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TRADITIONAL MASONRY AND CONTEMPORARY REINFORCED CONCRETE FRAME WITH INFILL WALL CONSTRUCTION IN SEISMIC AREAS

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SUMMARY

Historical methods of unreinforced masonry and timber construction in the seismically active areas of Kashmir, Yugoslavia, Mexico, and Central America are described and then compared with modern reinforced concrete frame construction with masonry infill walls. These traditional construction systems have exhibited a form of ductile behavior in past earthquakes, and may indicate potential areas for improvement of the design of modern reinforced concrete infill frame buildings with the use of brick masonry laid in weak mortar.

INTRODUCTION

For years, unreinforced masonry has been the specific focus of much of the concern over the safety of buildings during earthquakes. Although stone or brick masonry is excellent for building, making it strong and durable in most conditions, when subjected to strong earthquake forces masonry shows its inherent weakness. While it is extremely strong in compression, unreinforced masonry is weak in both shear and tension. However, unreinforced masonry has remained the preeminent material worldwide throughout human history, and has been, and continues to be widely applied even in seismically active areas.

The purpose of this paper is to explore the past and present uses of unreinforced masonry in earthquake zones, and to assess the performance of these methods of construction in earthquakes. The objective is to examine a number of different historical construction systems which utilized unreinforced masonry construction together with wood, and compare these with modern systems where masonry is used in conjunction with reinforced concrete.

THE CONCEPT OF THE "EARTHQUAKE-PROOF" BUILDING": FROM THE 1906 SAN FRANCISCO EARTHQUAKE TO THE 1985 MEXICO CITY EARTHQUAKE

Following the 1906 San Francisco Earthquake, the Trussed Concrete Steel Company of Detroit, Michigan issued a report entitled *Earthquake-Proof Construction.* This report, by Lewis Alden Estes [5], reported that none of the few then-existing buildings constructed in reinforced concrete were damaged by the earthquake. Estes extolled the virtues of this new system of construction by saying that "a reinforced concrete structure, when intelligently designed, generously proportioned, and honestly built, is a *monolith of great coherence and high elasticity,* combining the very properties best able to resist earthquake vibration [5]". He went on to say that "the essential quality a building should possess is stiffness. The frame should be strong and well tied together to obtain as nearly as possible the "monolithic" condition, so that the building will vibrate as a unit [5]".

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The promise which reinforced concrete held for the construction of buildings that would be safe in any earthquake appeared to be tremendous when the engineers inspected the ruins of San Francisco. Reinforced concrete eliminated the limitations of masonry construction: its weakness in tension. This 1911 report went on to favorably compare reinforced concrete with steel construction. Noting the failure of the rivets in several steel frame buildings examined, the report explained:

> It may be pointed out that *in a reinforced concrete structure, there is not possible that concentration of shear which may occur at a riveted joint.*

Almost three quarters of a century later, the September 19, 1985 Earthquake in Mexico City has showed that the promise of "earthquake-proof" construction has not, at least in practice, been widely realized. After the 1906 San Francisco Earthquake, and the subsequent earthquakes in 1907 and 1908 in Jamaica, Messina, and the Philippine Islands, the view of the few unscathed reinforced concrete buildings surrounded by ruins contrasted sharply with the view in Mexico City 80 years later. In the Mexico City Earthquake of 1985, one was met by the sight of shattered and partly collapsed reinforced concrete buildings standing amidst historic masonry churches palaces and historic houses which were virtually untouched. The unusual ground motion of the 1985 quake focused the damage onto buildings of a particular size, but other recent earthquakes have also shown that reinforced concrete buildings are vulnerable, even when subjected to more typical types of ground motion. While the immense promise of reinforced concrete has been realized to a large degree, when subjected to seismic forces it depends on a quality of engineering and construction which may not be realistic to expect every time, even with the enactment of stronger codes.

Thus, the ideal of "earthquake-proof" construction is probably more illusory than was believed in 1911. As has been shown by the recent events in Mexico, there is not only a variation in the magnitude of earthquakes, but also in the wave pattern, the duration, and the period of the shaking. Whereas large multi-story reinforced concrete buildings are usually safer than the older and smaller masonry structures, in Mexico they proved to be more vulnerable.

The case studies presented next illustrate uses of masonry as part of the common building practice in seismic areas. These examples provide evidence that the behavior of certain building systems incorporating unreinforced masonry are not so uniformly negative when subjected to earthquakes as many people have been led to believe.

TRADITIONAL METHODS OF CONSTRUCTION IN SEISMICALLY ACTIVE AREAS: KASHMIR, YUGOSLAVIA AND CENTRAL AMERICA

Earthquakes in Kashmir, India, have occurred with a degree of regularity over the centuries, and the Kashmiri people have had to learn to live with them. Kashmir is poor and largely removed from the mainstream of industrialized society. Until the present, construction methods there have remained almost the same as they had been for generations. Even while reinforced concrete has now made substantial inroads, construction in wood and masonry is still common. As a result, the building stock of the city provides a unique opportunity to examine a complete range of ordinary buildings constructed with traditional methods, designed to resist the worst effects of the earthquakes which periodically shake the city.

