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The role of Architects in Seismic Design

What we can learn from traditional construction.

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Abstract

In addressing the role of architects and the architectural aspects of earthquake performance of buildings, this paper has had three objectives: 1- to show that earthquake construction is not merely an engineering activity for structural engineers, it is an activity to be shared by both engineers and architects; 2- to demonstrate the role that non-computational or architectural aspects plays in determining the earthquake resistance of buildings, and 3-to emphasise the need for engineers to understand characteristics of traditional construction and for architects to understand the problems and nature of earthquake effects on buildings.

The non-computational aspects of earthquakes are all those activities which are related to the architect, from architectural design, detailing and construction techniques to managerial decisions related to the building construction process, rather than the pure engineering and mathematical aspects of structural analysis. This paper will concern the role of architects, by discussing such specific architectural aspects as architectural elements and their effects on the earthquake performance of buildings.

This paper tries to open up an area of study of architectural issues in earthquake resistance in buildings referring to the potential of traditional construction, which is done by traditional Architects; *Mimar*s, and will introduce a set of problems specific to 'Iranian Conventional' Construction Methods, where the role of architects is ignored. The justification for this lies in the general acceptance of; lessons to be learned from traditional construction, the insufficiency of structural calculation alone in the earthquake resistance of buildings, and the need for a combination of other issues, such as building form and configuration, materials and construction workmanship, with the structural aspects. These facts show that in the case of the majority of ordinary buildings in Iran, the problem is not the lack of structural analysis. Any improvement in architectural design changes of configurations and methods employed in their construction operations, would go a long way in effecting the earthquake resistance of the buildings.

Key words: Traditional construction, Conventional buildings, Seismic design, Architectural aspects, Building construction, Iranian Code for Seismic Design.

Introduction

The earthquake resistance of buildings depends upon three quite different processes in design. There is the overall layout of the building which determines the magnitude of the forces which come onto the building and their distribution: a distribution which is important in the vertical direction in section as well as the horizontal direction in plan. Secondly, there is the ability of the various parts of the building to resist these forces, the strength of individual members and the connections between them. Thirdly there are those aspects of construction, which are rarely mentioned at all ,non-structural or architectural aspects of building, non-load bearing walls and finishes. These may constitute a significant proportion of the mass of the building, their behavior may be quite independent from that of the main structural elements, and may cause serious danger to people or buildings.

Within the 'conventional' design process in Iran most of the effort has been focused on the second ones, that is the design of construction details. This is the area of design which is referred by the Iranian Seismic Code, an area of design which is regarded as the responsibility of the engineer who is educated to deal with the calculation of the forces and the design of elements to resist earthquake forces. It is also to a large extent the area over which building control efforts may be exercised. Because this aspect of design has received most attention, it will be dealt with first. It is, however, the contention of this paper that the other two aspects of construction, those that are informally within the control of the architect are at least as significant in determining the earthquake resistance of the buildings. A recognition of this would involve a considerable shift in the culture of design and the culture of building control. It will therefore be considered when the potential of traditional construction and the position regarding the engineering aspects of earthquake resistance have been dealt with.

In addressing the role of architects in earthquake design, in Iran, I should explain four phrases, which are vernacular construction, traditional construction, conventional construction, and modern construction. In Iran when speaking about traditional construction, it means vernacular architecture. Conventional construction is a sort of construction, which is neither traditional nor modern one. It is a malgama of modern construction and local technology. Local technology mainly is inherited from the vernacular construction. Persian vernacular architecture inspite of the use of week materials, comprises of some advantages and certainly presents lessons, to be learned in earthquake phenomenon.

Some of the advantages which have caused the buildings to be earthquake resistant are:

- The geometric plan *(Figure 1)*.
- Overall shape and configuration *(Figure 1)*.
- Symmetry in plan and façade *(Figure1)*.
- Symmetrical load distribution *(Figure 2)*.

Figure 2 shows that in this domes' ceiling, as the shapes get bigger, the loads also get bigger downward. There is a real relationship between the ornament and the structure. It means that even the ornament in some way helps the structure to bear load better. The three level base isolated foundation in *Figure3* is the other reasons of the potentials of the traditional construction, which can desipate earthquake forces and save the building. This sort of foundation is used in Guilan province at the north. These are all designed and built by traditional Iranian Architect who they are called *Mimar*.

