International Journal of Advanced Engineering and Management Research

Vol. 5, No. 05; 2020

ISSN: 2456-3676

COMMON REINFORCED CONCRETE BUILDING CONSTRUCTION DEFICIENCIES IN AFGHANISTAN AND RECOMMENDATIONS- A REVIEW ARTICLE

Mojeeburahman Mashal[1]
[1]Structural and Earthquake Engineering, Lecturer, Kabul Polytechnic University, Kabul, Afghanistan

ABSTRACT

Many parts of Afghanistan including densely populated cities such as Kabul are threatened by strong earthquakes. While earthquake destruction is mostly owed to the failure of civil engineering structures, deficient construction practice may further increase the susceptibility of structures to damage and even collapse. However, properly constructed buildings and other structures can help us minimize, if not completely eliminate, earthquake destructions. This review article discusses commonly shared important reinforced concrete building construction deficiencies in Afghanistan that are sufficiently critical that can compromise building integrity and structural performance of main force resisting systems during extreme loading conditions. The deficiencies elaborated further in this article include (1) Cutting/drilling of hardened concrete for inserting new member, (2) Confining infill walls -unintentional confined masonry type construction, (3) Offset columns between floors and Improper building framing, and (4) Inadequate footings/ foundations of buildings. The deficiencies are documented through visual inspection of numerous buildings during their construction. This article concluded that all of these critical deficiencies can result in increased vulnerability of these buildings during earthquakes. Such vulnerable buildings are likely to sustain excessive damage and even collapse during moderate to large earthquakes that will also be accompanied by increased causalities. Recommendations are made at the end to address reinforced concrete buildings construction deficiencies and ultimately to mitigate failure risk of buildings during extreme loading events.

Keywords: Afghanistan, Reinforced Concrete, Building, Construction, Deficiency, Earthquake

Introduction

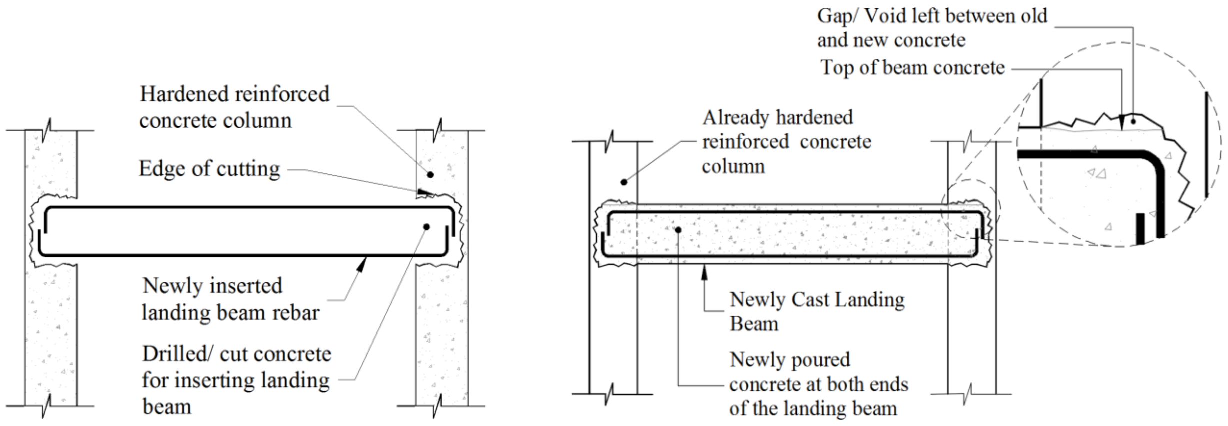
In the past two decades, countless reinforced concrete buildings in the form of houses, residential apartments, offices, business centers, religious centers, towers, hotels, gyms, educational centers, military facilities and many more are constructed especially in populated cities in Afghanistan. Some of these buildings are constructed by the government or foreign donors while most of the buildings are owned by individuals and constructed for housing or business purposes. Most of these privately owned buildings are constructed in planned and unplanned areas where local building authorities such as municipalities are not sufficiently involved to issue permits and oversee design and construction activities. Even in planned areas and with municipal construction permit, there is no any mechanism to monitor and quality control construction activities of these privately owned buildings. Because of this gap in law enforcement, a large portion of these buildings are not constructed according to the accepted construction standards and technics. This substandard construction on one hand and the potential of occurring of moderate to large earthquakes in many parts of the country on the other hand pose serious threats to the life and infrastructure especially in densely populated cities in the country. Additionally and apart from construction deficiencies, most buildings are not properly designed against earthquake loads [1] that further increase uncertainty on adequate performance of these buildings during large earthquakes. Recently the magnitude 4.4 earthquake of Paghmān, Kabul on July 06, 2020 alerted residents there and raised concerns about future larger earthquakes and the performance of these buildings.

