MASONRY TECHNOLOGY AS A CONTRIBUTOR TO AFFORDABLE CONSTRUCTION IN THIRD WORLD COUNTRIES

Tom Hines[1]

ABSTRACT

The benefits of masonry in construction are well documented throughout the history of the modern world. Important factors to consider are: (i) manufacturing is low energy intensive, (ii) construction can be accomplished with lower technology in labor skills than required for structural steel or reinforced concrete and (iii) very little machinery would be required to manufacture primitive units. This paper investigates the current technology of various developing countries and what advancements are possible and the inherent benefits of increasing their capabilities with new appropriate technologies tempered by their own natural resources.

INTRODUCTION

Over the past twenty years, research has been devoted to the improved production of extruded clay masonry and in developing a mortarless, dry stack technology such that minimize skilled labor would be necessary to install thus increasing the ability of low and non-skilled labor to build very strong and affordable facilities. These technologies are affordable and available in today's world economy and can be used in developing nations as a marvelous tool.

Since exterior plastering (rendering) of the masonry is customary in many developing countries, and filling the cells is required for stability, mortarless, dry stack masonry and its appropriate finishes would be common place. Additionally, dry stacking units signed for such purposes will reduce the required labor skill and maximize local capabilities.

History of Masonry

Throughout the history of man, one of the most formidable staples in his palette of construction materials is masonry - in many forms, types, and shapes. The use of brick as a building material dates back over 5000 years, [13. Some of the oldest and most beautiful examples of brick architecture are found in the regions of the Tigris-Euphrates Nile Valleys. The sun-dried bricks, used by the early Egyptians to build their dwellings, came from the alluvial clays of the Nile Valley, (Figure 1).

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1. Principal - Tom Hines, Architect - Denton, Texas 76208.
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In these areas, having an abundance of clay deposits and being scarce in wood and stone, people first learned to use the clay to make bricks, (Figure 2). With the advent of copper in the use of making tools by 4000 B.C., the Egyptians were able to perfect sophisticated materials and construction methods thus accelerating their technology, (Figure 3).

Development of this technology led to construction projects such as the Ziggurat at Ur, (Figure 4), and the pyramid near the city of Memphis, the first capital of Egypt, (Figure 5), the forerunners of the later large Cheops pyramid. Built of sandstone and brick, these pyramids were constructed in terraced steps. Evidence has revealed that stone was used in early Egyptian buildings; however the primary staple for all types of structures was brick. The use of masonry has continued through the centuries to modern times, [1].

History of Mortars

Construction processes that developed resulting from the use of brick, relied on an equal history of mortar - the substance holding the bricks in place. Not all masonry was laid dry. Mortar performs several essential functions. The plastic nature of fresh mortar permits it to fill voids between masonry units that do not exactly fit together and to gradually become adjusted to movements within a wall that occur during construction. Mortar helps make walls water-tight; it enables bricks and small stones to form a coherent mass and acts as lubricant to permit the sliding of heavy stones into position. The form and color of mortar joints contribute significantly to the appearance of a wall.

Construction history of the Roman Empire is rich with developments in forms and materials, but was no different than the surrounding countries until the introduction of a lime and sand based mortar, probably from Greece. This one discovery, of pozzolana, made possible a type of concrete of substantial strength, resulting in a complete acceleration of the technology. In Rome, the great structures we know today, are the results of such technology, [1].

The progressive development, though evidence of early mortar is scarce, can be shown from mud or clay, pure lime, lime and sand and lime and pozzolana. This discovery has been considered one of the most significant in history and only overshadowed by the modern times discovery of Portland Cement. Mortar characteristics are very diversified; fresh mortar, in its plastic state, will fill the voids between the larger and smaller units providing fits with the irregular shapes. As construction progresses, subtle settlement of the assembly provides for consolidation of the components but strength and durability are achieved, [1].

Use of a proper mortar will develop resistance to permeability, develop a coherent mass and will lubricate the larger units allowing for ease of placement and settling. All of this coupled with form and color of the joints not only develop the aesthetics of the assembly but the overall integrity. Within the progression of time and technology, mortars have changed in their properties also. Prior to the late 1880's only soft mortar (lime-sand mortar) existed in the construction palette. Since the methods were not as sophisticated as today, the mortar's ability to provide a cushion effect allowing movement among the units assisted in the building's ability to move during settling.

Contemporary Mortars

In our contemporary times two basic mortar classes exist for the mason: PCI - Portland Cement-Lime Mortar and MC - Masonry Cement mortar. There are five types of mortars manufactured with lime; M, S, N, O, K, [1]. The strengths and permeability of each decreases in order.

This occurs based upon their proportional mixes of Portland cement, sand and lime. Type M, and S mortars posses extreme permeability resistance and can be used in all conditions. Type N mortar should only be used in arid climates and in piers below grade. Type O and K should only be used in conjunction with non-loadbearing interior applications. Masonry Cement consists of the same types, M, S, N, and O, and conforms to the same grading and property standards of PCL mortars, ASTM C- 270-87a. This material is composed of Portland Cement, limestone and other air entraining materials. Though both equally conform, MC mortars are of poor quality with regard to resisting permeability, [1].

MASONRY IN EGYPT

Masonry in Egypt is adorned by a rich and colorful heritage, as discussed in this paper's Introduction. Common to Egypt and especially Cairo, the country's capital, and typical to many north African and Middle-East countries is construction using unreinforced clay bricks made by hand and dried in the sun; made by hand and dried in medium temperature kilns; and extruded clay bricks dried in medium temperature kilns reaching temperatures just below 1200 degrees F which will not quite vitrify the clay.

Unreinforced loadbearing masonry was the dominant system between the 1920's through the 1940's. Older buildings such as churches, mosques, palaces, museums were built using hand molded sun-dried bricks and limestone, and are considered to be of non-engineered technology or built through traditional experience and by rule-of-thumb, (Figures 6 and 7). The base materials of these rule-of-thumb buildings are bonded with burned ceramic mortars called "Kosmell" which is not cement based, [2].

Additionally, unburned clay bricks are used to provide flexibility around windows. Sometimes plastering (rendering) was used to cover the masonry and over time has suffered cracking and spalling thus exposing the soft masonry to weather conditions. The exposure weakens the wall system by deterioration, in many one-story residential buildings, shale clay and mud clay were used as the main building products, [2].

The above describe construction was considered reasonable by the Egyptian citizens despite the poor quality of material and inadequacy engineering until October 12, 1992. An earthquake registering 5.4-5.9 on the open-end Richter scale struck the Southern part of the Nile delta and traveled 70 km North-East into the greater Cairo metropolitan area. Though the trembler was quite a shock to almost everyone in the affected area, this event also brought to reality the inadequacy of the traditional building systems considered appropriate over the past 4000 years.

Despite the low level of seismic loading, many old loadbearing masonry buildings suffered significant damage. The generally poor performance of the masonry was the result of deteriorated conditions of these buildings due to lack of maintenance and the fact that buildings were designed on the "rule-of-thumb" with no consideration of earthquake loading.

Appropriate construction, sustaining only minor damage, were the engineered loadbearing masonry structures. This technology is currently in effect in Egypt but on a small scale. The capability of the indigenous labor to construct such structures, with some guidance, is well within their current experiences, [8].

MORTARLESS MASONRY IN SOUTH AFRICA

Development of advanced masonry system in South Africa has progressed due to its higher economic capabilities and world technology transfer capabilities. But for many parts of this country, the traditional types of hand-molded clay, sun-dried clay bricks as depicted in Egypt are the norm. These variable units are laid in mud mortar, sand-lime mortars or lime-sand-cement mortars. The finished walls are irregular and, due to their great porosity, rendering must be applied to produce a dressed and uniform finish.

Many projects are laid with dry stone or bricks using no mortar and rely on the shape to resolve moisture and structural concerns. Similar concepts have been used through-out Africa as at the Great Zimbabwe National Monument, {Figure 8) and Khami, [9].

The introduction of engineered reinforced masonry has been successful for the more advanced areas of the country but, the bulk of the people are impoverished and lack the resources necessary to afford advanced technology. Mortarless interlocking masonry seems to be an answer as an appropriate technology to areas that are labor intensive and need an increased quality unit but can be installed with current technology experience.

Mortarless units can be stacked without mortar and can be made on site with relatively moderate technology in the plants. The appropriate shapes closely resemble the traditional mortared units thus have the same appearance and acceptance, (Figure 9). Upon completion of construction the units made rendered; grouted or surface-bonded. Over 19 different systems have been introduced into South Africa, but none have progressed passed the initial permitting stage.

The various issues hurting this technology are:

- Non-compliance with code restrictions on non-traditional buildignh systems.
- Dimensional variations of the units due to limitations on the availability of appropriate manufacturing equipment;
- Lack of the coordination of associated building materials such as door and window frames to accommodate the systems;
- Technical detailing has been neglected to resolve all conditions affecting the interface of other conditions such as roof and foundation assemblies;
- Innovative building systems usually inevitably encounter resistance and the general public, as well as contractors, must be educated.

Appropriately done these systems have been known to reduce the associated cost of construction up to 40% over traditional mortared systems and productivity can be three times, [7].

MASONRY IN IRAN

Most houses in the rural dry areas of Iran are of adobe construction, made of sun-dried clay brick walls and domed roofs or vaults of clay or mud mortar. These simple adobe structures have very thick walls and roofs. These very heavy sections can be up to 1 meter thick in order to protect their inhabitants from the severe cold and hot weather, but are very weak in resisting horizontal vibrations produced by an earthquake. The connection of the vertical walls and the domed roof elements are the weakest. These types of failures usually begin in a corner by separation of the walls from the domed roof, as shown in (Figure 10) - an interior of a domed adobe house after the Ghaenat earthquake of November 14, 1979.

Domed structures, without vertical walls, fared better as shown by a water storage house in the village of Chaharfarsakh, (Figure 11). Struck by the Sirch earthquake of July 28, 1991, this was the only building standing in the midst of ruined adobe houses, even though it cracked especially at the lower half of the dome, [3].

The survival of this water house and a similar observed experience in the Tabas earthquake of September 16, 1978. indicates that the use of suitable geometrical forms, even with the use of poor materials, can produce earthquake resistant buildings. Monolithic and three-dimensional forms of these structures were greatly responsible for their integrity and resistance against strong horizontal ground motions, [3].

An adobe icehouse in Kerman, {about 28 miles northwest of Sirch) was built in the early 17th century, (Figure 12). This dome shape structure is supported by a couple of buttresses, (Figure 13), and built of poor adobe materials. Despite its very old age, the building went through the quake motions satisfactorily. Though separated from the dome as a result of the shaking, the buttresses provided a major contribution to the lateral strength of the building, [8].

Reinforced and unreinforced brick buildings consist of kiln fired brick walls with shallow Jack arch roofs supported by steel I-beams. Beams are usually laid a distance of 3-1/2 feet apart, and in-filled with shallow brick arches. The mortar used is sand-lime, sand-lime-cement and occasionally sand-cement. Due to their mixed construction, the performance of unreinforced brick structures in different earthquakes was poor and not better than the adobe houses.

Failures in the most common forms were in-plane shears, (walls perpendicular to the steel beams and infill arches), (Figure 14); out-of-plane separations of walls from the roof (walls parallel with beams and infill arches) with consequent vertical cracks, (Figure 1 5); and possible failures, and unseating of the steel roof beams resulting in the collapse of the roof.