Regarding to the conventional construction methods, there are some issues associated with architects' role. Configuration, which it is a matter of where buildings are located relative to other buildings; separation joints which connect structures or part of a structure together; stiff elements, such as floor slabs, not being adjacent to other structures *(Figure 4)*; the rupture of structural elements by an architectural element which causes short column illustrated in *Figure 5*; and soft story which is one of the main reasons for collapse of conventional buildings during earthquakes. These issues are only some of the many decisions made by architects.

It is possible to employ advanced techniques for structural computation with a little effort, but it is not possible to remove poor workmanship easily. In this respect, Ghalibafian (1985, p. 207) points out:

> *For earthquake mitigation construction, we cannot claim that just by structural computation and without any attention to the execution problems such as workmanship, resistance to earthquake is possible.*

An engineer himself, he argues that mathematical concepts of earthquake mitigation can not cover all factors such as construction principles, appropriate construction methods and workmanship. For the purpose of earthquake mitigation activity, the informal builders should be provided with some simple guidelines, construction-detailing techniques and constrains to raise the quality of their workmanship. The construction techniques, such as the alternatives for vertical ring ties suggested in this article, are not only comprehensible by informal builders, but also are practicable in terms of avoiding interruptions in bricklaying operation.

The collapses of the 1990 Earthquake can be attributed to a number of causes. The 1988 Code, which would have been sufficient to prevent collapses of buildings designed in accordance with its provisions, had not been in force long enough to have had any significant effect on the building stock. A number of buildings had, however, been designed after the introduction of the 1962 Earthquake Code and these should have survived the earthquake but did not. Their collapse may be attributed to two possible causes. Possibly the Code itself was inadequate, that is the engineers who were responsible for drafting the Code had done a poor job and, therefore, they must take some of the responsibility for the collapses that occurred. Even had the Code been adequate, there is still some concern about whether it would have been applied in practice by engineers designing particular buildings, because there was no provision for its enforcement at the design stage. This lack of control over construction also affected the standards of building, because there was no provision for inspection during construction. We can assume that some of the collapses occurred in buildings which were adequately designed but which were poorly built. We can see this from the experience of the *Roodbar* Hospital which was designed in accordance with the 1988 Code, should have resisted the earthquake. As it was a public building, we can be sure that the provisions of the code were observed in its design. If, therefore, the buildings were inadequate, it was because of the standards of construction and a contributing cause of this is likely to have been inadequate supervision.

Architectural aspects of buildings

Although there are a large number of seismic codes worldwide, most concentrate on structural elements and are written for engineers rather than architects. Few countries seem to have special codes of practice on this subject. Where such codes deal with architectural issues, the problem is that they are ignored[1] and not regarded as the architects' contribution to earthquake resistance. This is one of the problems concerning the implementation of the Iranian Seismic Code. The Turkish Code, for example, deals with details of construction for 'ordinary' buildings but does not discuss the plan forms to be adopted. In the United States, until the 1973 edition of the Uniform Building Code (UBC), architectural aspects of shape and irregularity were not dealt with in a specific part of the Code (Arnold & Reitherman, 1982, p.6).

While much of the Iranian Code for Seismic Design is directly or indirectly related to the architectural characteristics and configuration of buildings, all activities in the field of earthquake mitigation are concentrated on the structural aspects and analytical calculations. Many houses, of course, particularly in small cities and rural areas, are not provided with any structural analysis or calculations, because their builders do not normally employ engineers.

There are three stages in ensuring adequate earthquake resistance. First, there must be an adequate code to guide engineering designers. There is of course nothing to prevent all buildings being designed from first principles but this is an unrealistic expectation. Secondly, the provisions of the code needs to be incorporated into designs and this may require some means of checking and enforcing the design. Thirdly there must be some means of inspection to ensure that buildings are actually built according to appropriate designs and specifications.

If met, these three requirements, cover the engineering aspects of buildings. They ensure that within the formal sector of the industry a building's structure will be adequate. They do nothing, however, to ensure that the architectural design is sensible and does not result in large forces with which the engineer has to cope, nor do they ensure that the non-structural components of the building will be designed with earthquake effects in mind nor do they do anything about those buildings put up by the informal sector of the Building Industry which are without an engineering input.