In this review article, the most critical deficiencies (apart from the many minor defects which are not of great concern for the structural performance) that are common during construction of reinforced concrete buildings are discussed. The deficiencies were spotted during a relatively lengthy period of visual inspection of numerous reinforced concrete buildings during their construction. Deficiencies of the same nature were found among many buildings that made it possible to classify them in different categories. These deficiencies are: (1) Cutting/drilling of hardened concrete for inserting new member, (2) Confining infill walls - unintentional confined masonry type construction, (3) Offset columns between floors and Improper building framing, and (4) Inadequate footings/ foundations of buildings due to increased bearing pressure beneath the foundation.

Although there may be many other minor technical defects during construction that may not be critical to structural stability, the deficiencies discussed in this paper are critical as they may compromise overall performance of the structural system and sustain large damages to the building during earthquakes. For instance, cutting hardened concrete column to insert stair landing beam can result in substantial reduction in load carrying capacity of the column due to the damage (that is elaborated later) inflicted to the column, while stairs are designed for much higher live load (according to ASCE 7[2]) compared to serving floors. Elaborating these deficiencies, it is concluded that all of these common critical deficiencies result in increased vulnerability of these buildings during earthquakes. Failure of such deficient building increases causalities and economic losses.

Deficiency Type I: Cutting of hardened concrete for inserting new member

In search for common construction deficiencies in reinforced concrete buildings through visual inspection, it was found that in many buildings a portion of already hardened concrete member was drilled and cut to insert reinforcement of new member that was missed or intentionally left for ease in formwork and construction at all. A very common scenario was cutting part of the columns at their mid heights to insert reinforcement of stair landing beam. In one instance, the author observed a complete removal of the hardened concrete from the whole cross section of the column leaving only rebars to supporting the upper half of the column during insertion of landing beam. This deficiency is further elaborated here. Figure 1 and the accompanying Photo (1) show this type of deficiency. In Figure 1 (a), the already hardened column is drilled/ cut to insert landing beam reinforcement bars that were intentionally or intentionally missed during column casting.



(a) (b)

Figure 1 Deficiency Type I (a) Hardened column is drilled/cut and landing beam longitudinal reinforcement inserted. (b) Landing beam concrete is poured, a Gap/ Void is created due to concrete setting, concave up drilling/ cutting and concrete shrinkage.

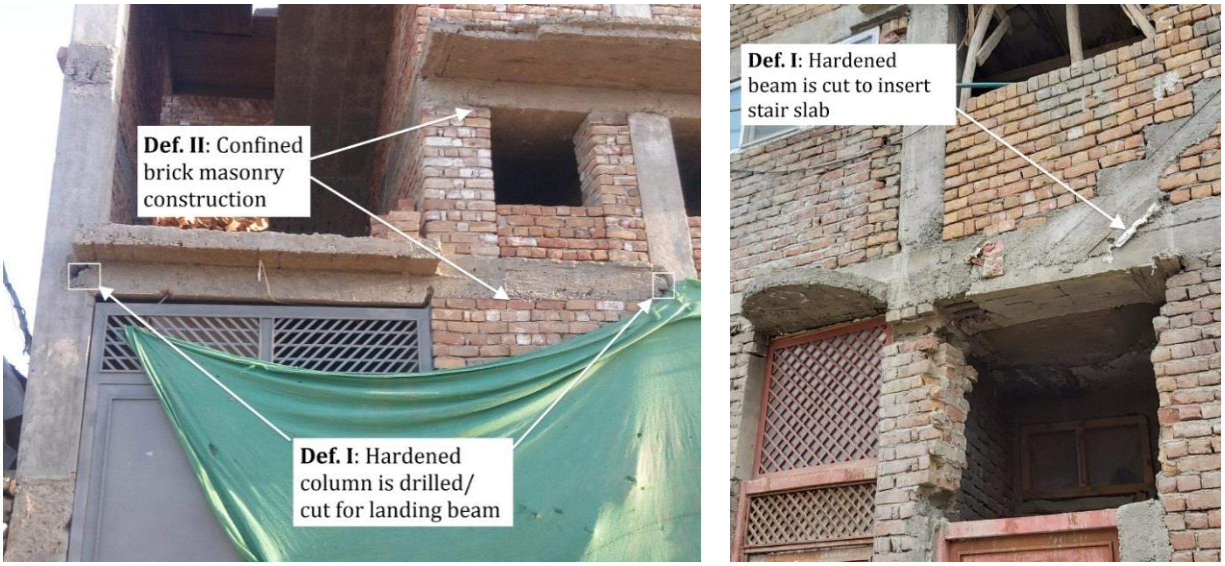
Stairs are designed for a live load of about three times that of the serving floors according to ASCE 7[2]. Considering this and the fact the stairs most likely receive highest load demand during emergencies such an earthquake, deficient construction of the main supporting elements compromises the structural stability of the building and makes it highly vulnerable during extreme loadings.