Engineered reinforced brick buildings in Sirch survived better than unreinforced masonry buildings after the trembler of July 28, 1981. The structure was made with steel tie beams and I-cross sections at the top of the external walls and the reinforced concrete vertical elements at some corners. One particular building was in the epicentral region of the earthquake and survived the strong ground motions with moderate structural damage and heavy partition damage. The bond between the steel tie beams and the brick walls failed.

Newly engineered reinforced brick buildings build with proper reinforcement, withstood the Sirch July 28, 1981 earthquake shaking with minimal damage, if any at all. These buildings used good quality extruded, kiln-fired bricks, sand-cement mortar, and concrete tie beams at the top of all walls (Figure 16). Resulting from the engineering, the buildings behaved like a monolithic box structure. In the town of Golbaf which was devastated by the shock of June 11, 1981 (killing 1 200 people out of a population of 13,000), the only residential building without any structural damage was reinforced with horizontal and vertical concrete elements as mentioned above.

Parallel with contemporary engineered structures, is technology used in a 1 70 year old brick wind tower in Kerman, (Figure 17a). A close-up of this 98 feet tall and 23 wide tower is shown in (Figure 17b) and is reinforced by the wooden poles or beams that project from the tower. This tower in addition to others of similar construction, survived the Sirch earthquake satisfactorily. The reinforcing horizontal poles have tied the airflow blades together and increasing the lateral strength, ductility and dampening of the relatively high masonry tower, [3].

Due to the lack of sufficient modern materials and economic feasibility, construction of adobe houses can not be abandoned immediately in many parts of the world. However the knowledge gained in the Iranian earthquakes provides evidence that adobe used with appropriate geometrical shapes and buttresses will be valuable aids in minimizing failures of the shapes made with the indigenous materials. While reinforced engineered masonry can be incorporated into some structures when financially feasible, the capability of appropriate masonry design will enable rule-of-thumb construction to be earthquake resistant.

MASONRY IN KUWAIT

During the late 1940's and early 1950's, before the introduction of reinforced concrete, the most common building system in Kuwait was unreinforced wall-bearing masonry with wood flooring. This system is in use today, but on a limited scale. Construction of one and two-storey houses where wood floors have been replaced by reinforced concrete slabs, and masonry walls have become high strength concrete blocks, [5].

In the early 1970's, Kuwait witnessed a huge surge in construction accompanying the oil boon. Reinforced concrete masonry and reinforced concrete wall-bearing systems were introduced by western influences to compete with the existing systems. The most predominant building system consists of a reinforced concrete frame filled with masonry elements such as concrete block and lime or clay bricks to form the exterior and interior walls, (Figure 18). These two new systems have been used in a number of projects built by the National Housing Authority, which is responsible for the construction of governmental housing projects, [4].

Current practices break the construction into four stages: Site and foundation work; construction of the skeleton frame; finishing activities which include the masonry infill of the frames; and finally site works and commissioning. The time required to perform each stage and complete the project is dictated by the number of floors and cycles of the stages for each floor, [4].

The main advantage of using the system lies in with the time saved in construction of the frame and infill walls simultaneously. This provides a reduction in the many steps of each phase required with a reinforced concrete frame system. Additionally there was a considerable savings in the required amount of materials.

The additional benefits of the reinforced masonry system over the conventional system in use in the Kuwait and countries of the Middle East are apparent in terms of savings in the materials and in construction time, which make the masonry system more economical that systems currently used. Once the first few projects were constructed; overcoming the learning curve of experience; training the construction force and coordinating the project, a savings of 15-20% in terms of cost and the projects can be completed in 25-30% less construction time, [4].

The employment of this system and its success was never more evident than during the Iraq invasion, occupancy, and liberation of Kuwait between August, 1990 and the end of the Gulf War, in developing their resistance, the Kuwaitis used their houses to launch a resistance movement against the occupying army. The Iraqi army would surround and shell resistance centers and set them afire. If houses were occupied, then a longer period of shelling ensued. Considerable damage was done in terms of fire and shelling regardless of the resistance. Of the 51 damaged houses surveyed and assessed after the war, 45 had reinforced concrete frames, 4 were of the reinforced concrete wall-bearing; one house was built of unreinforced masonry and another was of the reinforced wall-bearing system. Some buildings were subject to shelling and fire. The extent of damage and subsequent performance was different for each system as Discussed below:

- Reinforced Concrete Skeleton with infill Walls fared exceptionally well against shelling and fire. The concrete frame and the diaphragm strength of the floors absorbed the shock and kept the buildings from collapse.

- Wall-Bearing Unreinforced Masonry Buildings fared equally as well. Subject to shelling and fire, a large hole developed but loading was distributed through the masonry and the building withstood the existing loads. The fire was contained within the floor and repairs were easy, (Figure 20).

- Wall-Bearing, Reinforced Masonry Buildings that were subject to fire endured the stresses and attack. Damage was limited to non-structural elements. Reinforced masonry buildings have thicker walls thus providing a thicker cover for the reinforcing steel. Compared with the reinforced concrete frame buildings, which were condemned due to heat deterioration of the reinforcing steel compromising the structural integrity of the frame.

The practices of using masonry as infill walls or reinforced load-bearing walls proved to be very useful in these ways: i) Due to their higher resistance to fire, they prevented fire from spreading to adjacent rooms and buildings and ii) in the case of infill walls, after the loss of the supporting members, these walls acted as wall-bearing elements and kept the building standing, thus saving lives and enabling repair work to be carried out later, [5]. The masonry's ability to provide such secondary capacity is due to a phenomena call arching.

MASONRY IN INDIA

Over 600,000 mud hut villages are home to some seventy percent of India's people. In these villages the major construction material is clay brick. These hand made bricks are frequently sun-dried but may also be fired in simple kilns such as clamp kilns, as depicted in a tiny hamlet in Kashmir, (Figure 21). The firing of the kilns (using wood or cinders) and the clay production usually takes place close to the building site. Though the bricks have a variety of shapes and are low strength, this non-engineered application in one and two storey assemblies have been proven over time and often looked upon as quality rural construction, [6].

Larger production facility, like this one in Auranbad, a town 187 miles east of Bombay, are usually set up along river banks, (Figure 22). Here the bricks are hand molded, dried in the clamp kiln; low strength; vary greatly in shape and most of the labor is performed by the women. The bricks are usually used for buildings up two stories in height.

Hand molded bricks produced from a Bull's Trench Kiln, (Figure 23). are considered "good quality" unit and are used in engineered loadbearing masonry structures up to three stories in height. This type of appropriate technology, raises the quality of the brick without excessive technology and allows the indigenous labor to prosper and gain in achievement.

In 1967 a mechanized brick production facility was established in New Delhi using a Hoffman chambered kiln, (Figure 24). The estimated capacity would be 40 million bricks a year. The current production, in 1994 is approximately 2 million bricks a year. This is due to the fact that the kiln is oil fueled. So costly modifications were made to utilize coal due to the oil crises in the 1970's. To control fire-cracking and other problems arising from firing the local clays, a separate drying stage of two to three days in heated drying racks was established. This required more manual labor for a two stage process of stacking bricks to dry and again for firing. The kiln. There was also no accurate control over the kiln firing temperatures.

Given all the issues resulting from installing a mechanized molding plant, the brick were more than twice the cost of hand molded bricks. The bricks are usually 4-5 times stronger than the hand molded bricks. These stronger bricks are usually used as the walls of the first two stories of multi-story building the cheaper hand molded units are used for the third stories and above. Mechanized bricks account for almost 8% of the total brick production in the country.

Figures 25 relates the type of masonry construction projects typical of events over the past 12 years. In this urban center, slum clearing is a typical event for housing projects. The units for this building were hand-molded bricks of medium strength first storey and then the cheaper units of uncertain strength finished out the building.

The extensive amount of tooling and finishing of the units is a result of the poor quality of the bricks and the vast amounts of water used is to reduce the absorption rates of the porous units that are not fire to vitrification.

The demand for shelter is increasing yearly due to the overall increase in population and urbanization pull. Brick is widely produced and used throughout India and has a time proven adaptability to rural and urban applications. Engineered masonry, as in most countries of the world is still relatively new to India, yet it holds great promise for alleviating the shelter problem, (Figure 26). The feasibility of loadbearing masonry structures up to five stories in height was based partly on research work and partly on demonstration projects sponsored by the National Buildings Organization in Delhi. Such structures have proven to be extremely economical compared to reinforced concrete, such that over 60,000 apartment units have been built, [6].

MASONRY IN COLOMBIA

The construction industry in Colombia is one of the main contributors to the gross national product and in the source of employment of a significant percentage of the labor force, especially for moderately and the low trained workers. From less than 4 million inhabitants at the turn of the past century, the population of the country has grown to 34 million today. The demand for housing is high and it explains why residential construction makes 75% of the production of the construction industry.

Indigenous to Colombia is the Colonial type of construction brought by the Spaniards during the 16th Century. There two types: Adobe and "Tapia Pisada" or compacted earth. These materials were the major materials used to construct houses, Churches and Institutional facilities until the turn of the past century. Damage to these types of structures from three recent earthquakes; (November 23, 1979 which measured 6.4 on the Richter scale and effecting the Western and Central parts of the country; December 12, 1979 measuring 7.8 on the Richter scale and affecting the city of Tumaco, and Cali some 174 miles from the epicenter; March 31, 1983 in Popayan measuring 5.5 on the Richter scale), was intense. The old colonial part of the city of Popayan was damaged beyond repair and buildings up to 5 stories were effected.

The second group of construction used Unreinforced Masonry and covers a period from the early 1900's and is currently being used today. Until 1950 houses of unreinforced masonry resembled Colonial construction but the walls were not as thick and solid clay bricks were used. Window and door openings were smaller and the roof structures were similar, [11].

Several aspects of these previous construction types changed in the early 1950's with the advent of industry produced bricks and Portland cement was introduced into mortar, [11]. Due to the character of the bricks and their continuity, walls became more slender a large percentage of the new construction had light reinforced concrete frames confining the masonry, (Figure 28).

1972 brought the onset of a financing mortgage systems that produced a boon of construction which in turn affected the quality of construction due to the lowering of the standards of many good practices. More demanding layouts, needed for marketing reasons, required larger opening for windows and doors; vertical continuity was lost form floor to floor and the confining light reinforced concrete frame was abandoned altogether. The behavior of these structures, during the earthquakes was devastating and many buildings were damaged beyond repair.

Engineered Masonry was introduced during the mid 1970's. A small number of these types of buildings were exposed to the earthquakes. A group of seven identical six-storey apartment buildings in the city of Pereira were shaken by the November 23, 1979 earthquake. Built under North American standards of practice and the design theory at that time, these buildings suffered virtually no damage. Several adjacent buildings with concrete frames and masonry infill walls were severely damaged, [10,11].

Damage to Non-Structural Masonry, especially partitions, was evident in all the buildings exposed to the three earthquakes. Resulting from the collapse of several major facilities were strict design parameters for quake stability into the Colombian Building Code, [10,11].

The development of engineered structural masonry in Colombia has taken place in less than 20 years and two factors were fundamental in this process:

- The interest of a group of builders and structural engineers in using more sensible structural solutions for low and medium income housing; and
- The opportune inclusion of structural masonry requirements in the building code.