Most of the traditional buildings in Srinagar can be divided into two basic systems of construction. The first system, known as "Dhajji-Dwari," is the one referred to in the 1913 quote above (illustration # 1). It consists of load bearing masonry piers and infill walls, with wood "runners" at each floor level used to tie the walls together with the floors. The second system, "brick- nogged" construction, consists of a braced timber frame with masonry infill.

The Dhajji-Dwari consists of a "trabeated structure comprised of adobe [or fired brick] piers and timber beams....These piers usually rise from foundations made of rubble masonry bonded with lime mortar. Mud mortar is used for the rest of the pier. The space between the piers is built up with...bricks bonded with mud mortar and the thickness of such infills may vary from one brick to two and a half bricks. The upper story (or the attic) walls are usually thinner than the ground floor walls." [7]

The construction practices used for these buildings in Kashmir, which stand in contrast to the codes and commonly accepted practices today, include 1) the use of mud mortar of negligible strength for the masonry, 2) the lack of any bonding between the infill walls and the piers, 3) the infrequency of the bond between the wythes of the masonry in the walls, and 4) the use of loose brick nogging in the interior partition walls.

In a report on the damage resulting from an earthquake in 1967, two Indian engineers, N. Gosain and A. S. Arya, described the damage to the different types of traditional and modern construction in Kashmir. While they were critical of many of the characteristics of this system, they did find that the use of the timber runners was of significant benefit.

> The timber runners...tie the short wall to the long wall and also bind the pier and the infill to some extent. Perhaps the greatest advantage gained from such runners is that they impart ductility to an otherwise very brittle structure. An increase in ductility augments the energy absorbing capacity of the structure, thereby increasing its chances of survival during the course of an earthquake shock. This was substantiated by the observation that "dhajji-dwaris" in which a larger volume of timber was used were comparatively safer. [7]

The timber "runners" in the Dhajji-Dwari buildings do not constitute complete frames, as they do in the traditional brick-nogged or "half-timbered" structures. Instead, large timbers "runners" rest along the load bearing masonry walls with the floor beams and the "runners" for the cross walls lapping over them.

Gosain and Ayra note that during the 1967 Kashmir earthquake taller buildings of 3 to 5 stories survived relatively undamaged. It is just such buildings which were observed almost a century earlier by Arthur Neve, a British visitor to Kashmir who witnessed the 1885 kashmir earthquake. Neve noted that,

> The general construction in the city of Srinagar is suitable for an earthquake country; wood is freely used, and well jointed; clay is employed instead of mortar, and gives a somewhat elastic bonding to the bricks, which are often arranged in thick square pillers, with thinner filling in. If well built in this style the whole house, even if three or four stories high, sways together, whereas more heavy rigid buildings would split and fall. [11]

From these historical observations one can identify a tension between two aspects of seismic design: structural strength versus flexibility. Observations from Srinagar lead to conclusions that almost diametrically oppose the conventional wisdom of most engineers in the present: that buildings more loosely built perform better than those which are more rigid. The stiffer a building is, the stronger it must be in order to avoid fracture. Because of the primitive materials and means of construction in Kashmir, strength was not possible, so flexibility was necessary.

The second traditional structural system found in Kashmir, and also in Yugoslavia, is the timber frame infilled with brick. The brick-nogged construction in Kashmir is just one variation of a traditional construction method which has existed in many parts of the world for centuries. In England and Europe, Medieval half-timbered construction is very similar. Another example of the brick-nogged system is common in Yugoslavia, where major earthquakes recently have occurred. In Skopje, a few such buildings which survived the disastrous 1963 earthquake still exist. These buildings, which are rapidly disappearing, are an important last trace of the old city. They are constructed of timber with infill of adobe or fired brick. This infill is only 1/2 brick thick in a two story building (illustration # 2). In one survey of the damage caused by the 1963 Skopje Earthquake, a London engineer, N.N. Ambraseys reports that the "old adobe construction, particularly those with timber bracing, resisted the shock with some damage, but behaved far better than the brick or the hybrid construction."

Exactly how did these adobe buildings resist the earthquake? Either they were rigid and strong enough, while light enough in weight to stay within their elastic range, or they absorbed the energy through the cracking and shifting of the masonry infill, without causing the failure of the wood frame. By observing the primitive method with which they are assembled, the wood timber joints are probably not of sufficient strength for the buildings to resist the forces in a rigid manner. It is more likely that the combination of the wood with low strength masonry and mortar allowed the absorption of the energy of the ground motion in a ductile fashion by the cracking and shifting of the infill masonry beyond its elastic range. In fact, the angles and distortions of the buildings of this type both in Yugoslavia and in Kashmir are evidence of this. The principal difference between the Dhajji-Dwari and the Brick-nogging methods is that the masonry in the former type is load bearing. In an earthquake, this load bearing quality provides a greater resistance to shear forces and to the out-of-plane displacement of the masonry. On the other hand, the brick nogged construction is effective in resisting the forces through the lateral restraint of the masonry by the timber frame. Both systems show a gain in ductility over that of ordinary unreinforced masonry.

