These columns of ICJ offer an opportunity to the engineering fraternity to express their views on the current practices in design, construction and management being followed in the industry.

To share your opinion with our readers, you may send in your inputs in about 1500 words via E-mail to editor@icjonline.com

What ails old buildings in Mumbai?

C.S Suryawanshi

There are numerous old composite buildings in Mumbai constructed with wooden/steel frames and bricks, which are in acute need of repair and restoration. In this paper, the author outlines the reasons why buildings become unfit and provide some typical construction details that are found in old composite structures. It is concluded that a holistic approach should be taken for the repair of these buildings.

The phenomenal growth of industries in Mumbai coupled with its pioneering position in the field of textile manufacture, since over a hundred years, has caused an influx of migrants into this city. The unabated migration to the city has created severe housing shortage. It is reported that nearly 50 percent of the city's population stay in slums and squatter settlements. This unprecedented growth has created numerous social and health problems. The Rent Control Act has been the most commonly blamed factor for deterioration of the housing stock. Since 1915 a variety of acts have been imposed, partially lifted and again reimposed with limitations on rents with reference to types of lettings and real estate rates.

With certain modifications Bombay Rents, Hotel Rates and Lodging House Rates (Control) Act 1944 was brought in, and since then the already existing housing shortage continued to be acute. An important feature of the act was that, the landlord cannot charge any unrealistic rent to the tenant, other than the standard rent, and has to keep the premises in tenantable conditions. Due to the pegging down of the rents to the 1940 level, the landlords found it unrealistic to maintain old buildings as the prices of building materials and wages have risen phenomenally, and they were left with the meagre returns after payment of 37 percent of the current rate as municipal taxes.

Thus, as the landlords were unable to carry out repairs as they were considered to be unfeasible within the framework of existing rent and its permitted increase, old buildings were therefore left unattended leaving them in potentially-dangerous position, occasionally leading to collapse, especially during monsoon.

A study undertaken by a local institute some years ago revealed that 90 percent of the dwellings in Greater Mumbai were rented and only 10 percent were occupied by their owners. Nearly, 80 percent of the low income house holds live in *chawls* and nearly 90 percent of them dwell in one room dwellings whatever be the size of their dwelling and house hold. The magnitude of the problem becomes all the more evident when it is realised that the bulk of the population belongs to the low-income group and is unable to undertaken even basic repairs. In recent years, certain attempts have been made to reconstruct of old buildings. However, it was observed that the low-income group tenants are not in a position to bear the burden of outgoings mainly in the form of municipal taxes, even when tenants were offered to them free of cost.

Applying the term 'faulty building' to such structures is a harsh judgment for houses that may be a century old and are still standing in a more or less sound condition. Moreover, the principles of building, then practised were also different. Today, using timber embedded in brick wall (constructed in lime mortar) may not be plausible, but it served these buildings well, going by the fact that some of them are still standing.

Many of such buildings are still sound and standing because the safety factor applied in their design was quite high. Considering the level of building knowledge at that time and local exposure conditions, the use of timber, bricks, lime, mortar, etc was adequate, even if one allows for the fact that the sizing of the elements was perhaps a matter of tradition rather than understood as a design principle. Had these buildings been maintained properly, the current stage of deterioration would not have arisen.

Why buildings become unfit?

Old buildings become unfit for habitation as a result of one or more of the following factors.

(i) *Neglect of normal repairs:* Buildings reach a dilapidated state after routine repairs have been neglected consistently over a period of time. This neglect can pose an immediate threat to the occupants (exposed joints in a brick wall, for instance, can also cause an injury) and can eventually lead to a structural weakening of the whole building.

(ii) *Instability of the structure:* Widening cracks in the wall, a low creaking sound from wooden beams or posts, progressively noticed sagging of beams , may constitute an early indication of a loss of structural integrity.

(iii) *Dampness:* Dampness is another factor that can lead to serious problems in buildings. A damp patch is usually noticed near the water closet (WC) and bathroom area. Leaky joints in the water supply and drainage systems are very often responsible for walls suffusing with moisture. Discoloration and peeling off wall plaster are sure indications of dampness.

If unattended, the moisture is liable to travel towards the structural wooden or reinforced concrete members and enhance their decay.