MASONRY IN PERU

Prior to the Spanish conquest of Peru in the mid 1500's, the Inca Indians had developed a cities constructed with stone and clay masonry. The ruins of Machu Picchu, (Figure 28), near Cusco, is a good example of their capabilities. The Spanish conquest brought colonial development to Peru along with is architecture and traditions, [14].

During this time Peru experienced similar technology development as did other South American countries. Most houses in the rural areas and even community buildings were built with adobe walls and grass thatch or wood roofs. Except for the years between 1856 and 1862, when a large penitentiary was built with ceramic blocks molded from a machine borrowed from the United States, [12] hand made adobe bricks were made and served as the indigenous material for housing and most buildings, (Figure 29).

This practice continues even today. In the early 1950's the practice of engineered masonry technology started. This concept brought with it the manufacture of extruded and machine molded bricks that were sun-dried and kiln-dried. The construction of many buildings, including houses resulted from plain (unreinforced) engineered masonry. Structures were more economical, required less time to construct and could be more than two floors tall. It was not until seismic damage to these buildings, resulting from the Chimbote volcano eruption of 1970, in caused a change, [12,13] (Figure 30).

Today all three practices are used throughout the country. In the capitol city of Lima, many high-rise buildings have been constructed since 1979, (Figure 31). The two practices of reinforced engineered masonry construction are infill panel and confined design, [14], (Figure 32). The government of Peru is working very hard to eliminate the development of squatter settlements around the urban areas, [14]. Most of the houses built on squatter land are of adobe and some plain masonry, [14]. These areas, now called new towns by the government, are at best susceptible to the worst type of damage that could result from seismic activity, [13,14].

The introduction of mortarless interlocking masonry came in 1984 with the advent of the Mecano block, [15), (Figure 33). Believed to be a major contributor in reducing the cost of masonry construction, this unit is currently used in commercial and residential construction. This development has promise in many areas of Peru, in that the required amount of skill required to install the block is greatly reduced in that it is self-aligning and leveling, [15].

The ability of Peru to make mortarless interlocking technology available to the outlying areas will not only improve the quality of housing structures but will sufficiently aid in the reduction of seismic damage, [16].

SUMMARY

Throughout the world masonry construction exists in many forms, good and bad. The readily available materials of clay, water and straw enables even the poorest of nations to provide shelter for its people, crude as it may be. The dilemma is that, through the ages, passed from generation to generation, the same basic methods have prevailed. Thus without formal education and technology transfer from country to country and urban city to rural hinterland, the people continue to suffer from not being able to raise themselves from poverty.

Countries that experience seismic activity have a greater burden to strive to improve. As has been discussed, the practice of adobe and plain masonry construction puts the citizens in grave danger of losing the houses they struggled very hard to get but their very lives hang in the balance. Masonry technology provides even the poorest farmer the capacity to improve his standing with only marginal increase in brick manufacturing techniques.

Research shows that a brick with as little strength as 1000 psi can withstand minor seismic shock and handle loads of up to 3 floors, [17]. This paper has discussed the progress of countries that have moved their technology from adobe to plain masonry with relative ease. When seismic activity has taken severe tolls, reinforced masonry technology was begun. To many countries reinforced masonry technology would be an inappropriate technology. To these circumstances, they should look to how Iran solved problems by using geometric shapes with adobe technology to withstand the loads.

Mortarless interlocking masonry can provide solutions in countries currently using plain and reinforced masonry. The material is user friendly in that little skill is necessary. It is much stronger in the assembly than an assembly of the highest strength bricks. Mortar is not required to put the units together. Surface bonding and parging can be used also.

The technology can be put in place and be appropriate considering the skill level of the people who will benefit and use it is sufficient - more so than with clay masonry, [18,19]. The capability to make the masonry already exist in several countries and is spreading, but it can only progress behind a good plain and reinforced masonry technology, it is ever so important that people be able to use good bricks. It is even more important that when shaken, the bricks stand and not collapse.

DEFINITION OF TERMS USED FREQUENTLY IN THIS PAPER

Adobe -	a mixture of clay, sand plus a stabilizing agent usually straw and dried in the sun.
Plain Masonry -	construction relying upon the mortared masonry unit (concrete block or clay brick) for strength.
Reinforced Masonry -	construction relying upon a composite system consisting of the masonry unit, reinforcing steel, grout and mortar for developing the maximum capability of each material all working together to support the loads.
Engineered Masonry -	planning and designing of masonry construction regarding the physical and material properties of components, i.e. reinforcing steel; masonry unit; mortar and grout.
Wall of Load Bearing -	relying upon the masonry wall to absorb all loads as opposed to using a frame or restraints.

FIGURES

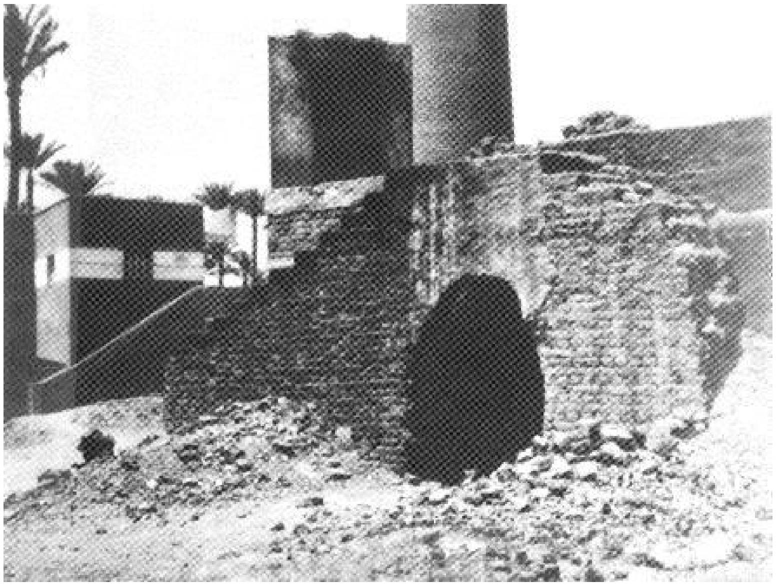

Figure 1 - Brick work detail in the old Cairo quarters on an old but operational brick kiln.

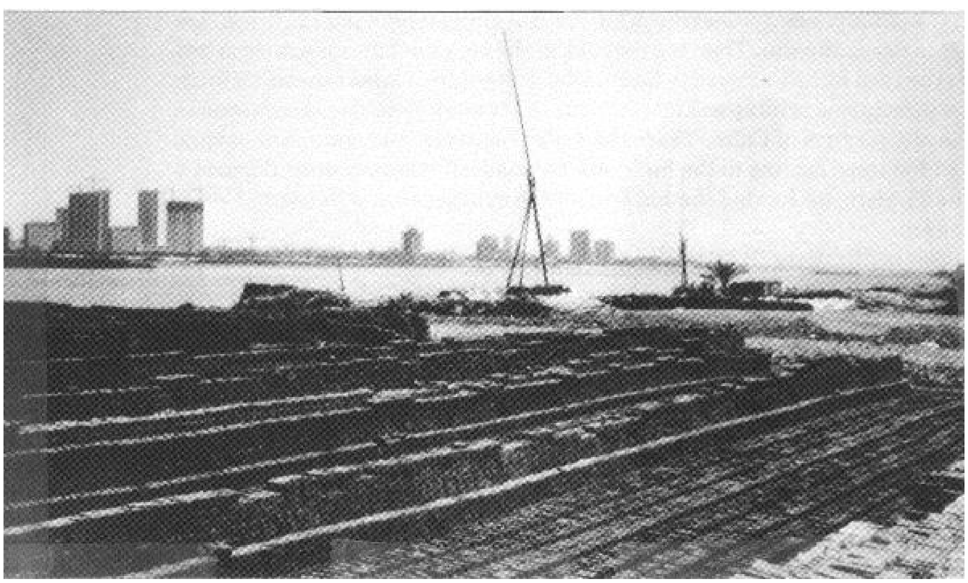

Figure 2 - Present day brick manufacturing in Egypt. Sun drying of bricks before going through the kiln. Little has changed in this process from ancient to present day Egypt.

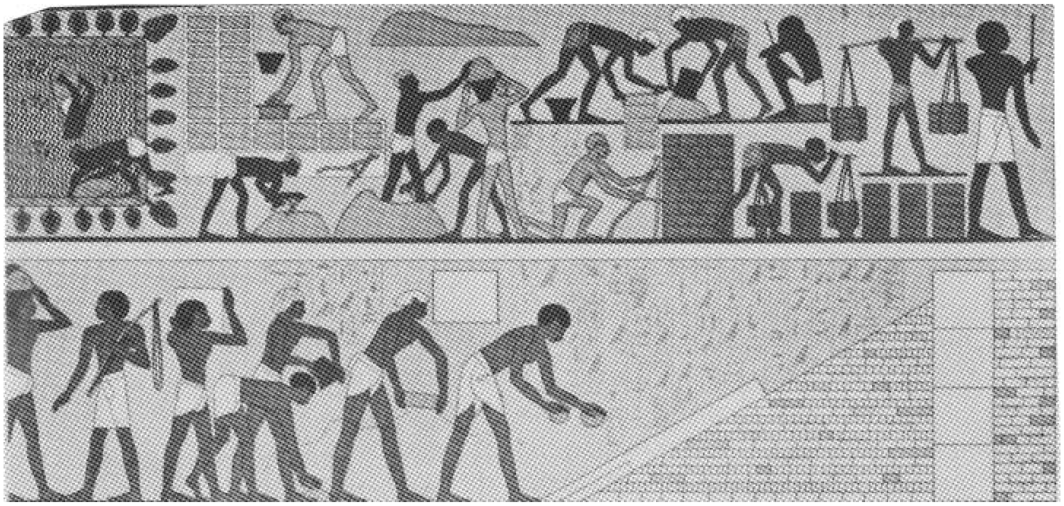

Figure 3 - Making bricks. Mural from the tomb of Rekhmire, the vizier of Pharaoh Thutmose III, depicts brick making in Egypt at the time of the exodus (1446 B.C.). At the top, two men draw water from a pool for making mud. Beside them, two men work the clay. Slaves press the clay into molds from bricks, and left in the sun to dry. The panel below shows how the bricks are laid with mortar.

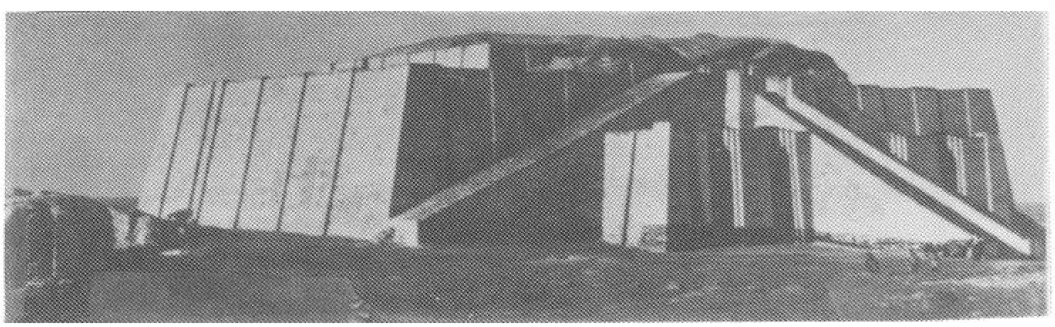

Figure 4 - Ziggurat at Ur - The temple at Ur was used in the pagan worship the Abraham left behind when he traveled to the Promised Land. The work ziggurat is an English rendering of the Assyrian ziggurratu "height or pinnacle". Circa 2900 B.C.