A different variation on the infilled timber frame system is common in several countries in Central America. This system, which reportedly was introduced from Spain during the colonial period, is known in Nicaragua as "Taquezal", or "pocket" system, and in the neighboring El Salvador as "Bahareque". In Taquezal or Bahareque construction, the timber frame consists of a row of studs, approximately 2 feet on center. These studs, which are approximately 51 x 102 mm are set within a heavy timber frame. The timber frame consists of hardwood posts, often made of unsawn logs, at the corners and at points in the walls approximately every seven feet. Wood lath or bamboo is then nailed across the studs to form a kind of basket, and the resulting pockets are filled with the loose material, either small stones ("Taquezal con piedra"), or balls of mud ("Taquezal con barro terra".) The wall is then usually plastered with a final layer of mud or lime plaster (illustration # 3).[3,6]

Buildings of this type at one time filled Managua, the capital of Nicaragua. In 1932 about 85% of the buildings in the city were of this type [8]. These buildings in Managua merit particular study, because the records show that their performance was very different in the 1972 earthquake than they were in the 1931 earthquake. In 1931, Freeman [8], compares the safety of the Taquezal buildings from collapse..... to that of the "Baraccata" type of historic reinforced aseismic masonry construction developed in Italy in the 18th and 19th century.[13]

In 1971, the results were quite different. In a report by the Earthquake Engineering Research Institute, Richmond, California, engineers observed that "approximately 70% of the Taquezal buildings in the central area of the city collapsed or were seriously damaged. This mode of construction was the major cause of the high death toll." [3] This same report recommends that Taquezal should be banned in earthquake-prone areas such as Managua.

The chance to study all of this in detail was afforded on October 10, 1986 by the earthquake in El Salvador. San Salvador was filled with Bahareque buildings. They range from one and two story early 20th century buildings in the city center, to one story squatter housing in the outskirts. The damage to this type of construction was extensive, and ranged from a minimum of a loss of some of the exterior stucco to total collapse. The squatter housing in certain areas was particularly hard hit, leaving many people homeless.

Examination of this damage was revealing. While damage was extensive, it was not universal. Some buildings held together quite well. It was possible to document structures in every stage of disintegration, and this was quite revealing. In almost every case, in structures in which some failure occurred, beyond just the shedding of stucco, the failure originated at a point where the wood armature was rotted or damaged by bug attack. Those structures with a greater level of damage were invariably those which were more rotted. In addition, with the less substantial squatters housing, the structures tended to come apart at the seams, as no provision had been made to hold the walls and roof together.

What is interesting here though is the fact that the primary cause of failure of this class of buildings might not have been directly the result of a defect in the system itself, but rather, a problem in the long term stability of the structures affected by environmental factors other than the earthquake. When the Taquezal buildings failed in the 1972 earthquake, the stresses apparently exceeded the strength of the wood frame's ability to restrain the masonry, and the structures collapsed. Often the rotting and termite damage caused the structure to fail first at the bottom.

Looking more closely at the performance of the Taquezal and Bahareque buildings which remained standing after the earthquake is revealing. Most of both the Taquezal and the Bahareque buildings are plastered on the exterior in order to give a more substantial effect (illustration # 4). In the 1931 earthquake in Managua, Freeman notes that practically all of the plaster was shaken off of the Tarquezal buildings. This also was observed to be the case in San Salvador in October, 1986. The fact that during the earthquake it was dislodged from practically the entire surface of the walls can be interpreted as a function of the distribution of the earthquake stress throughout the wall, rather than its concentration in one localized area. Wherever the earthquake shaking has caused a slight shifting and cracking between the masonry units, the brittle plaster on the surface was thrown off. The shedding of the plaster, therefore, draws attention to the fact that the earthquake stress is absorbed throughout the wall, so that no one major destructive crack occurs.

CONTEMPORARY MASONRY INFILL WALL CONSTRUCTION WITH REINFORCED CONCRETE

Reinforced concrete is, in fact, a remarkable material with many useful attributes, including the ability to cast the structural elements directly from the raw materials at the site, rather than manufacture them in a plant in advance, as with wood or steel, and the possibility of using materials - water, sand, limestone, and thin bars of steel - which are often much less expensive than either wood or steel alone. However, the same attributes which make reinforced concrete so useful and economical also can be the major causes of failure in earthquakes. The chances for hidden errors and deficiencies unique to the reinforced concrete exist at every step (illustration # 5). For example, in the 1964 Alaska Earthquake, the collapse of one building was traced to the failure of one column in which was found the remains of a workman's lunch!

When Le Corbusier published his drawing of the "Domino House", showing the idealized skeleton of a poured in place reinforced concrete building, the architectural possibilities of this new material were just beginning to be explored. A large building with a completely "open" plan was possible, with cantilevered floors supported only by columns. The minimum necessary to complete the structure was presumably to enclose it with glass. However, few buildings would serve their intended purpose when enclosed only with glass. Into this idealized concrete (or steel) structure go partitions, stairways, elevators, heavy equipment, and exterior enclosure. All of this material has an impact on the seismic performance of the building, especially as is often the case, when the interior and exterior infill walls are constructed of heavy unreinforced masonry.

