INCESSANT BUILDING COLLAPSES: A CASE STUDY OF TWO FAILED BUILDINGS IN BENIN CITY, NIGERIA

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ABSTRACT

This paper examines the causes of incessant building collapses in Nigeria by conducting structural assessments on two failed church buildings in Benin City, Nigeria used as case studies. Re-construction schemes were developed as remedial measures to repair the failed structures. Implications of the collapse for structural design and construction were discussed and suitable recommendations were made to prevent future incidences. It was however deduced that the major cause of collapse of buildings result from the attitude of stingy or overbearing building developers who in a bid to save money employ quacks or incompetent individuals as structural engineers or contractors to design, supervise and deliver their projects. This gives rise to the use of substandard materials for construction; crude or arbitrary construction procedures and negligence in carrying out proper designs; use of drawings which are either not approved by appropriate Town Planning Authorities or approved without proper validation of the structural details; non-compliance with specifications and details on working drawings; hence failure is inevitable.

Keywords: *Building; collapse; structural design; materials; Nigeria*

INTRODUCTION

Buildings are structures designed and constructed with relevant engineering materials to provide cover from inclement weather conditions or protection against danger (Taiwo and Afolami, 2010). A building can be considered to be of high quality if it meets certain primary needs of its users including provision of security, safety to lives and facilities, convenience as well as the social, psychological and economic fulfilment achieved by occupants. However, there are certain situations where buildings fail to meet the daily needs of its dwellers, as such, causing serious anxiety to stakeholders such as occupiers, owners, developers, government, and physical development planning authorities, resulting in collapse leading from failure. A building, therefore, must be designed to satisfy its functional requirements by ensuring safety to users throughout its service life. However, some buildings do not fulfil their intended purpose during the design life as a result of partial failure to outright collapse of structural components or the entire structure.

As stated by Alutu and Anyata (2008), failure is anything from simple loss of serviceability to outright collapse. In addition, Taiwo and Afolami (2010) pointed out that failure could be seen as an intolerable difference between observed and expected performance which occurs when a structure or its components can no longer satisfy its basic functions. Ayininuola and Olalusi (2004) identified two major types of failure in building; cosmetic and structural. Cosmetic failure results from structural modifications such as renovation or retrofitting operations in the building and this only affects the outlook of the building, while structural failure affects both the outlook and structural stability of the building.

For example, a small crack on a wall may not be considered a failure until it results in large or excessive deflections to other structural components. Roddis (1993) distinguished between defect and failure in buildings. Defect occurs when deflections in a building causes certain amount of cracking or distortion evident in weakened foundation, cracks in floors, walls, and roofs while excessive deflection that results in serious damage to partitions, ceilings and floor finishes is referred to as building failure. Most failures are categorised as loss of serviceability which subsequently involves relevant forms of retrofitting measures by assessing the residual strength of the structure

However, in the case of outright collapse, the building needs to be demolished and reconstructed. Collapse is a state of complete failure, when the structure has literally given way and most members have caved-in, crumbled or buckled; the building can no longer stand as originally built (Dimuna 2010). In other words, whenever a slight structural defect is noticed on any part of a building, immediate repair and maintenance works should be carried out after proper investigation to forestall further deterioration which could lead to progressive collapse.

As stated by Wardhana and Hadipriono (2003), collapse occurs when the entire or a significant part of a structure falls down thereby losing the ability to perform its function. Building collapse may be classified as total and partial collapses. Total collapse implies that several primary structural members of a building have fallen down completely while partial collapse suggests a condition where only some of the primary structural members of the building components have fallen down. Following the incident of the collapse of the ill-famed World Trade Centre (WTC) twin towers in New York on the September 11, 2001, Bazant and Verdure (2006) described progressive collapse as a failure mode of great concern for tall building subjected to fire, internal explosions, external blast, impact, earthquake and foundation movements, and also typical of building demolitions.

There have been several reports in print media and on cases of building collapse around the world. Nigeria is not an exception. In historical times, that is, even before the seventeenth century, buildings failed through formation of a collapse mechanism by the development of sufficient number of cracks on the face of arc-hes, domes, vaults and stones or concrete used to provide long horizontal spans.

These failure could be attributable to outright mistakes, poor construction, inadequacies in empirical rules for sizing of a building and insufficient knowledge of the structural implications of a new building design. As a result, collapses were limited by employing empirical observation to determine the minimum safe ratio, t/l ('t' refers to the thickness or depth of the structure and 'l' its span) and at least, keep the ratio slightly higher than the minimum as well as the excessive use of materials for construction, although this is not economical (Cowan 1989).