Figure 5 - Pyramid at Memphis, Egypt. The forunner of the later Cheops pyramid. Circa 2650 BC.

Figure 6 - Use of stone and brick masonry around window openings.

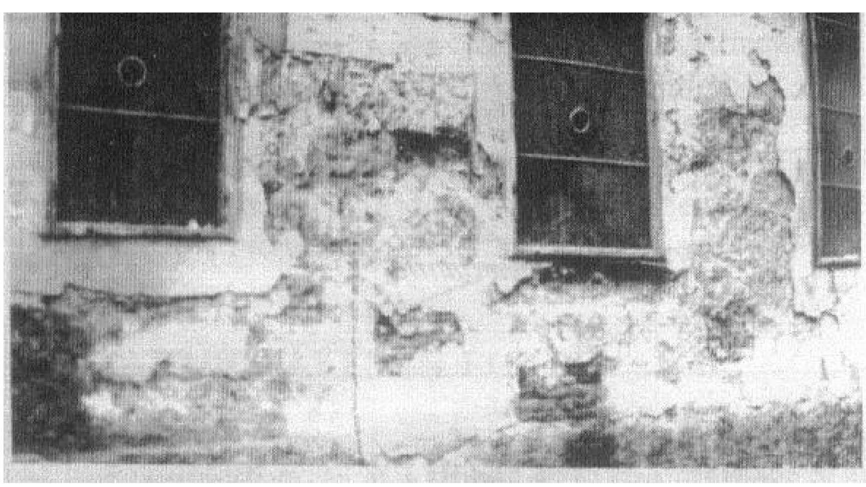

Figure 7 - Deteriorate surface of stone masonry due to poor maintenance and construction materials.

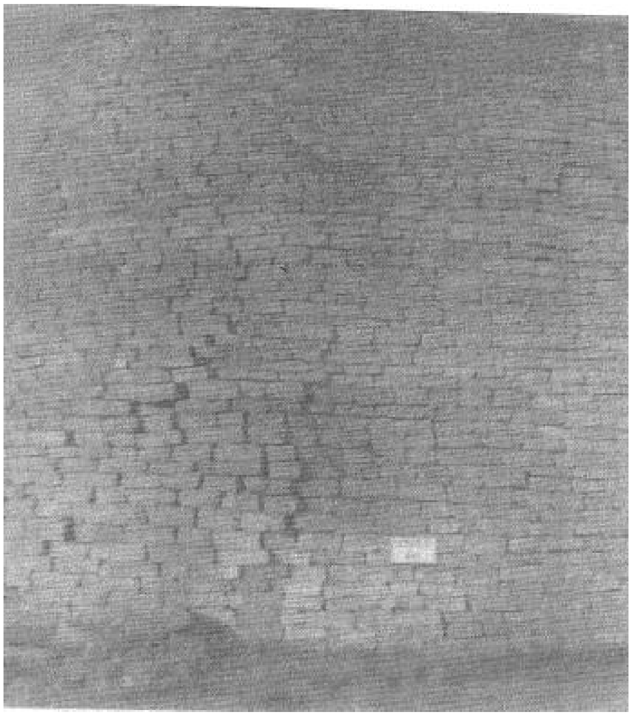

Figure 8 - Western entrance wall, Great Enclosure of the Great Zimbabwe Museum. Stones are dry-stacked.

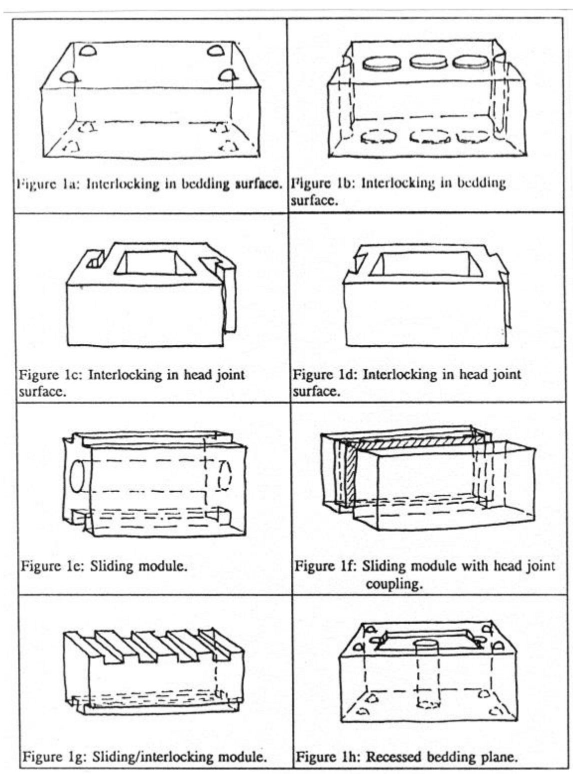

Figure 9 - Variations of mortarless interlocking concrete masonry units submitted for approval in South Africa

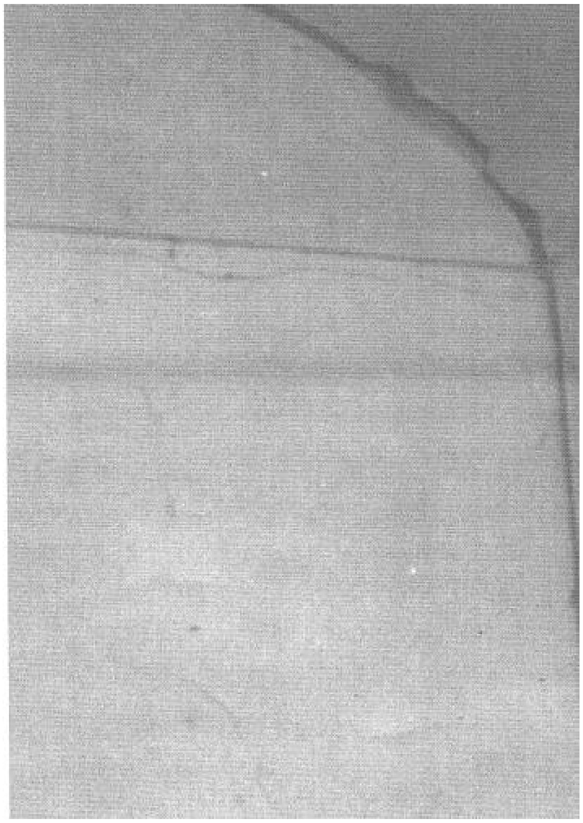

Figure 10 - Intersection of wall and vault roof cracked resulting from seismic loading.

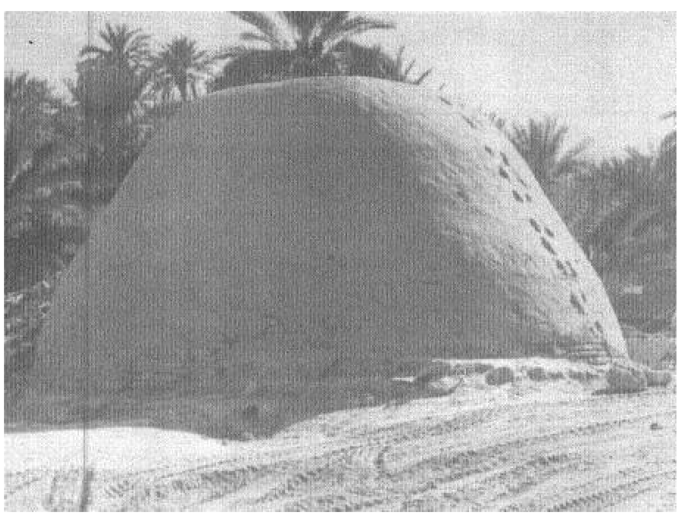

Figure 11 - Dome water house built of adobe was not affected by seismic loading.

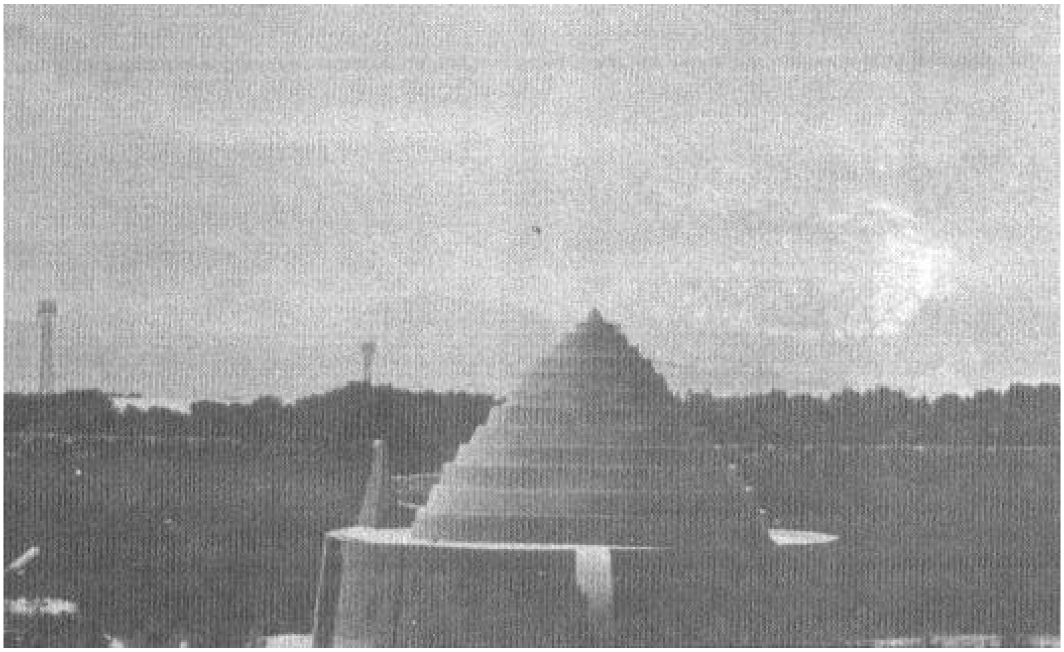

Figure 12 - Dome shaped adobe icehouse supported by adobe buttresses survived seismic loading without damage.

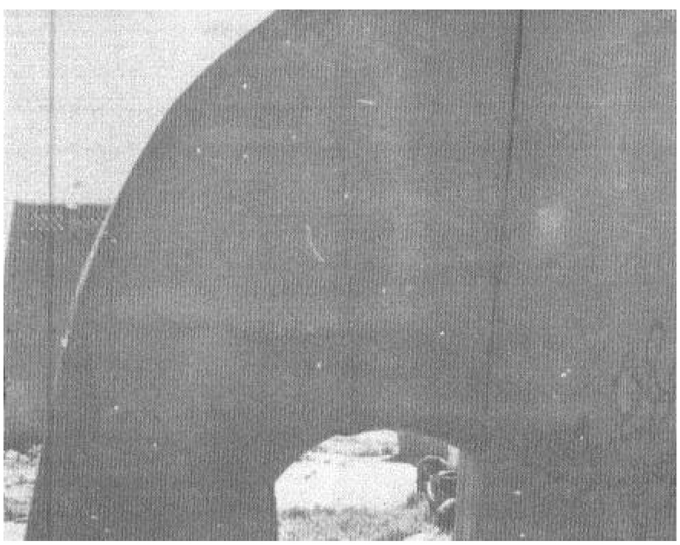

Figure 13 - Adobe buttress of adobe icehouse shows separation and continues to support loading.