It is often striking to note how many buildings both in Mexico City and in San Salvador which had appeared to be solid concrete shear wall structures prior to the recent earthquakes are revealed by the earthquake damage to include a generous amount of unreinforced brick masonry in their construction.

What we are dealing with in most areas which rely on reinforced concrete as a primary building material for most of their construction, therefore, is not a problem of architectural style, but rather one of a hybrid construction system. This hybrid system of reinforced concrete structural frame and unreinforced masonry infill (brick, block, or hollow tile), by their combination, may put these materials at their worst advantage in the case of an earthquake. This is especially true when, as was frequently noted to be the case in, for example, Mexico City, the engineering of the concrete frame ignores the lateral force effects of the masonry, treating it only as additional dead load.

One of the problems which has been confronted with these walls in earthquakes is the fact that they are inherently very stiff and brittle. If the lateral loads are great, and the building frame is flexible because of a lack of specially designed shear walls, the deflection of the frame throws all of the lateral force onto these infill walls which were never intended to carry it. As a result, diagonal shear cracks will develop. If the shock is great enough, these walls can be shattered. The failure of the walls across one floor of a building can lead to the creation of an unintended "soft story", resulting in the collapse of the structure in subsequent cycles (illustration # 6).

Another problem caused by the action of the infill walls within a reinforced concrete moment resisting frame is the development of the "equivalent diagonal compression strut". When the frame deflects, it will bear upon the wall on its upper corner, forcing the wall to begin to develop diagonal shear cracks. The diagonal cracks do not, however, necessarily cause the wall to fall away. Instead, the masonry is restrained within the bay under massive pressure from the deflected frame. All of this pressure is delivered to the top of the column just below the intersection with the beam [2]. The resulting stresses can be sufficient to cause the column to fail in shear, again leading to the progressive collapse of the structure as the loads become greater as they shift to each successive column in a chain (an example of this damage can be seen in illustration # 6).

From the foregoing description, it would appear that the infill walls in modern construction behave differently than the masonry infill in the historic brick-nogged construction in Kashmir and Yugoslavia. However, this contrast in performance is perplexing. If the equivalent diagonal strut is of danger to a reinforced concrete frame, it would most certainly be more hazardous to the weak timber frames found in Kashmir, Yugoslavia, or El Salvador. The difference, however, is not in the strength of the masonry, but in its weakness - that is the weakness of the bedding joints in the traditional examples compared with modern construction methods.

Returning to the observation about the soft clay mortar used in Kashmir made by Arthur Neve, the contrast between the historic and the contemporary masonry is clear. Modern masonry is not necessarily much stronger as a system, but the bedding mortar is stronger. Modern mortars are made with a strong mixture of Portland Cement, rather than lime, and the resulting mortar often has a compressive strength similar to that of concrete. As a result, in modern construction, the bricks are often weaker than the mortar. While stronger mortar can help provide for a wall with greater strength within its elastic range, the problem in earthquakes, is that the shear failure of the masonry units themselves can lead to the collapse of the wall. If, on the other hand, the mortar is weaker than the bricks, it will act as a kind of buffer. The shifting and cracking in the bed joints can allow the wall to move in a nondestructive manner. In addition, the internal friction of the sliding of the masonry along its bedding planes provides an important energy absorption and dampening effect. As long as the masonry stays in place, it can help prevent the overall structure from collapsing. In short, the cracking or crushing of the mortar within the bedding joints of a wall does not materially reduce the effectiveness of the wall in bearing loads as long as the bricks remain whole. As one restoration mason explained: "Mortar is meant to hold bricks apart, not hold them together."

In examining these various approaches to construction in earthquake-prone areas, it may be more important to compare the failure mechanisms of the different systems than it is to compare the relative strength of the materials or of the system. Strength can be important in preventing damage in mild earthquakes, but in severe tremors, even massive strength can be overwhelmed. A failure mechanism which allows sliding movement and horizontal cracking, while leaving the walls in place is what is ultimately important.

This difference was made apparent by certain examples investigated in Mexico City after the 1985 earthquake. In this earthquake, it is possible to test this hypothesis by comparing the results of the earthquake on different buildings, all of recent vintage, and all using some form of composite concrete and masonry construction. One example is a commercial building located only one block from the well documented Juarez Hospital Building, which collapsed, killing about 800 people (illustration # 7).

This building was tall enough and narrow enough to be expected to be vulnerable to damage from the severe shaking. In spite of this, the only evidence of distress was the loss of some of the stucco on the front of the structure. The structural system is a concrete frame with infill brick walls. The side walls, and rear wall, were windowless, whereas the front wall had large industrial windows. The concrete frame included a horizontal reinforcement of the masonry at mid- floor level. This building is similar to a number of commercial buildings in the same neighborhood of the same height and structural system, all of which appeared to be undamaged. The significance of this building, and of its like neighbors, is that they were very cheaply built to a very low standard. The concrete work appeared to be very weak and uneven, with many cold joints and rock pockets. The cement looked weak and uneven both in placing and in curing. The brick was very roughly laid, without attention to the compaction of the mortar or striking of the joints. In addition, with one wall of windows and three blank walls, the building seemed to be a prime candidate for tortional movement. In spite of this, both of these examples survived unscathed, while the new 8 story wing on the Juarez Hospital totally pancaked. Also, one other major modern building in the same block as this building, with infill masonry within a concrete frame, suffered extreme damage. Almost all of the infill masonry had been blown out of the concrete frame, and parts of the frame were damaged.