This gives us some problems to deal with. It would be advisable to provide some guidance to architects, so that they may be aware of the effect which their designs may have on the forces generated by an earthquake. This may take the form of simple rules placing limits on certain design features. Some guidance needs to be provided for architects, when they are dealing with those aspects of the building which will not come under engineering scrutiny, for example, suspended ceilings or non-load-bearing partitions. Some controls need to be exercised over the design of buildings in the informal sector of the Building Industry and measures need to be put in place to ensure adequate standards of construction in both the formal and informal sectors.

The architectural aspects of the earthquake performance of buildings are those features that are decided by the architect, before the engineer makes his contribution. The overall form and configuration of building, for example, is an architectural issue which will have consequences with which the engineer will have to deal. On the other hand the architect may select or design non-structural elements or decide upon their configuration without reference to the engineer. Apart from the overall configuration of the building, this may include the

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[1] The Iranian Seismic Code, for example, consists of three chapters of which Chapter Three, generally, deals with architectural issues. This code which is published within the World Seismic Code (Japan, 1988). The third chapter is omitted in this international publication.

specification of: architectural design, configuration of building, construction techniques, including non-bearing interior partitions, exterior infill walls (assuming these are not intended to contribute to structural rigidity), suspended ceilings, building contents and the like. Bearing this in mind, it could be said that the architectural aspects of earthquake performance of buildings means, their non-computational or non-structural aspects. Even when a structure is adequate, non-structural elements may cause by their destruction, serious damage and risk to the occupants. These risks are serious even in a building in which the structure is safe. Lagorio (1990, p.2) states that damage to the architectural elements, during an earthquake could cause major economic losses even with minor structural damage. He notes that the damage in the 1964 Alaska Earthquake, could account for up to 65 to 70 percent of a building's repair costs.

In rural areas, where builders in the informal sector of the Iranian Building Industry undertake building construction, there is no computational analysis of structure. The resistance of buildings, however, in the city of *Masooleh*, shows that informal builders can build resistant buildings without any need for computation. This suggests, therefore, that simple and easy rules may be provided which would be comprehensible by builders and which can effectively help earthquake mitigation in the informal sector of the industry in small cities and rural areas.

The overall form of a building is one the main aspects for determining the effects of earthquake motions upon it. As Perry (1990, p.72) has demonstrated, the effect of the basic weaknesses of building form in the Loma Prieta Earthquake in 1989, and the consequent damage of many buildings in the earthquake, showed that the overall shape and form of buildings is one of main reasons for building failure. The North Earthquake also demonstrated a close relationship between form and the building's seismic performance.

Architects play a key role in determining the form and function of buildings, defining and balancing many different and often conflicting factors. One of these is the degree of coincidence between the Centre of mass and the Centre of resistance. While an engineer may understand these factors well, he can never fully overcome the effect of inappropriate building form. For this reason, the architect may have a more significant effect on the earthquake performance than the engineer and a close relationship between the two professions is usually necessary. Because earthquakes affect the whole building, earthquake resistance is a shared architectural and engineering responsibility. The importance of the effects of architectural aspects on the earthquake performance of buildings is not a new concept. The concept has long been recognized by engineers[2] who have been engaged with the problem. In this respect, Arnold and Reitherman (1982) agree with those engineers who have placed equal importance on architectural aspects and lateral design forces.

The following is a brief discussion of some of the building forms and their workmanship consequences that are related to the requirements of Chapter Three of the Iranian Seismic Code. The chapter, for example, sets down certain requirements for the construction of masonry wall construction, some of which are related to the need for vertical and horizontal ties within the masonry. These are formed by vertical reinforced concrete columns at intervals

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[2] Holmes (1976), Degenkolb (1977), and Teran (1972) are among them.

and at the corners of buildings with the maximum spacing of five meters (the Iranian Seismic Code, 3-9-2-1). Alternatively, instead of vertical columns, vertical bars can be used which are distributed along the wall and are in turn linked together by tie bars within the mortar bed joints. These requirements are summarized and illustrated in *Figure 8,* which has been redrawn from the Code[3].

Bricklayers have been trained to adopt this method but the construction of the vertical ties in particular interrupts the operation of bricklaying and slows down the work. For this reason the builders avoid doing that and leave out the ties. One can only speculate whether ignorance or lack of will is the greater influence on standards of construction in this respect. Simple and clear detailing can easily remove the problem. One of the problems, besides the interruption of bricklaying, is related to the reinforcement of masonry construction which is suggested by the Code. It is not clear how the ties are located inside the walls in relation to the brick size. The other problem is that for the use of vertical steel bars inside the wall, it is not clear that how it possible to design a particular size of vertical void within the wall in order for bars to be located and filled by concrete. These problems are a few examples among many which show how the implementation of the Code could effect earthquake resistance.