Specific to type I deficiency depicted in Figure 1 above, the following resultant drawbacks can be noted:

1. It is most likely that the newly added landing beam longitudinal reinforcement may not develop sufficiently at its both ends due to confined space after drilling/ cutting of the column.
2. Most likely a Gap/ Void (see enlarged part of Figure 1 (b)) is created at both ends of newly inserted landing beam after pouring its concrete due to concrete setting, possible concave up drilling/ cutting and concrete shrinkage. This gap has considerable negative impact on the performance of beam-column joint:
    a. The gap results in absence or lack of bond between already hardened column concrete and the newly poured beam concrete. This lack of bond substantially reduce (since essentially the cross-sectional area of column is greatly reduced) flexural and axial capacity of the column.
    b. The gap may lead to compressive yielding of column reinforcement due to lack of concrete to support axial load of the column. Yielding of column rebar may lead to creation of a plastic hinge at the joint.
    c. Due to the lack of bond (even lack of bond may be present outside of the gap zone due to cold joint action and without using bonding agents) between already hardened column

and fresh beam concrete, the beam may actually perform more as simply supported beam (or at least with partial fixity) rather than with fixed ends.

3. In addition to the above, the drilling/ cutting of freshly hardened concrete (that most likely is not of 28 days) itself harms column concrete.



(a) (b)

Photo 1 (a) Hardened column in a five story residential building is drilled/ cut and landing beam inserted (Photo from Mr. Naeem Sorosh, 2018). (b) Hardened beam is cut/ drilled at a four story residential building and stair slab is inserted (Photo by the author, 2020)

Drilling/ cutting of hardened concrete to add new member is a common construction deficiency shared among many newly constructed buildings in Afghanistan. Buildings with such deficiency are highly vulnerable especially during extreme loading events such earthquakes.

Deficiency Type II: Confining Infill Walls- Unaccounted for Confined Masonry Construction

This type of reinforced concrete building deficiency is more widespread than any other deficiencies discussed here. As with the confined masonry construction, in most of the reinforced concrete buildings inspected, masonry infill walls (mostly brick walls) were constructed before the surrounding beams and columns. This is done to avoid the extra formwork needed for these beams and columns and the fact that very little or no cracks are initiated at the interface between wall and beams/ columns during earthquakes.

Confined masonry construction consists of masonry walls and horizontal and vertical RC *confining members* built on all four sides of a masonry wall panel. Vertical members, called *tie-columns* or *practical columns*, resemble columns in RC frame construction except that they tend to be of far smaller cross-section. Horizontal elements, called *tie-beams*, resemble beams in RC frame construction [3]. To emphasize that confining elements are not beams and columns, alternative terms horizontal ties and vertical ties are sometimes used instead of tie-beams and tie-columns. In confined masonry construction, the walls are the main load bearing elements resisting both gravity and lateral loads, while all of the buildings visually inspected were moment resisting frames where walls are non-structural or non- load bearing elements and the load is carried out by beams and columns.

Although confined masonry construction by itself (that is detailed as bearing wall system) has performed satisfactory in past earthquakes in regions of high seismic risks [3], however indeliberately confining infill walls in a moment resisting frame (that is not accounted for in the analysis and design) make the structure vulnerable due to several reasons. It is important to note that all the buildings were analyzed and designed as moment resisting frames without taking confining the walls in to account in analysis and design of the structures. In other words, there is difference between designed system (moment resisting frame system) and constructed system (hybrid load transfer mechanism with both frame action and truss action).