Why this difference in performance? It may not be possible to determine all of the factors involved, and the slightly lower height may have reduced the stresses on this particular example. However, it is clear that the seismic forces were considerable. However, the masonry walls in this building survived without failing through the development of diagonal shear cracks caused by the deflection of the internal structure against the comparative rigidity of the brick exterior walls, and without masonry falling out of plane because of inadequate horizontal restraint.

This example has two important attributes which may be major factors in their survival without damage. 1) The masonry itself was integrated into the structure of the wall in such a way that it was under load. 2) The masonry walls were capable of some lateral movement, and thus the absorption of seismic energy, without destructive cracking. In both cases, the structural frame, and the masonry wall, were constructed so that the materials worked together in an integrated way. The nature of the cheap and rudimentary construction system which was used in their buildings lead to what may have been an unintended but important asset. The masonry was constructed together with the reinforced concrete frame. In fact, what is usually done is that the masonry is constructed first, and then the reinforcing bars for the columns and the beams are placed into positions. The form work is then attached to the masonry, and the columns and beams are poured. In effect, although the building is a frame structure, the beams then impact some of their load upon the masonry.

Unlike those buildings where the masonry is deliberately held back to avoid the damage from the "equivalent diagonal compression strut" effect, there is no such effort here. The resulting integrated system actually appears to have performed better because it comes closer to achieving the "monolithic" quality originally attributed to reinforced concrete in the 1911 report *Earthquake-proof Construction* quoted at the beginning of the article. Normally these walls would not be strong enough to carry the extremely large loads demanded of them, so some energy absorption must be occurring within the brick wall itself without destructive cracking, and without the shearing off of the columns by the equivalent strut. The hypothesis here is that the cracking which does occur is invisible because it is a minor cracking and compression across the entire surface, and it is limited to the mortar joints, rather than occurring as destructive cracking at the center of the wall. This invisible cracking can be observed more clearly when the masonry wall is covered with stucco. The shedding of the stucco in the earthquake is evidence of the flexing and cracking of the wall across a wide area. If the wall is still intact, the evidence of the movement of the wall, i.e. the evidence of its "ductile" behavior, lies in the shedding of this brittle stucco surface.

This is exactly the same kind of ductility which is observed to have occurred in the historical examples in Kashmir, Yugoslavia, and Central America. The principle attributes which provide a continuity between these Mexico City buildings and the historical examples, is 1) the integration of the masonry into a restraining structural frame of a tension bearing material (wood, concrete or steel), 2) the existence of load upon the masonry wall (not making it load bearing for the floors of the structure, but only, bearing a portion of the weight of the walls from ground to roof), and 3) the use of weak mortar (lime mortar in the older structures; poorly cured and loosely placed cement- lime mortar in the most recent one near the Juarez Hospital).

The loading of the masonry, which develops through the construction of the concrete frame directly upon the masonry walls rather than the subsequent infilling with a gap, is of critical importance in the seismic response. It provides a much larger vertical force component to work against the lateral forces. This bearing of weight has the effect of "post-tensioning" the wall, despite the fact that the frame is still designed to carry the floor loads to the ground. This integration of the materials avoids the problem of the structural frame pounding against the non-structural masonry walls. The "wild card" in this analytical deck is the use of weak mortar: All of the above would not work if the infill wall was excessively rigid and brittle. The wall must deflect so that the forces can distribute themselves throughout the buildings entire frame and wall system. To do this, the microscopic cracking of the mortar joints between each of the layers of brick is necessary.

It is the cracking along the mortar joints which can convert brittle masonry into a ductile building material. If the mortar is too strong, the forces are concentrated along the diagonal within each panel causing the bricks themselves to crack and fall apart. If it is weak, the slippage can take place along each horizontal joint where the movement is so slight as to be non-destructive to anything but the surface stucco or interior plaster finish.

While the historical examples do not *prove* why these particular buildings in Mexico City survived, the examples do provide a significant insight into the potential for an alternative approach to earthquake resistant construction, particularly in poorer neighborhoods or in developing countries where highly trained engineers are not available for most construction projects.

CONCLUSION

The relationship between the historic systems and modern reinforced concrete construction may seem tenuous. There are, indeed, so many variables, that it is hard to make a direct comparison. However, it is still important to draw these comparisons for two reasons: 1) the extensive destruction of many modern buildings in recent earthquakes requires that we take a broader, more critical approach to the development of new aseismic design and construction methods, and 2) the often sweeping condemnation of historic masonry buildings in seismic areas as dangerous, and their resulting disfigurement or destruction, demands that we develop a more informed approach towards understanding their true structural attributes.