(iv) *Internal arrangement:* Positioning heavy furniture or machinery near the walls may sometimes induce a shear force in addition to the dead weight already sustained by the floor supporting system. Due to this, the wooden members in the walls may start sinking at the wall junctions.

(v) *Change of function:* In cases where residential structures are being used as commercial or industrial establishment, the vibrations induced by the machinery on different floors may induce a wave into the body of the structure and when the response wave of the structure and the forced wave synchronise, the oscillations get induced and the system may sometimes fail as a result of resonance.

The use of a building involves a continuous process of the residents' adapting themselves to its peculiarities. People personalise the space they use, arrange furniture and other fixtures in the manner they please. Changes in the pattern of occupancy, that is, changes like the expansion, contraction or reorganisation of the family are carried out recklessly such that sometimes even structural changes are carried out without considering the stability of the edifice.

Construction details of old buildings

Most of the old buildings in Mumbai were constructed as load bearing-cum-wooden post framed structures. The end cross walls support the load. The intermediate wooden posts (whether free or embedded in partition walls) act as the frame. In the past, the use of well-seasoned timber in the structure to support the flooring and girders was very often resorted to. Wood from Burma was regularly shipped to Mumbai in the form of logs, beams, posts, and rafters were cut to the required size. The wooden posts were embedded in the wall to support the wooden beams, which in turn supported brickbat-coba flooring laid in lime mortar.

The floor was constructed strong enough to support the dead load of flooring material and a live load to the extent of about 200 kg/m^2 in the initial stage. The brickwork provided between the two wooden posts was often constructed with lime mortar. The thickness of the brick wall was usually uniform and devoid of the slenderness concept (a uniform thickness is noticed even upto the sixth floor). The practice of constructing load-bearing walls to increase the buildings stability was also much favoured. With the advent of rolled steel, the use of such joists as girders in flooring became popular, but even then they were supported on wooden posts, the cross joists sometimes did not rest properly on the supporting walls.

Factors of structural significance

Contrary to popular belief, there are occasions when buildings in fact, respond quite significantly to the changes in loading conditions and changes in the environment. To the inspecting engineer, these 'reactions' or 'movements' should be of utmost importance in assessing the building's structural stability. In important structures, special care was taken to allow for such movements. However, in 'ordinary' constructions the problem was often ignored, thus giving rise to consequent problems.

Some important causes of alarming movements in older buildings are:

(i) the use of non-commensurate working stresses without corresponding increase in elastic moduli

(ii) ignorance of slenderness concept

(iii) use of visco-elastic materials.

From the failure of some of the old structures in Mumbai, it was generally observed that the failure or collapse was not because of failure of foundations. Of greater importance was the differential movement between horizontal elements of the superstructure, often between the ground floor and the first floor and between the top floor and the roof. Horizontal movements cause serious disturbances in the supporting columns and walls. Certain factors causing these movements in the structural elements are discussed below.

Elastic properties of materials

Bricks, like other ceramic materials, are characteristically brittle and their stress-strain relationship is linear upto the point of fracture. The modulus of elasticity, E, of bricks ranges from 3.5 kN/mm^2 (for low strength) to 35 kN/mm^2 (for high strength bricks).

In respect of brickwork, which is an assemblage of lime mortar and bricks, the data on elastic properties is rather scanty, and the problem is further complicated by the non-linear stress-strain relationship. Typical values of E for brickwork may vary from 1 kN/mm^2 to 20 kN/mm^2 for low strength and high strength brickwork. In respect of wood, which is highly anisotropic material, its strength and elastic modulus are higher in a direction parallel to the grains than in the radial or tangential directions. E varies considerably with different varieties of wood. It is high for hard woods like teak and ebony and lower for soft woods. Moisture content (MC) in wood, affects E value considerably. Usually, E is inversely proportional to MC.

Typical E values for soft woods in longitudinal direction range from 3 to 5 kN/ mm^2 at 20 percent MC to 15 kN/ mm^2 at 2 percent MC. For hard woods, it ranges from 10 to 20 kN/ mm^2 in the direction of the grain and the value at right angles to the direction of the grain is 1/20 of the longitudinal value. As against this, the value of E for steel is about 200 kN/ mm^2.

