with horizontal ties at intervals. They improved the resistance by ensuring that walls always crossed at the corners and afforded a proper boxed structure improving the lateral resistance. Wherever possible, especially on the street edge, they built a stoop which stabilizes the wall as well as allows people to sit out and partake of the street life. Their dwelling layout improves on the semipublic domain along the street and a private zone placed beyond a court and takes into consideration future additions of appliances and amenities

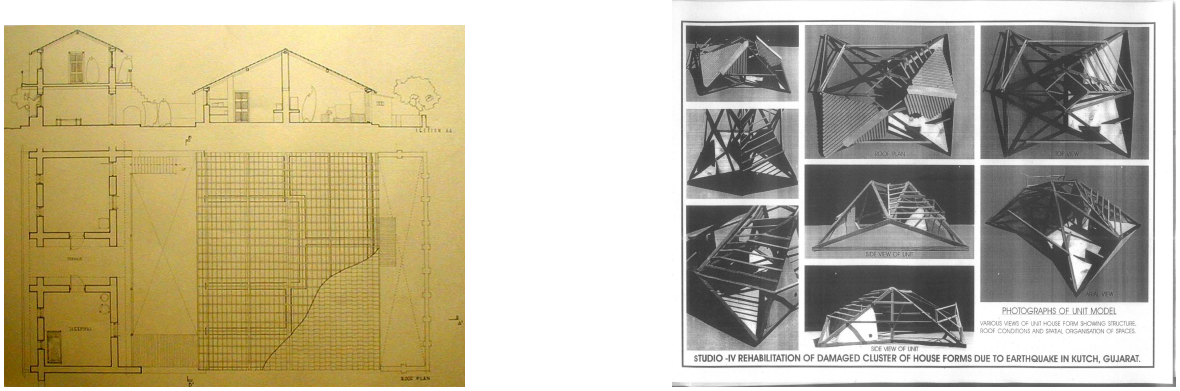

Fig. 2 Unit by Group 1 and Triangulation-Group 2

Group 2 Proposal

In the case of this group, its members were deeply shaken by the piles of chunks of walls and roof frames that were seen all over the region as we travelled and at Kalyanpur. They reasoned that the final form taken by the collapsed walls and roofs can be taken as a stable form since it cannot be disturbed, or deformed, further in an earthquake.They explored triangulation in three dimensional forms and arrived at tetrahedral forms of wall and roof. They also drew upon analogy with the practice of crashing test cars to improve upon impact resistance and brought all that to bear on the design of the dwelling.

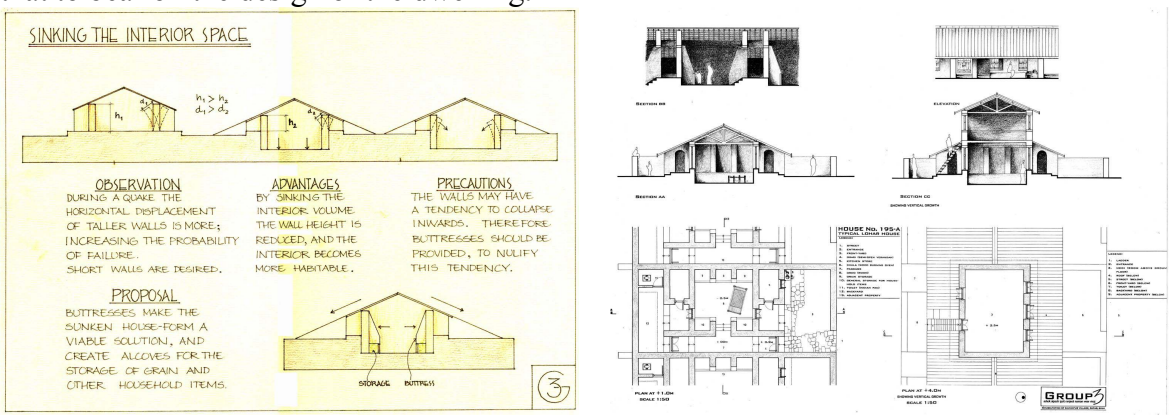

Fig. 3 Unit and Integrated box action -Group 3

Group 3 Proposal

For this group the weak points of the dwellings at Kalyanpur were the junctions between the roof and the wall and the wall with the ground. Lacking a strong bonding, each of these components shook at different frequency and eventually fell apart. Their design therefore proposes strengthening the way these components come together.

The main load bearing walls therefore extend beyond rooms and taper down to ground level and in the process kind of act as buttresses which hold the roof frame in the place. The designs also suggests sinking the dwelling in the ground reducing heights and hence control displacement at the roof level which can ensure better resistance and stability to the whole form. The dwelling also draws upon the local traditions in terms of the lifestyle and zoning and use pattern of the spaces based on the cultural traditions and the climate of the place.

Summary

This studio exercise based on real context helped the students to understand the importance of dwelling form, materials and construction techniques and structural system for a seismic resistant architecture. A faculty team comprising architects and a structural designer for this studio was especially helpful, more so since it started with the joint fieldtrip and until proposals were finalized.

For both the faculty and the students who only knew of the impact of earthquake in theory till then this was a very crucial lesson and both of them strived to harmonize and integrate engineering and architecture. This studio was a special case in that it followed an earthquake in the area but its single most significant lesson is that teaching of structures including earthquake safety should be an integral part of the architectural design studios. This would also help in developing respect for both the professions, which would be very useful in practice.

Acknowledgements

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