Inherent in this historical and cultural approach to earthquake engineering analysis is the belief that we must pay greater attention to 1) the cultural and social limitations on building construction practice, and on the adaptation, maintenance, and use of existing buildings. The 'high tech' and sophisticated engineering solution will not help protect those people living or working in structures which were constructed by themselves or by builders who are uninformed of such solutions, even if they could be afforded, which often they are not. In looking realistically at earthquake safety, therefore one must avoid the temptation to rely on what is possible in terms of engineering design or materials, and instead look critically at what is more probable. It is not engineering "know how", but rather the local economy, labor supply, materials production and delivery, available engineering expertise, and inspection thoroughness which will determine what is actually built.

Between the possible and the practical in most earthquake affected cities exists a great gap. Failing to provide for the existence of this gap will lead to the construction of buildings which will fail in future earthquakes. The enactment of more stringent engineering regulations is simply not sufficient. In many developing countries, sophisticated engineering, and the delivery of materials of uniform quality, may not be possible to expect for every building constructed. What is needed is a system which relies on a combination of traditional vernacular forms of construction with modern materials and technology, rather than exclusively on modern engineering, for its success.

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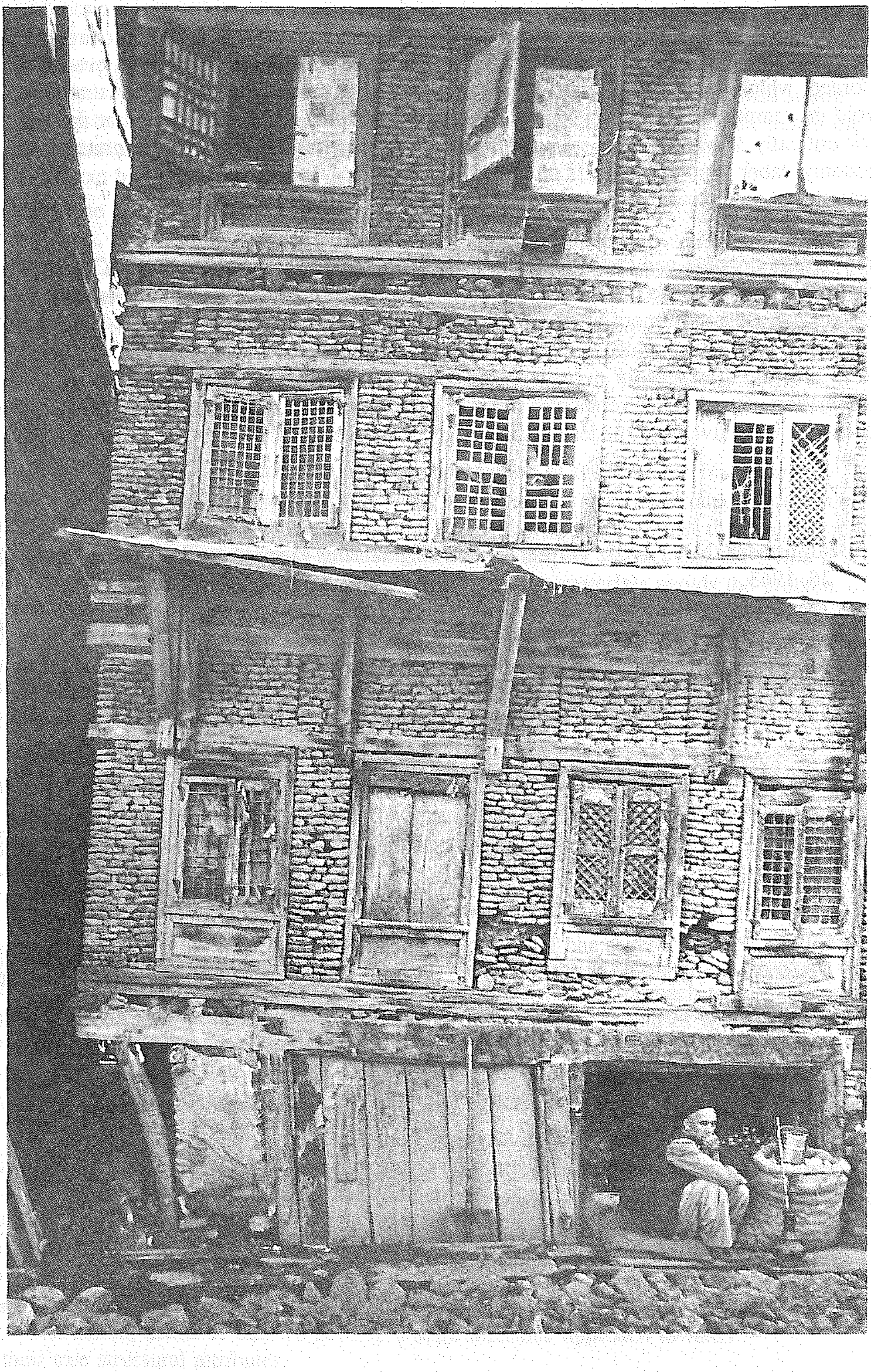
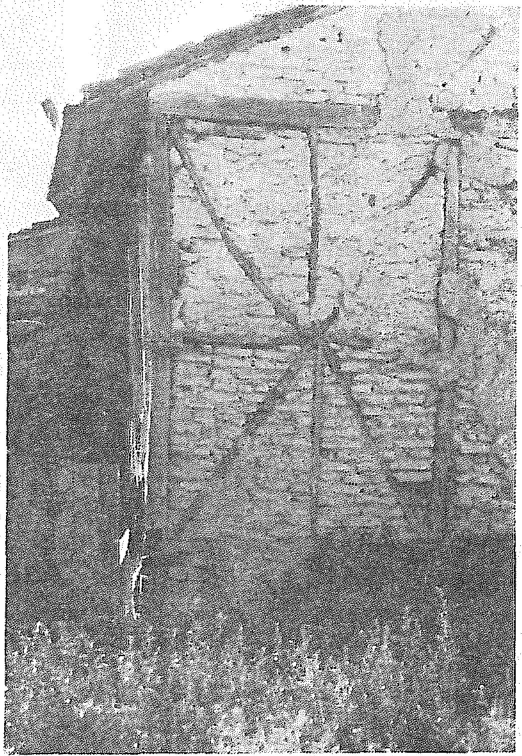
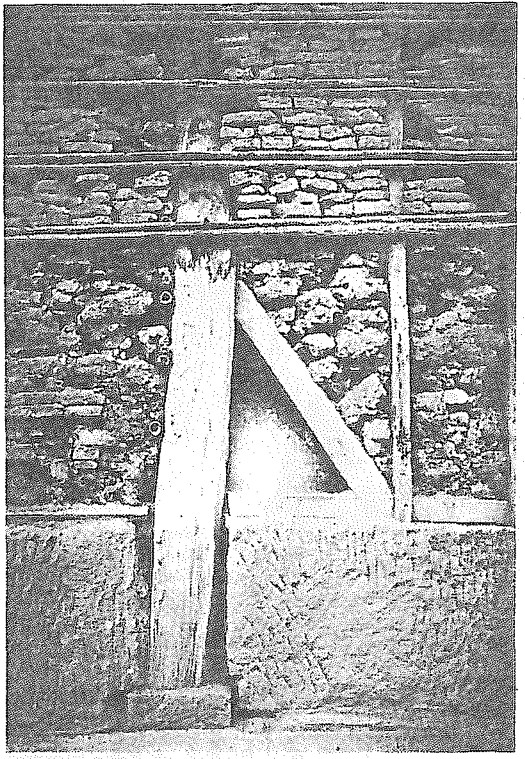