Movements in walls and columns

Generally, walls and columns carry compressive loads.

Columns and walls buckle under eccentric or high compressive loads when they become laterally unstable. The amount of movement in the lateral direction can be assessed when permissible material stress is related to slenderness ratio (which is defined as a ratio of effective height to the least lateral dimension). In slender walls where the bulging exceeds 10-12 mm, it is recognised as the beginning of structural failure.

Wooden posts acting as columns are also subjected to instantaneous deflections.

The differential modulus of elasticity of brickwork and the varying moisture content (MC) in the wooden post make the system behave independently and cracks may get formed at the junction of the two.

Movements due to creep and moisture

Building materials, when subjected to sustained loads undergo instantaneous, elastic deformation, followed by a time dependent deformation which is known as creep.

In porous materials like bricks and wooden members which are capable of absorbing or giving off moisture, the creep strains are closely linked with moisture movement. Moisture movement leads to progressive contraction or expansion of the brick and wood-work, which in turn causes adjacent plaster to peel off and fall, exposes the joints or causes cracks (in wood) depending on the type of the material. In long-term movements, the magnitude of moisture strain is not negligible when compared with strains caused by loads.

Movement in walls

In brickwork, creep depends upon various factors including industrial strengths of the bricks and mortar, the moisture absorption capacity, the stress level, temperature, humidity and age at loading.

From a comparative study, it has been revealed that 20 to 40 percent of the combined elastic and creep strain occurs in the bricks. Bricks account for 85 percent of the height of the wall so the strain in the bricks will be comparatively small.

Bricks sometimes also undergo reversible expansion and contraction, mainly due to moisture movement. Superimposed on this small movement there is a larger irreversible expansion that takes place over a long period. This tendency is prone near water carrying sources in every building, that is, near the water closets and bathrooms. Load bearing walls as well as the ceiling systems are badly damaged and deterioration is further enhanced.

Movements in flooring system

Beams, whether made of wood or steel or of composite materials, suffer creep strain in bending, that is, in flexure. The mortar in the body of flooring in contact with beams, loses its bond with the skin of beam and peels off and this is the first indication of flexural distress.

Experience has shown that visco-elastic building materials show substantial changes due to creep and moisture movement over a long period. This is exactly what happens to old buildings. In Mumbai, ceiling beams were also found to have lost bond with the mortar. The continuous removal of mortar even forms holes in the floor, which constitute a serious warning of the likely eventual collapse of the floor as a whole.

Temperature movement

Buildings in Mumbai are not subject to frequent fluctuations in temperature. However, on the eve of the monsoon (May to June) the temperature changes may induce thermal stresses in structural members exposed to the sun. When the thermal stress in the plaster exceeds the tensile strength of the mortar, the surface cracks. The plaster loses its bond with the mortar in the joint and bulges out — exposing the joint. The exposed joint forms a passage for further entry of deteriorating agents.

Surface moisture travels through the exposed joint and disfigures the internal surface causing the plaster to fall. The moisture in the brickwork is absorbed by the adjacent wood supporting the floor assembly, leading to the decay of the end of the wooden support.

The decayed ends of the wooden beams continue developing cracks and create a clear gap between the wall and the flooring. Some times, this gap shows as a dip (a sunk area) in the floor. This acts as a warning to the occupants. When the moisture leaves the wooden member, the residual (already reached service strain) longitudinal strain in the wood causes a noise, which is a sign that the wood cannot bear even the existing load. However, this noise goes unheard in the day-to-day commotion.

Dynamic movements

Many buildings adjacent to roads and railway track are subject to forced vibrations. The effect of movement due to vibration is particularly serious in tall, slender buildings, where displacement of several centimetres can occur at the upper floor levels. Vibration induces an additional movement to elastic and time dependent deformations.

Static deflection may occur under a steady force and it is mainly responsible for inducing lateral movement, in addition to the other movements, in internal panel walls. Further, external load bearing walls too get badly affected by this type of movement.

Failure mechanism

From the foregoing discussion, it will be seen that movements in buildings, due to one or combined effects are of prime importance, and have a serious consequence at the end.