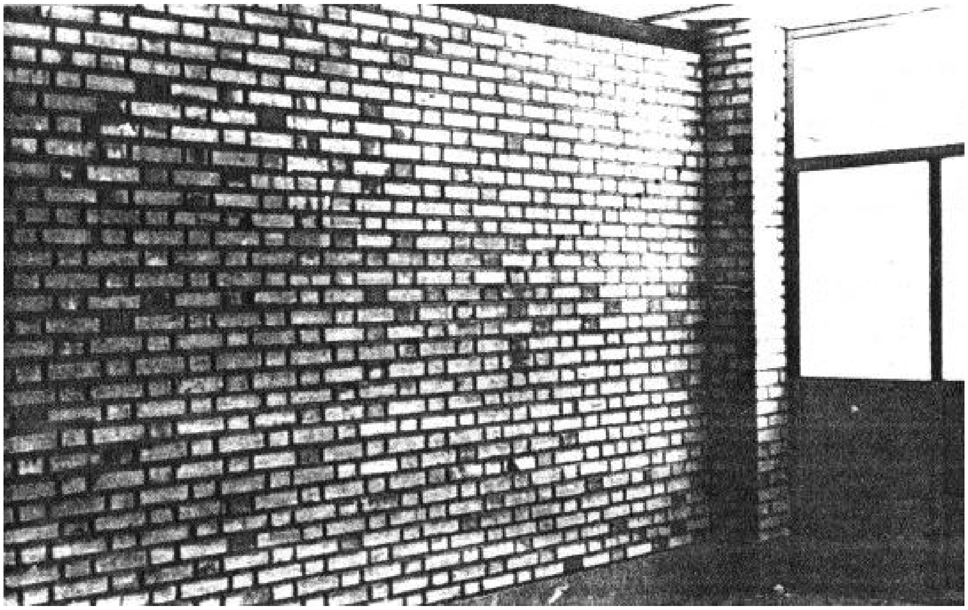

Figure 14 - Failure cracks in hte masonry wall of a building using arched roof supports with steel beams. Cracks result from in-place shear.

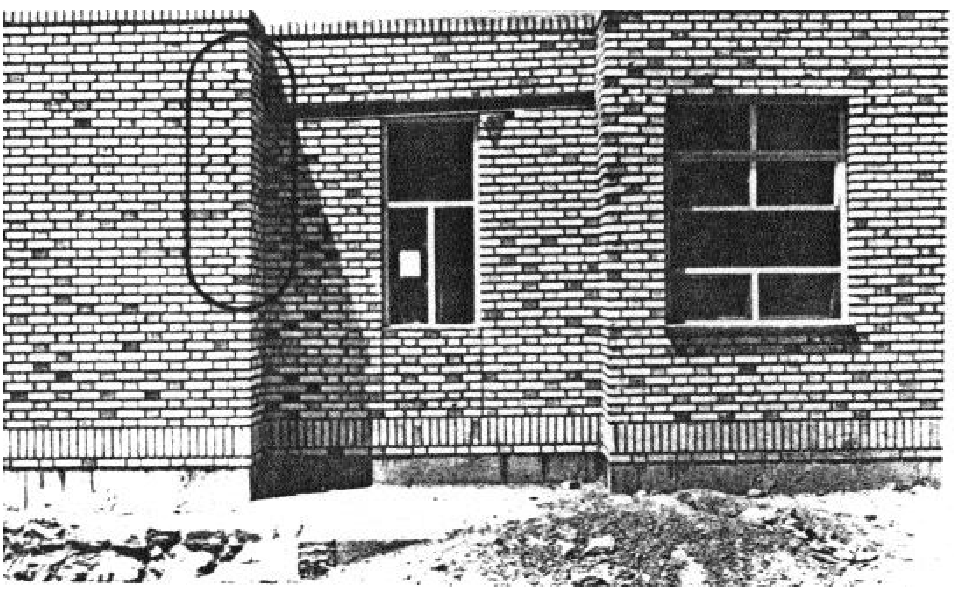

Figure 15 - Commercial building with infill arches of plain masonry with versicle cracks resulting from out-of-place shear.

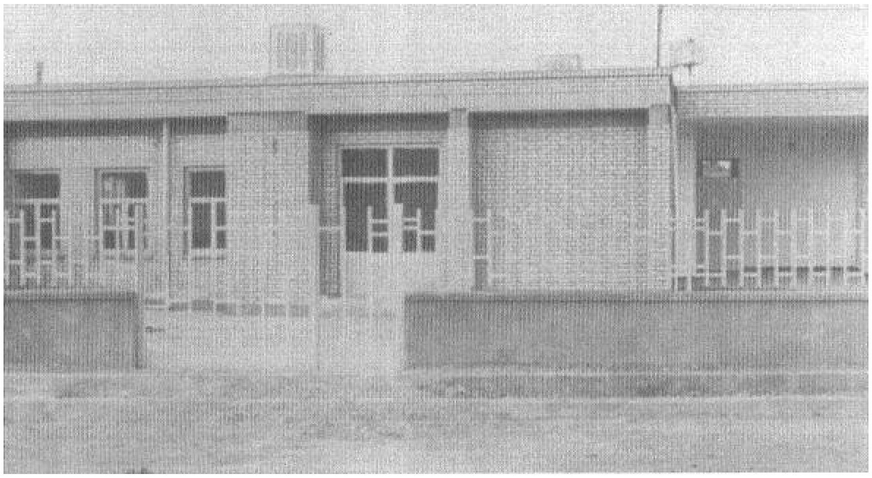

Figure 16 - Engineered reinforced masonry building that survived the Sirch earthquake of July 28, 1981.

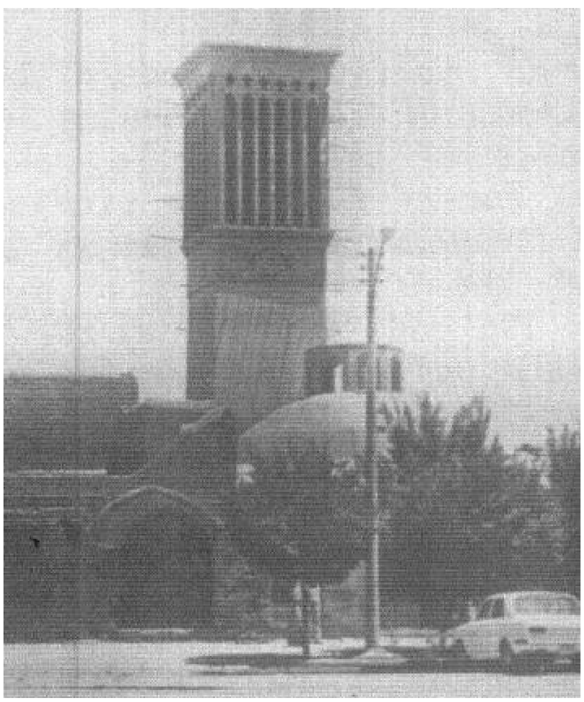

Figure 17a - 170 year old plain masonry tower in Kerman, survived the Sirch earthquake.

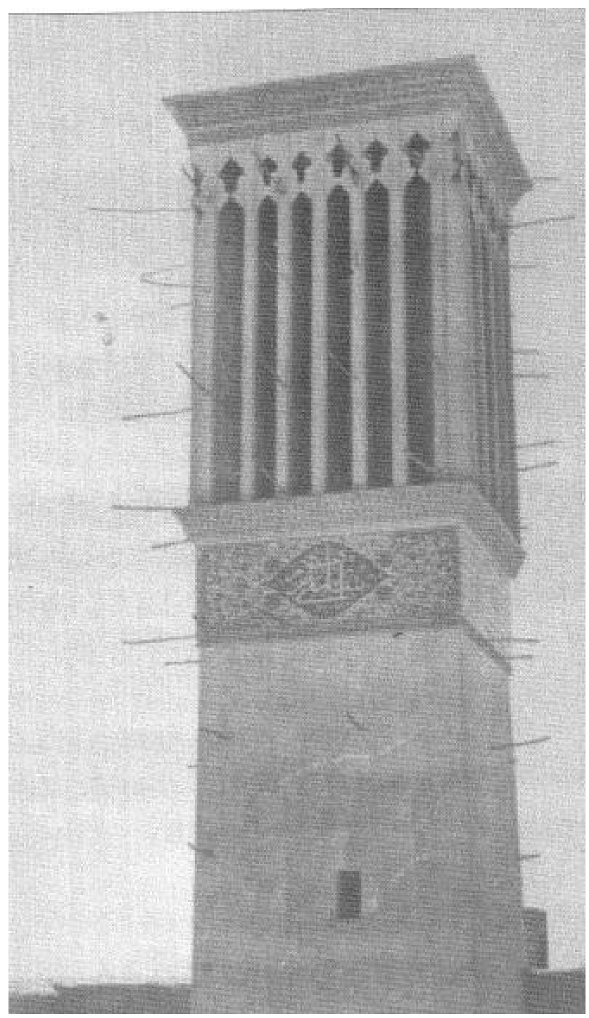

Figure 17b - Close-up of Tower

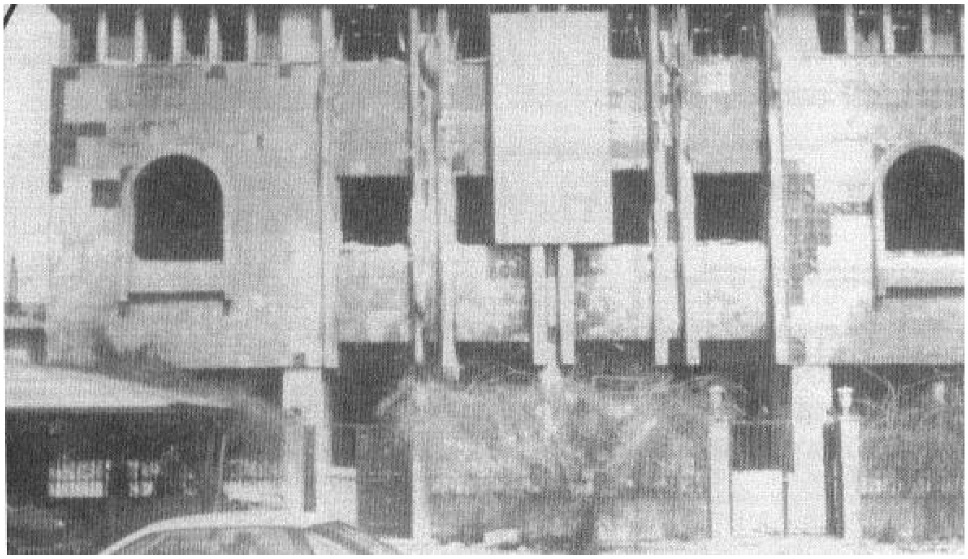

Figure 18 - House in Jabriya district of Kuwait built with a reinforced concrete (RC) frame, with infill masonry walls, subjected to a severe fire.

Figure 19 - Building with a RC frame, with infill masonry walls, subjected to shelling.