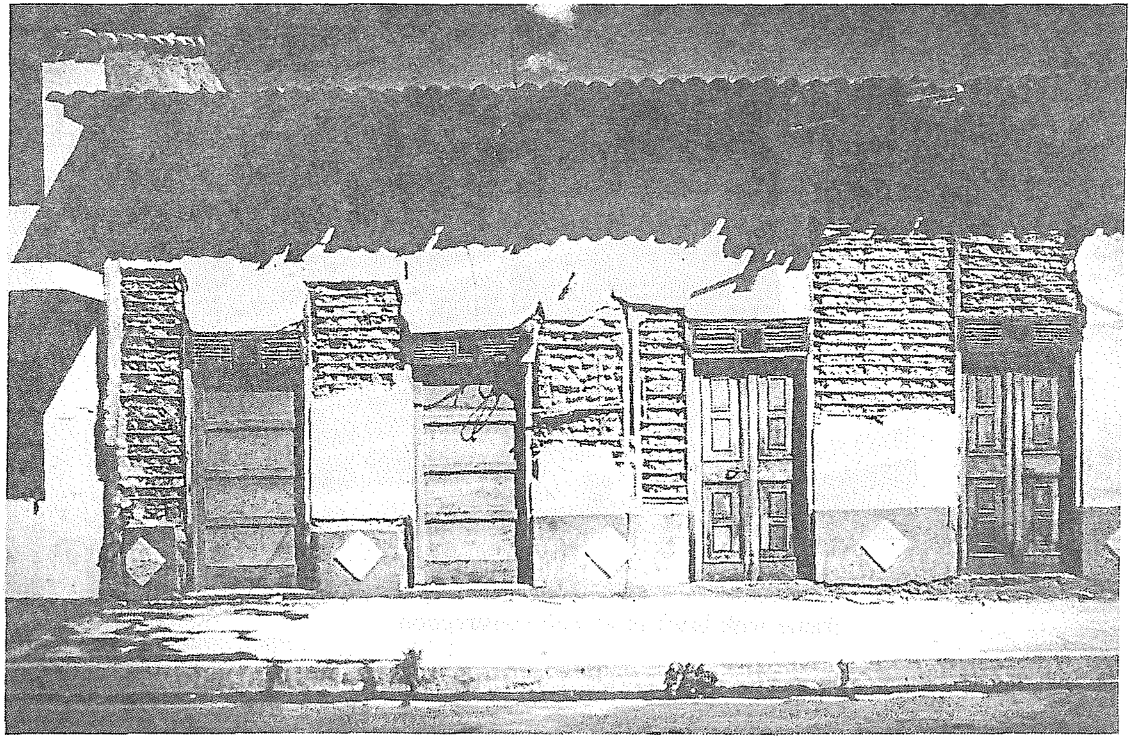
1. SRINAGAR, KASHMIR, INDIA, 18th. Century building illustrating Dhajji-Dwari construction affected by earthquakes.