The movements induce stresses and strains in the structural elements of the building. The time dependent strains are more influenced by addition or depletion of moisture content in the materials having affinity to water.

Wood is a single structural element which is most susceptible to bending and compression and thus deformation. It is possibly the only building material subject to severe deformation. When wooden posts are embedded in, or placed in contact with, visco-elastic, hygroscopic building material like a brick wall constructed in lime mortar, the wall cannot structurally sustain a load other than its own and due to creep strain can be deformed causing a lateral thrust on the butting wooden post.

External walls act partially as load-bearers and as enclosures of the wooden posts. Water from rain or nearby leaky WC joints can disturb the composition of the walls. Temperature strain induces stress in excess of the one, which can be borne by joint covering media, that is, plaster. The plaster crumbles, making a through passage for subsequent rainwater to gain access to the wooden beams and posts, thus increasing their moisture content.

The moisture in the wood causes it to decay. The ends of the beams and posts begin to decompose as a result and leave the bearings, causing continuous cracks above and below the floor level. This is the stage when a chain of reactions gets set in and steadily progresses. The collapse of the structure is generally initiated at the junction of the wall and floors and allows the partition walls to crumble. In many cases, the end walls are seen standing showing the bearing location of the decayed wooden rafters requiring repair.

In some cases, where steel has been used in the flooring system, the wooden posts embedded in the partition walls give way causing the girders to leave the bearing at the central supports and cave in leading to the ultimate collapse of the system.

New over old

Very often during repairs, old structural members are provided with an additional load of new materials. This excess load surpasses the residual moment of resistance set in due to elastic behaviour and the situation advances towards the collapse point.

Two similar looking items, (old and new) having dissimilar modulus of elasticity behave independently and induce an elastic strain that causes movements. During repairs the cross walls are frequently replaced and provided with RC beams to rest on and act as cantilever, counter weight. This breaks the cross wall's lateral link in the walling system due to differential stressing. The chain which used to support the interacting strains is disturbed leading to the possible collapse of the structure. The progressive chain of reactions once set in, cannot be stopped unless the structure is demolished in order to avert accidents or damage to adjoining property.

Conclusion

The following points should be kept in mind by engineers dealing with repairs to old composite structures.

(i) One should not carry out piecemeal repairs; structural repairs carried out, in parts, to the floor, for instance, break the interactions present internally in the old structure. The old (not replaced) floor may start behaving independently, inducing subsidence moment at other end.

(ii) If a crack to the floor wall junction and an adjoining wall is noticed, it is a clear indication of progressing chain reaction which could lead to a collapse in the near future.

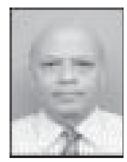
(iii) In the case of external walls, bearing cracks — initiated due to elastic, creep, moisture or dynamic movement noticed to be running diagonal to, or separating the wooden post junction — suggest the wall needs total demolition and not partial replacement.

(iv) Overloading of the existing structure should be avoided. In fact, attempts should be made to reduce the loading

(v) It is essential to adopt a holistic approach in the design, repairs and reconstruction of old buildings.

References

1. Suryawanshi, C.S. Old dilapidated buildings: The mechanism of collapse, *Real Estate Housing Magazine*, pp. 29-41.
2. Addleson, L. *Building Failure, A Guide to Diagnosis Remedy and Prevention*, The Architectural Press 1982.
3. ______*Defects in housing Part-3 repair and modernization of traditional built dwellings*, Association of Metropolitan Authorities, March 1984-1985.
4. ______*Assessment of damage in low rise buildings with particularly reference to progressive movement*, HMSO, Building Research Establishment Digest 251, 1981.
5. Eldridce, H.J. *Common Defects in Buildings*, HMSO 1976.
6. Hodgkinson, A.J. *Hand Book of Building Structures*, second edition, Structural Press 1983.



Dr C.S. Suryawanshi obtained his doctorate from the University of Amravati, Maharashtra in 1995. He holds postgraduate degrees in structural engineering, law and construction management. Formerly, he was chief engineer (PWD), Maharashtra. His doctoral work was related to renovation, restoration and rehabilitation of old buildings constructed during British era in island city of Mumbai. He is a structural consultant and contract specialist, presently working as a senior consultant in Mumbai.

• • •