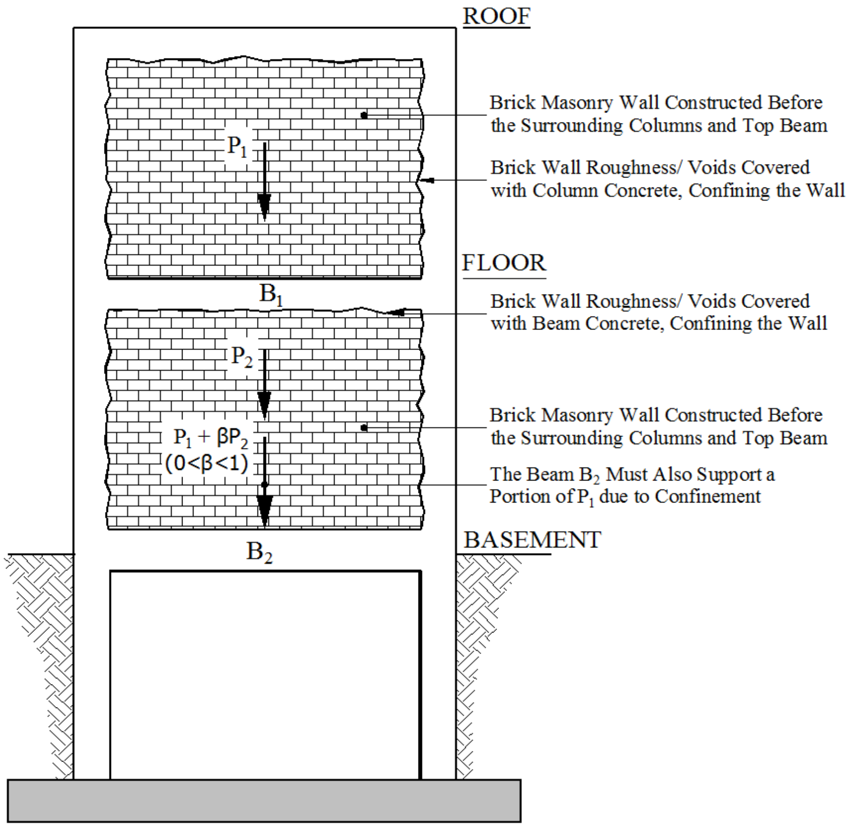


Figure 2 Deficiency Type II: Unintentional confining of the infill walls that is not accounted for in the analysis and design of the structure.

(a) (b)

Photo 2 (a) Confining brick masonry walls (by columns and beams) in a school building (Photo from: https://www.facebook.com/MUDLAFG/photos/a.157128744449109/1539201206241849/?type=3&theater). (b) Confining brick masonry wall by beam (Photo by the author, 2020)

1. Confining infill walls in most cases modifies stiffness distribution of the building due to inappropriate/ unsymmetrical locations of confined infill walls. Stiffness modification results in redistribution of forces in the structure leading many times to overstressing of members that were barely adequate for resisting the loads before stiffness modification (i.e. when the infill walls are not confined).
2. Confining infill walls changes center of rigidity of the structure and hence results in larger eccentricity and ultimately increased torsional irregularity. This increased torsional irregularity that was not accounted for during analysis and design (i.e. it was designed as moment resisting frame where infill are considered not be confined) further stresses structural elements.
3. In fairly moderate number of cases, it happened that infill walls were confined in one or more upper floor(s) while not confined or no walls located at all at a lower floor. This scenario results in transfer of large amount of gravity loads from the upper floors to the beams in lower floor due to relatively lesser rigidity of the beams compared to that of walls. This again overstresses the lower beams as the actual scenario was not accounted for in the analysis and design of the building. As per 12.4 of ASCE 7[2], the loads further increases due to the effects of vertical component of earthquake loads. This is depicted in Figure 2 above.