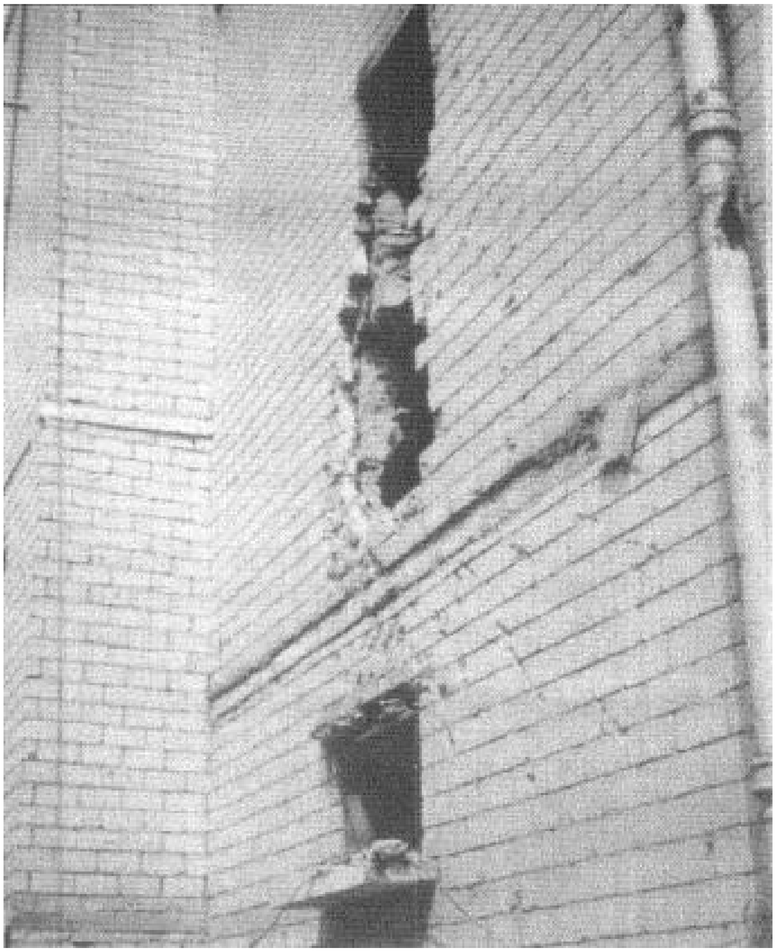

Figure 20 - Unreinforced masonry bearing wall subjected to shelling and fire.

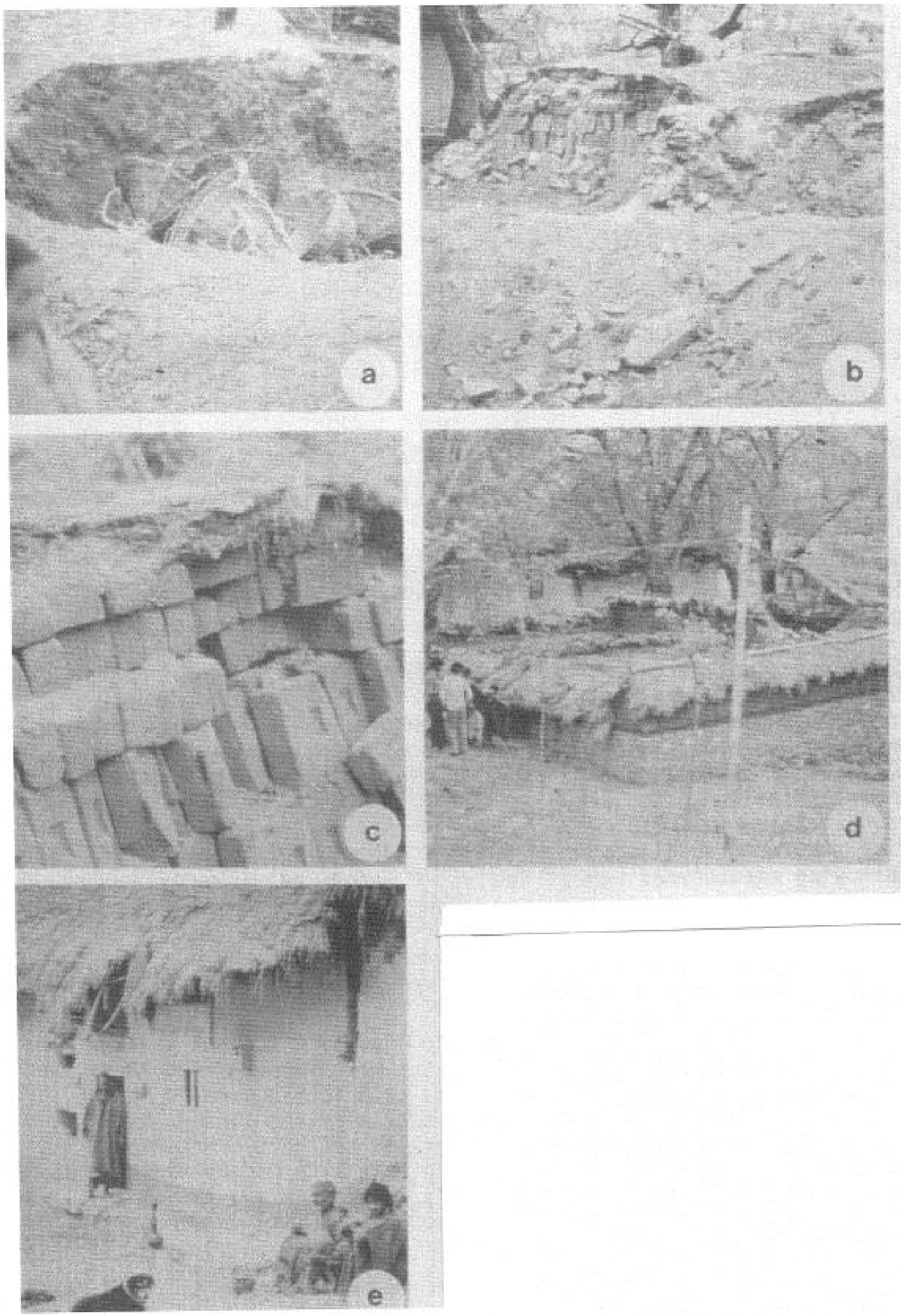

Figure 21 - Primitive brick manufacturing in India. (a) Manual digging of clay with 50m of the building site; (b) Simple kiln adjacent to the building sire; (c) Detailed view of bricks at top of the kiln set-up; (d) Brick masonry wall construction on top of stone masonry foundation. Note the straw cover when construction stopped. (e) Typical exterior plaster parging and/or whitewash.

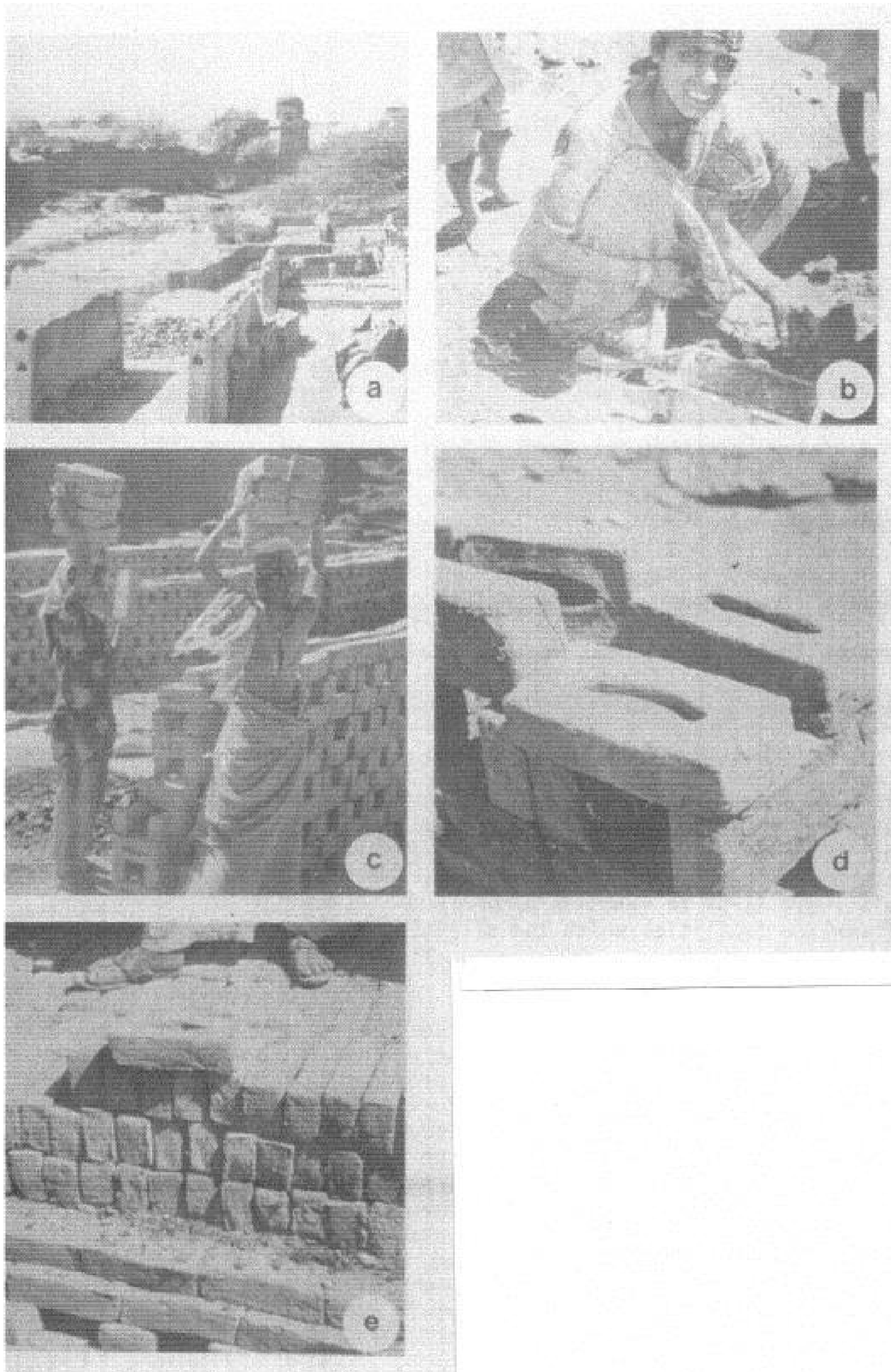

Figure 22 - Typical town brick production in Aurangbad. (a) View of production facility along a river bank; (b) Bricks are hand molded singly; (c) Bricks are stacked for drying before firing; (d) Variable dimensions of drying brick; (e) Newly fired brick exhibits extensive shape defects.