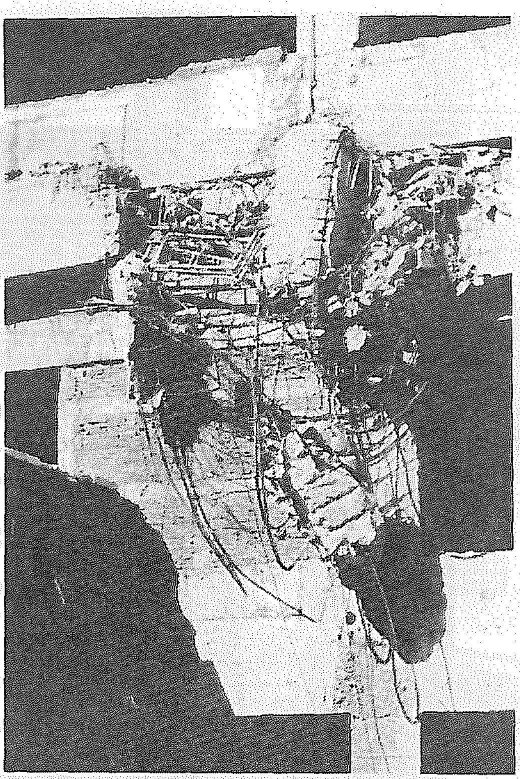
2. SKOPJE, YUGOSLAVIA, timber frame with brick infill construction.



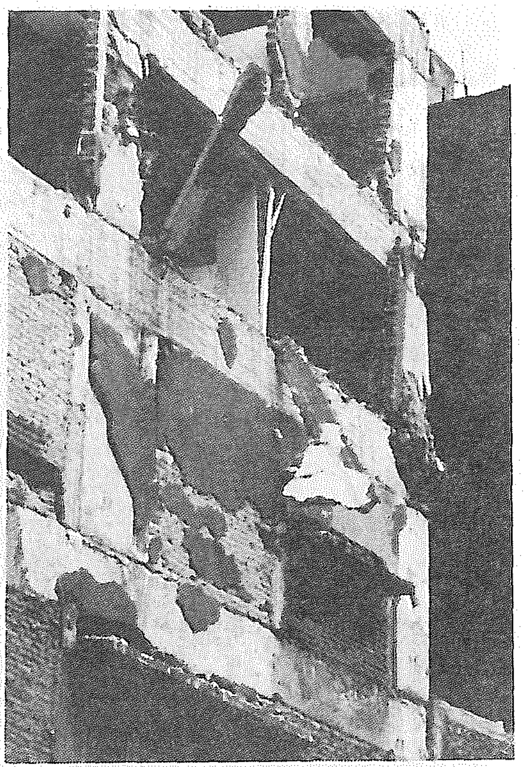
3. NICARAGUA, detail showing "Taquezal" construction without surface stucco.



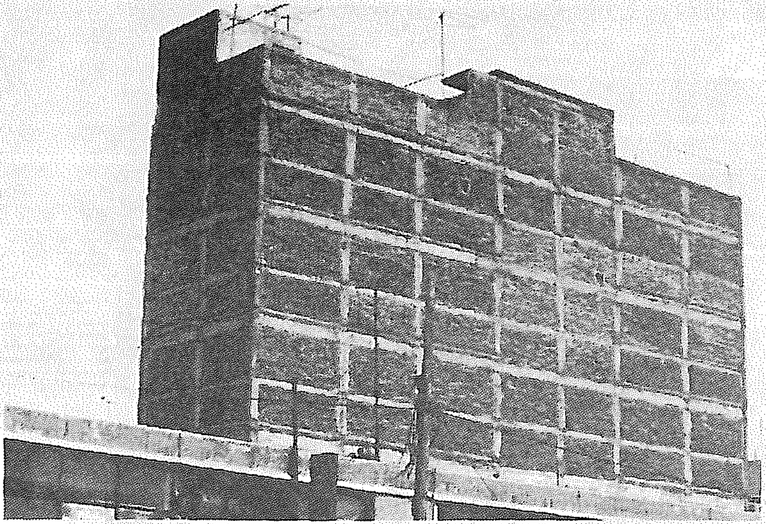
4. SAN SALVADOR, building showing loss of stucco from October 1986, earthquake.



5. MEXICO CITY, detail of collapsed col umn, Banco de Mexico building, showing evidence of poor quality concrete.



6. MEXICO CITY, detail of concrete building showing failure of column and collapse of the brick infill after the September 19, 1985 earthquake.



7. MEXICO CITY, commercial building showing concrete frame with brick infill wall construction.

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