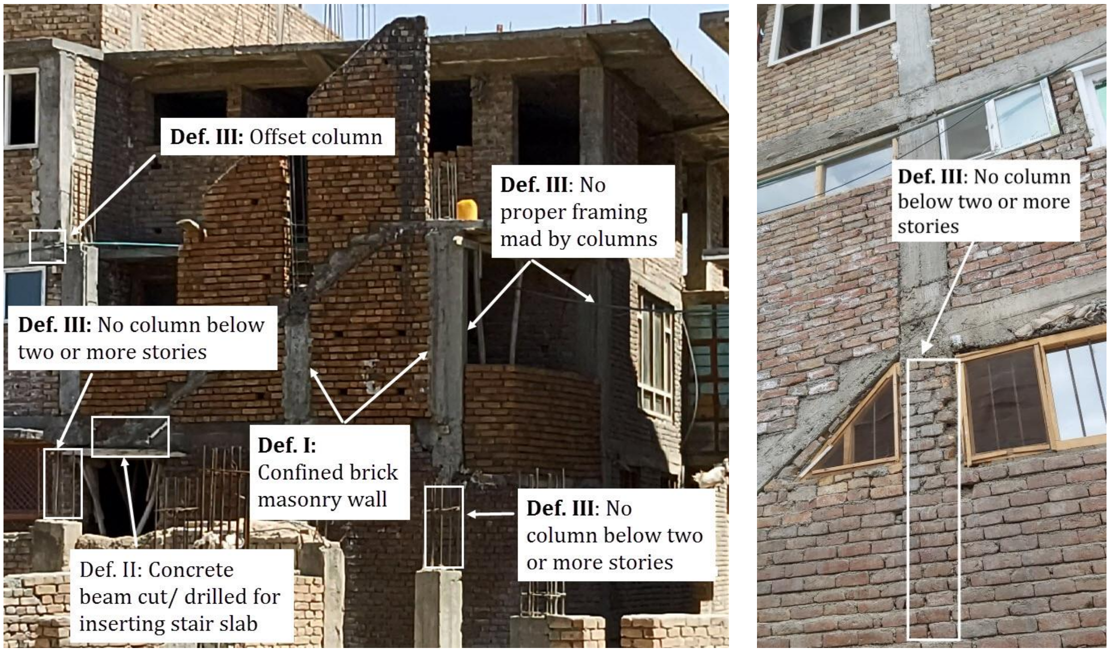
In addition to the above, confining infill walls have other detrimental effects such as out-of-plane collapse, short column effects where infills are raised only up to a partial height of the columns and soft-story effects where a story has no or relatively lesser infills than the adjacent stories. This later is of great importance as most of the inspected building had their ground stories without infills (except at boundaries) to facilitate parking. Confining infill walls that are not accounted for during design and detailing put large concentration of ductility demand in a few members of the structure and can significantly alter the collapse mechanism [4]. Soft story irregularity is one of the main reasons of the building damage during past earthquakes and has been mentioned in almost all reconnaissance reports [5].

Deficiency Type III: Offset Columns between Adjacent Floors and Improper Building Framing

Inadvertent/unaccounted for offset of columns between adjacent floors and the resultant improper building framing was another common construction deficiency spotted during the visual inspection of reinforced concrete buildings. Although columns can be offset due compelling reasons at the design stage, it should be insisted that all the offsets inspected were inadvertent and not accounted for in the design of the building. Unsymmetrical column cross sections and column offsets between adjacent floors can cause the load path to deviate from the centroidal axis of the column, thus, causing unexpected stress distributions among structural members [6]. Column offset that is not accounted for in the design can overstress beams and columns at the joint where the offset is located. In an offset, a portion the upper column load is transferred in the form of shear force to the beam running into the offset joint directly below the offset column that may be very large shear load for the beam if not designed for it properly. It is also to note that shear failure is critical and brittle failure that is accounted for in design by using smaller resistance factors (or larger safety factor if ASD is used).

In addition to the shear overstress of beams, offsetting column that is not accounted for in design hugely reduces the axial and bending capacity of the joint as these are proportional to the overlapped area of the two offset columns at the joint. Beside this, poor detailing in beam-column joint (that is most probable) and detailing of stronger beam than column further negatively affects the performance of the beam-column joint.

In many other instances, reinforced concrete buildings were constructed such that no complete and appropriate frame over the height of the structure could result. Columns were removed in a lower floor for any reason but provided in upper floor(s) that again in addition to increasing torsional irregularity results in creation of a soft story mechanism. Soft story buildings are extremely susceptible to earthquake induced damage and even collapse [7]. See Photo 3 below.



(a) (b)

Photo 3 (a) Multiple construction deficiencies in a four (or more) story reinforced concrete building (Photo by the author, 2019). (b) Deficiency type III, column at a lower story is removed (Photo by the author, 2019)

Deficiency Type IV: Buildings' Inadequate footing and foundation

As was previously mentioned, the recent rapid urbanization and increase in population in Afghan cities (especially Kabul) resulted in a high demand for land use and housing in the city. Because of this increased demand, builders and buildings' owners tend to maximize building footprint area and minimize essential auxiliary areas such as parking, landscaping, roads, streets and adjacent structure.