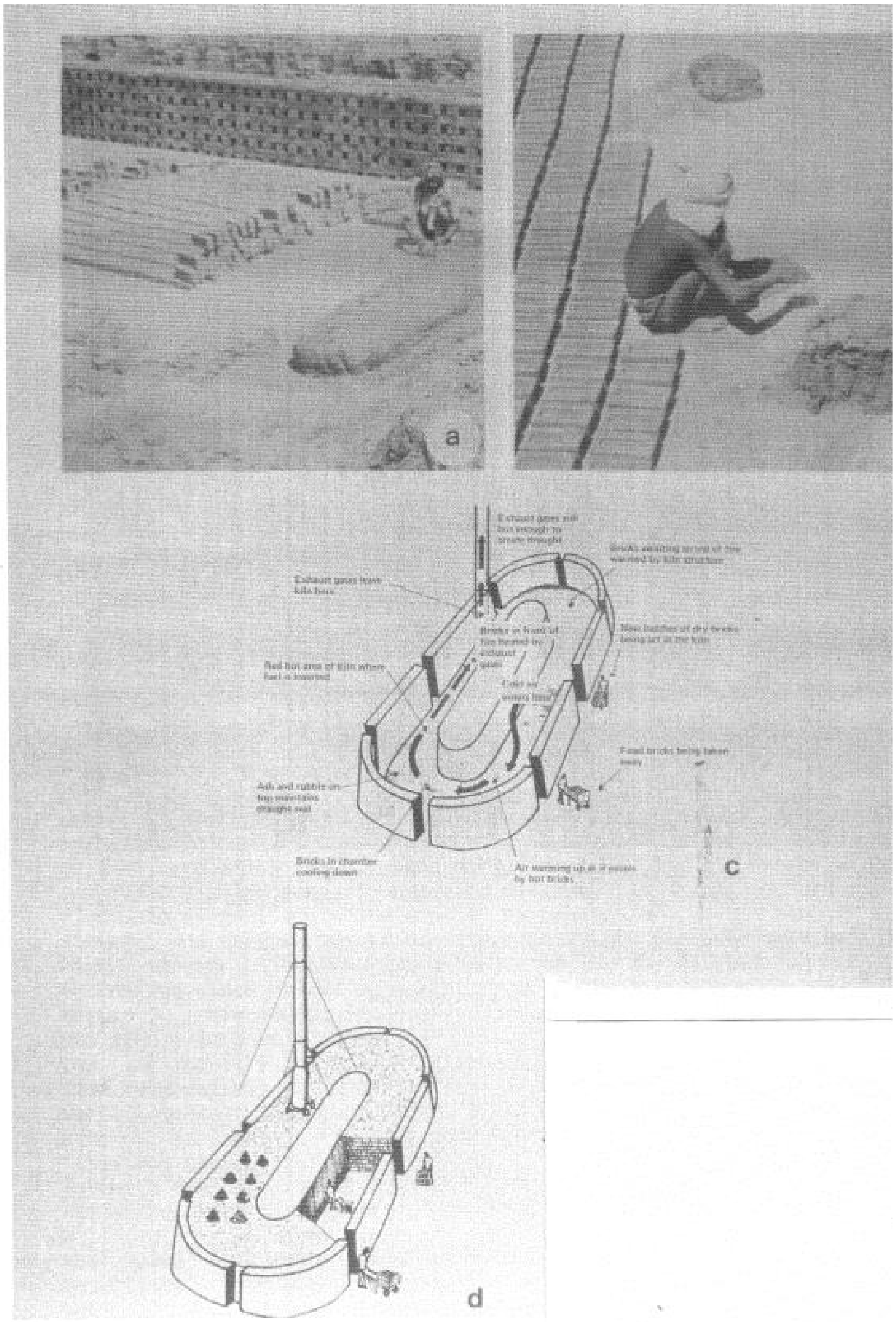

Figure 23 - Hand-molded clay brick production in New Delhi. (a) Hand molding set-up with prepared clay which frequently has weathered over several days; (b) Freshly de-molded bricks show few dimensional defects; (c) Principal of Bull's Trench Kiln; (d) Loaded Bull's Trench Kiln with movable chimney.

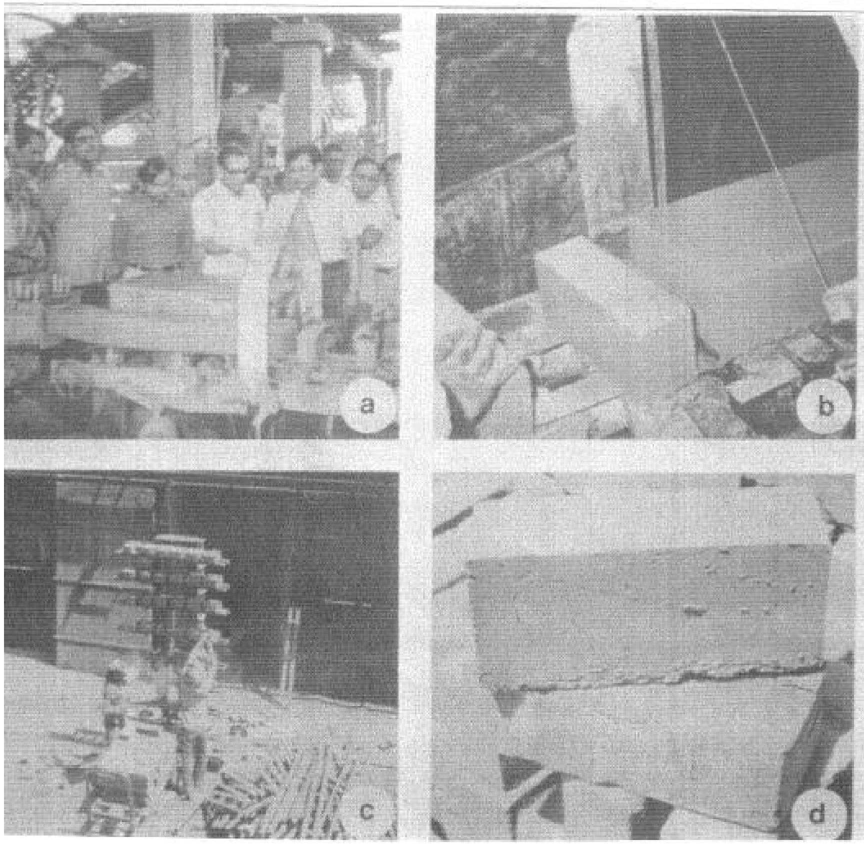

Figure 24 - Mechanized city brick production in New Delhi. (a) View of extruded clay ribbon; (b) Wire cutting one unit as a time; (c) Manual stacking of brick fro drying stage; (d) Typical solid wire cut brick displays flat parallel surfaces.

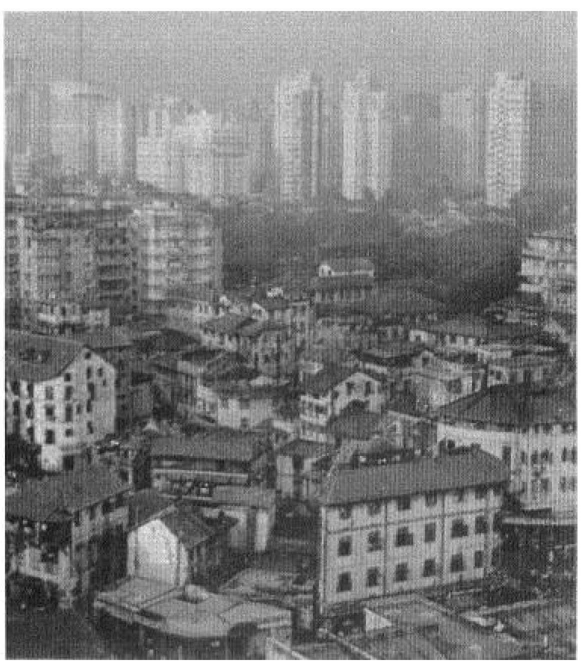

Figure 25 - High-rise masonry and Concrete structures and slum areas at the edge of downtown Bombay.

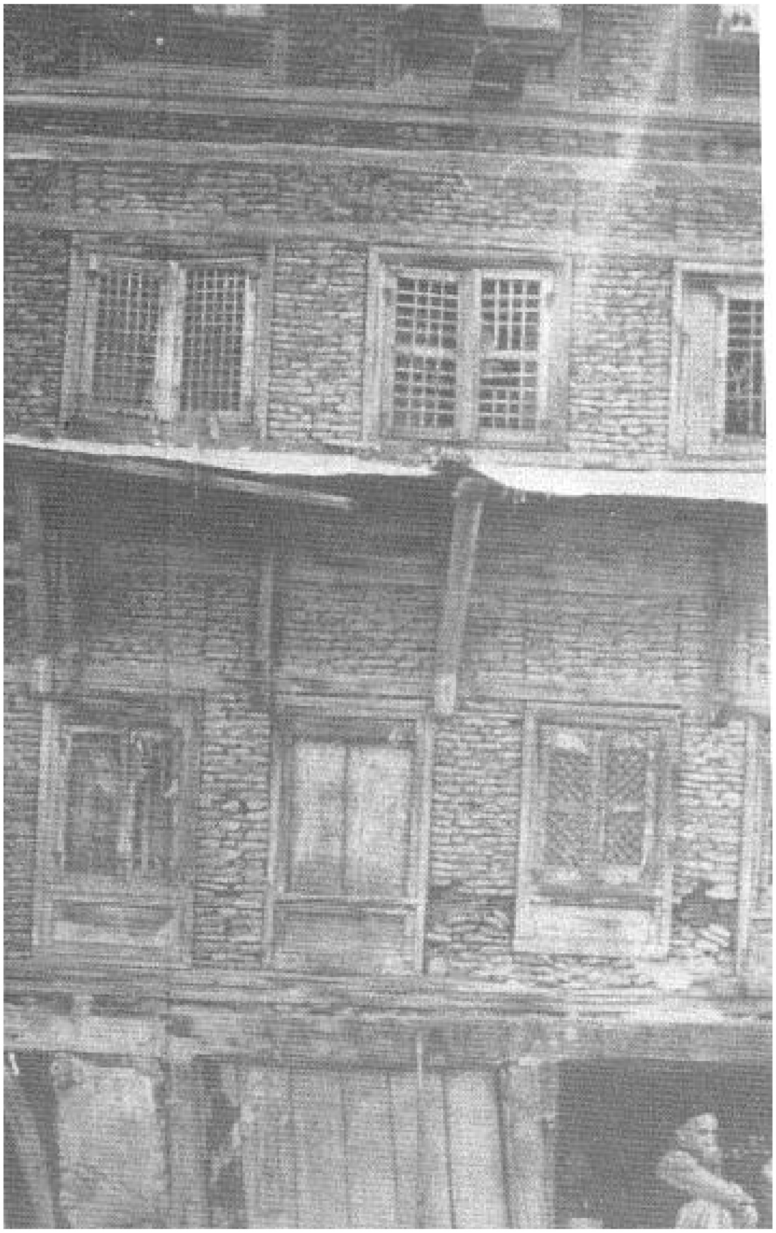

Figure 26 - Slum dwellings constructed from adobe and display effects of earthquake loading.