In Southern European countries hollow clay blocks are commonly used for walling in combination with a concrete frame which is either built first and then infilled with blocks or is formed after the blocks have been laid by leaving out blocks at corners or other places where columns are required and then pouring concrete into crude shutters. In Iran such a solution is unlikely to be adopted, although hollow clay blocks are available and used in frame buildings. The problems with domestic construction are twofold. Firstly bricks and block are carried loose in tip-up trucks with the result that there is considerable damage in transport and delivery. Secondly there is consumer resistance to the adoption of the blocks for external walls because diurnal temperature changes cause considerable thermal movement of these clay blocks because of their low thermal capacity.

The role of the tie ring lies in tightening the walls together particularly at the corners, in tightening the floor/roof as a monolithic unit and above all in tightening the floor/roof to the walls. For the tie ring to act as a bracing and diaphragm system for floor or roof, it is necessary for the ring itself to be braced at its corner, which could also help the corners of the building, where the walls intersect each other, to withstand earthquakes.

Reinforcement of masonry construction consists of the ring tie and also the reinforcement of walls. Reinforcement of walls comprises vertical and horizontal ring ties. There are some alternative solutions for implementing ties which are considered here. Although, these alternatives are being introducing for the first time into Iran, they have been used for many years in some European countries. They are described below in detail.

Bricklaying

One of the problems of implementing of the Iranian Seismic Code in masonry construction (*Figure 6*) is a lack of specific detailing for reinforcing masonry walls. The bricklayers avoid doing the reinforcement suggested in the Code, because it causes an interruption in

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[3] Unfortunately, as the authors observations show, these requirements are commonly ignored in practice.

brickwork. Different brick or blockworks practices can, however, be adopted to leave holes which form columns without interrupting the work, one of those is illustrated in *Figure 8*.

Hollow concrete block

Perhaps one of the main problems of concrete block masonry is a lack of reinforcement. The reinforcement of a building is important, because of the weaknesses of blocks which are produced without standardization and also because of the necessity of reinforcing masonry buildings to withstand earthquakes.

Ordinary concrete blocks are produced by many small individual firms, many of which are in the North. Their quality, because of the scarcity of cement, is not standard. There are a small number of block producing firms which produce blocks for use in joist-block floors/roofs. They are mostly government controlled firms and their quality is based on the Iranian Standard and Industrial Research Institute (ISIRI).

Concrete block masonry construction is commonly used with pitched roofs without reinforcements. One of the reasons for the lack of reinforcement of block masonry construction in the country is the difficulty of fulfilling the shuttering requirements for the reinforcement of concrete tie beams and columns. Wood for shuttering is both expensive and scarce.

An attractive method of reinforcing masonry construction is to insert steel bars into the block voids as vertical or horizontal reinforcement to be filled with concrete grout to produce reinforced concrete ties inside the walls. **U** shaped block courses can produce the horizontal reinforced concrete tie beams, if the filled cavity is suitably reinforced. Because shuttering for reinforcement of masonry construction is costly, the use of the concrete blocks can greatly reduce the cost. The concrete block is capable of being installed to form horizontal and vertical reinforced concrete ties, without any use of extra shuttering devices. *Figure 9* illustrates two examples of blocks that could act as reinforcing moulds for masonry construction.

The above examples are possible modifications of ordinary two core concrete blocks. Furthermore, it would be better to design and produce three core blocks with indent heads (for vertical reinforcement and also for filling mortar into the vertical gaps), *Figure 10* shows the various sizes. The half size blocks helps the laying of the blocks on top of each other and their infilling with concrete into crude shutters. Although this provides a solution which may be adopted, the concrete block is unpopular because of a general desire to expose brickwork.

Another alternative for reinforcing blockworks is the use of a ‘pilaster column’. A pilaster column allows the girder to stop short of the inside of the wall and to rest on the widened portion of the wall and this is shown in *Figure 11*. The ordinary block of (a) and especial blocks of (b) & (c) form the pilaster column for both masonry construction wall and reinforced concrete frame construction. It should be noted that *Figure 9* and *Figure 10* are introduced for vertical reinforcement which is more crucial, in term of blockworks without interruption, than the horizontal reinforcement which lays on the block’s bed joints.

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