Per author's experience in structural design of buildings, in most cases the maximization of building area results in placing end columns of buildings very close to the adjacent property line so that there is very small portion or no foundation/footing beyond the outer face (s) of the outermost columns. Although based on geometry, height of the structure and supporting soil condition, this limitation in size of foundation shall not be source of a major concern, however, for tall building founded on poor soils; the limited width of footing/ foundation beyond the outer face of building results in concentration of bearing pressure beneath the foundation above the bearing capacity and sometimes in negative pressure during application of lateral loads and therefore should be accounted for properly. The use of deep foundations is also not common in the country because of the increased construction costs and involvement of relatively advanced technical expertise and construction technology which are not widely available. This situation adversely affects the structural soundness of newly constructed buildings and business towers.

The shallow foundations especially those adjacent to the property line in most of the buildings are vulnerable to different failure modes associated with inadequate footing area at outside and corner columns including bearing capacity, differential settlement, punching, and strength of foundations. This scenario is even getting worst during earthquakes as it further stresses or puts in tension the outermost footings/foundation. Softening or failure of the ground due to redistribution of pore water pressure after an earthquake which may adversely affect the stability of the foundation post-earthquake is another common drawback of such inadequate footings/ foundation.

Conclusions

This review article elaborated on common critical construction deficiencies of reinforced concrete buildings in Afghanistan. Four types of important unfavorable construction practices or deficiencies that can affect overall structural performance of the main force resisting system during extreme (especially lateral) loading events such as a strong earthquake were discussed. These deficiencies were investigated through visual inspection of numerous buildings during a relatively lengthy period of time by the author. The included were (1) Cutting/ drilling of hardened concrete for inserting new member, (2) Confining infill walls -unintentional confined masonry type construction, (3) Offset columns between floors, and Improper building framing, and (4) Inadequate footings and foundations of buildings.

Cutting/drilling of hardened concrete members mostly for inserting new reinforced concrete members that were missed intentionally or unintentionally was one of the construction deficiency shared in numerous buildings. This deficiency as previously elaborated compromises the load carrying capacity of both the old member and the newly inserted member in many ways.

Unintentional or unaccounted-for confining of brick masonry infill walls was observed as another most common deficiency during construction of reinforced concrete buildings. Confining infill walls without accounting for it during design can have detrimental effects such as overloading some structural members, increasing torsion in the building, soft story effects and short column effects. These are frequently blamed for damages in post-earthquake damage field investigations reports

Offset (eccentric) columns and improper building framing was another common construction deficiency. Numerous buildings with moment resisting frames were observed that lacked column(s) in a lower story while there were columns in upper stories. This situation causes overstressing beams (mainly in shear) and creates soft story mechanism and increased torsional irregularty.

Lastly, the author observed construction of reinforced concrete buildings with inadequate footings/ foundations due to increased bearing pressure above the bearing capacity and sometimes negative pressure under footings/ foundation. Without careful consideration (which is the case for most buildings observed) limiting the width of footing/ foundation beyond the outer face(s) of column(s) due to adjacent property line results in various unwanted situations that can compromise stability of the structure.

Overall, this paper concludes that a considerable amount of reinforced concrete buildings in Afghanistan are constructed with critical construction deficiencies such as cutting/drilling of hardened structural members, unintentional confining of masonry infill walls, eccentric column and improper building framing, and inadequate footing foundations that can cause considerable damage to these deficient buildings and can even collapse them during extreme loading events.

Recommendations

The flowing recommendations are made to address the common critical construction deficiencies of reinforced concrete buildings in the country.

1. Cutting/ drilling of already constructed structural member should be avoided at all. This can be done by proper detailing and follow of the construction plans of the building and frequent inspection of the construction activities by qualified engineers.
2. Masonry infill wall that are not bearing type in nature shall not be confined. For this, building framing in a story under construction must be completed first followed by construction of infill walls. A mechanism shall be provided to allow free deflection of flexural members.
3. Columns offset should be avoided unless properly accounted for it in the design. A complete building frame (without removal of columns in any story or without columns deviation that is not accounted for) is needed to anticipate satisfactory performance of the building during earthquakes or other later loadings.
4. Buildings need to have adequate footing/ foundation area so that nowhere the bearing pressure exceeded the allowable bearing capacity and that nowhere the foundation is in tension with the supporting ground.
5. Overall, regular inspection of the construction activities by qualified engineer and local building authorities can greatly reduce the amount and severity of such deficiencies.

Acknowledgement

None.

Conflict of Interest

None.

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