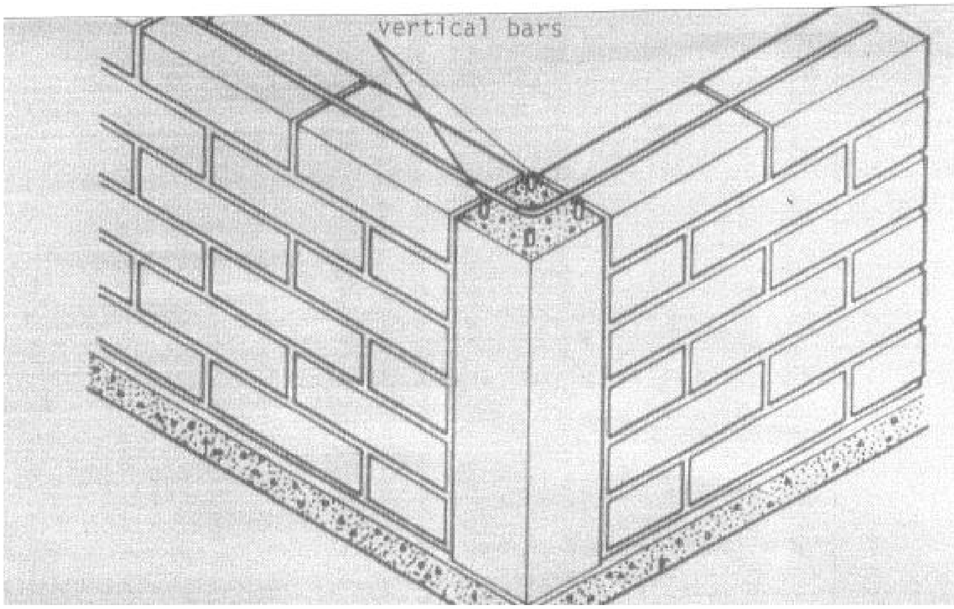

Figure 27 - Newly confined reinforced concrete frame and engineered masonry walls.

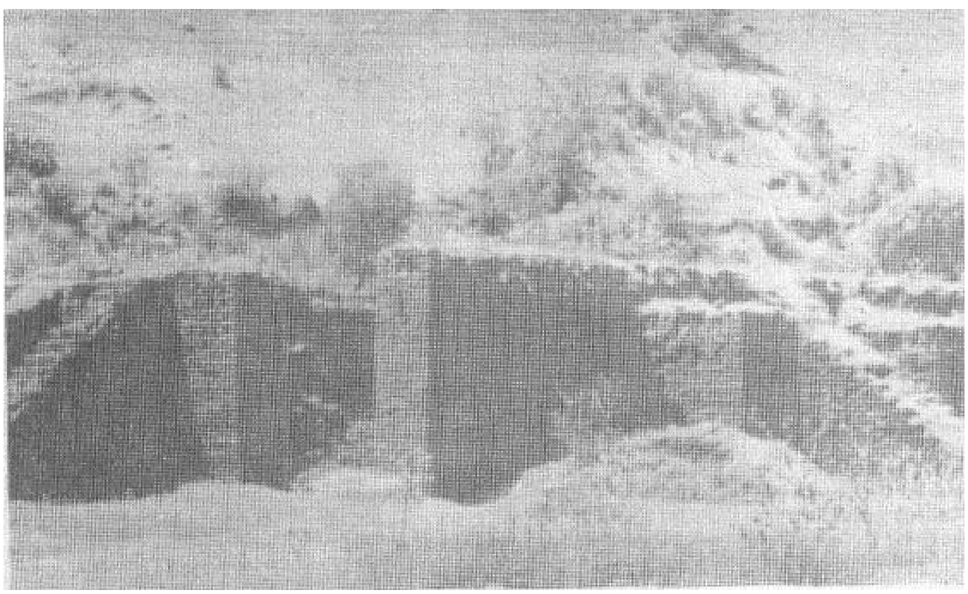
Figure 28 - Ruins of the Inca Empire City of Machu Picchu. Constructed of sun dried adobe masonry bricks.

Figure 29 - Typical hut construction of adobe and stone walls and floor with a roof of straw.

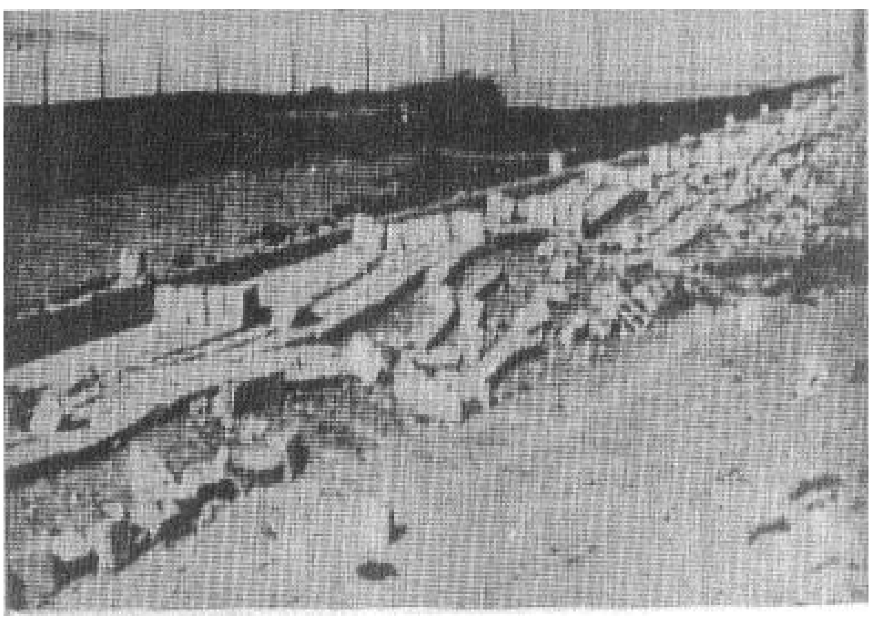

Figure 30a - Damage to adobe walls and hut from seismic loading resulting from the Chimbote volcano eruption.

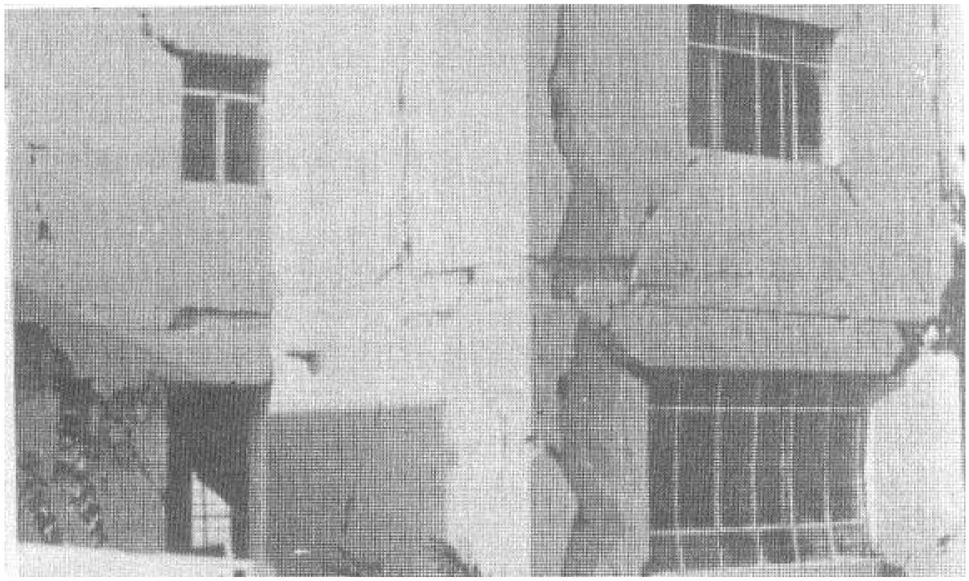

Figure 30b - Building ruins resulting from the Chibute earthquake.

Figure 31 - Reinforced concrete and masonry high-rise construction in Lima. Low-rise reinforced masonry housing units in the foreground.

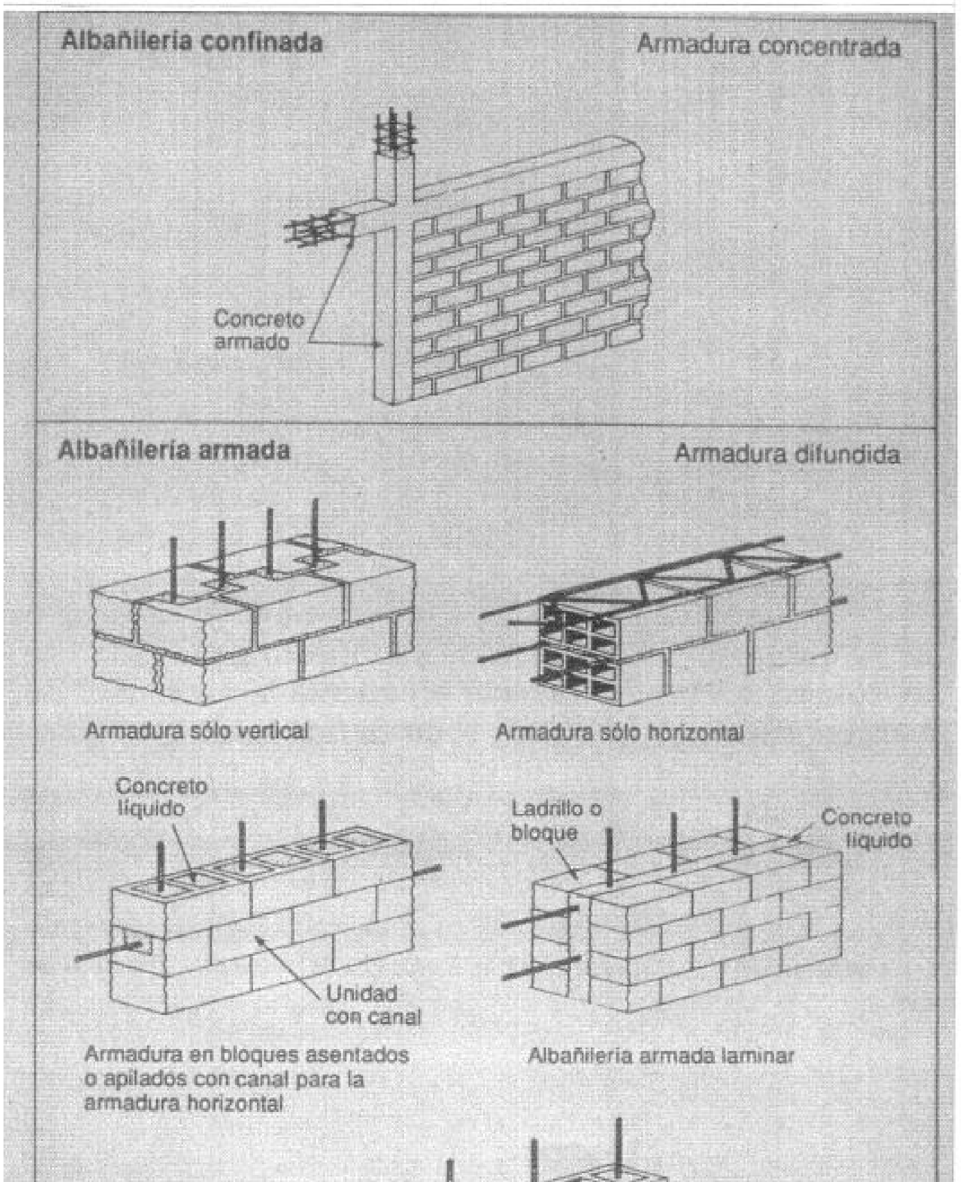

Figure 32 - Construction approaches to reinforced engineered masonry construction.

Figure 33 - Advertisement for Mechano mortarless interlocking block in EL Ingeniero Civil Magazine published in Lima, Peru.

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