In modern days, apart from the fall of the WTC twin towers, a well-known incident which resulted from planned man-made attack; there are a number of other cases around the world. Ronan Point apartments collapse in U. K. when kitchen gas exploded on the 18th floor sending a 25-storey building to the ground in 1968; the 2000 Commonwealth Avenue Tower collapse in Boston, 1971; The Civic Center of Pavia in 1989; and collapse of Murrah Federal Building in Oklahoma City in 1995, where air blast pressure caused the collapse of few lower floors while the upper floors failed by progressive collapse. In year 2000, a four-storey commercial building at 14th and 2nd Avenue in Brooklyn, USA, collapsed and vacant building at 124th Street in the north of Manhattan in New York the partially collapsed in 2007. Similarly, a five-storey vacant apartment building in Manhattan that earlier appeared to be falling apart for months finally collapsed on March 4, 2008. Other notable collapses include an uncompleted building that showed sign of breaking up in central Nairobi, Kenya collapsed in 2006; an apartment building in downtown Baku, Azerbaijan on August 28, 2007; and a twelve-storey apartment building in northern Egyptian port city of Alexandria, Egypt on December 19, 2007; while on 29 March, 2008 in Luanda, Angola, a six-storey police building collapsed with detainees and other people trapped and injured. In May 2008, a wall collapsed at a building site in Farooq Nagar, the suburbs of New Delhi, India; and hotel building consisted of a basement plus three upper floors located opposite Ahmedabad main railway station, Kalupur, India on February 3, 2008 (Heinle and Leonhardt, 1996; Binda et al., 1992; Levy and Salvadori, 1992; Bazant and Zhou, 2002; Pearson and Delatte, 2005; Bazant and Verdure, 2006; Adediji, 2006; Yussuf, 2006; Ismayilov, 2007; Islam, 2008).

Similar cases of collapsed buildings exist across the country. Some recent examples of the most critical cases i.e. those with the greatest number of casualties, will be highlighted. St. Dennis Catholic Church, Bariga experienced structural failure killing 3persons in 2000; also same year, notable Eleganza building in Ikota, Ajah collapsed due to structural failure recording 3 deaths. In 2001, a residential building in Odo Ikoyi, Akure collapsed due to an inferno, but no life was lost; same year, Karunwi Central Mosque, 21 Buhari Street, Mushin fell as a result of structural defect with 7 lives lost. A 3-storey building at Mosadolohun Street, Iba came down in 2002 on account of structural failure leaving 15 dead and several injured. Onyearuegbulem market, Akure gave way in 2003 due to poor workmanship and under-reinforcement of cantilever end of beam although no lives were lost. In 2004, office building at 10, Elias Street, Lagos Island failed due to dilapidation from lack of maintenance, leaving 8 persons dead. The following year, no lives were lost when a residential storey building at Adeniji Adele Street, Lagos Island fell down due to structural defects. Structural elements of the NIDB Building, Broad Street, Lagos Island gave way following a fire incident on the building in 2006 however, no casualties recorded. In 2007, several people died following the collapse of a residential building in Ebute-Metta, Lagos due to unauthorised conversion and poor supervision /materials; while in 2008, due to faulty construction, 13 casualties were recorded in the collapse of an office complex in Abuja. In 2009, due to excessive loading and faulty construction 9 persons died while 21 persons were injured following a building collapse at Ojerinde Street, Idiaraba. In 2010, 23 persons were confirmed dead while 10 were injured when an office complex in Abuja failed due to overloading on the floors. Residential building in Kano collapsed in 2011 due to rainstorm claiming 6 lives. Finally in 2012, due to unsupervised demolition, 2 persons lost their lives in the collapse of an office complex (Ayedun et al. 2012; Fakere and Fadairo, 2012).

The incidents of building collapse within Nigeria in recent past have resulted in the tragic loss of many lives and the destruction of valuable property assets. Within the last two decades, there have been over 40 cases of building collapse across the country recording about 470 deaths (Boye-Ajai, 1995 and Dimuna, 2006)

Quick analysis of their report showed that the proportion of collapses in Lagos compared to that in the rest of the country is highest, over 60%. From an unofficial investigation piloted by the Nigeria Institute of Buildings (NIOB), Arayela and Adam (2001) asserted that the collapse of buildings in Lagos state over the past 45 years (1955 – 2000) far surpasses that in the rest of the country. Analysis of building collapses in Lagos state between years 2000 and 2010 by Oloyede (2012) revealed that year 2006 recorded the highest proportion of collapse representing 24.10%, almost a quarter of the total number of collapses in Lagos over the ten-year period. Although the numbers of collapsed buildings in Benin City are not comparable to those in Lagos, there are still a few similar cases in that state.

The main causes of collapse of buildings in Nigeria as reflected in these reports are attributable to defective structural works resulting from the use of sub-standard building materials (Dimuna, 2010). However, a significant number of collapsed buildings in Lagos are caused by poor/faulty foundation used for construction. This results from inadequate geotechnical and soil investigation tests. Causes of building failures are not limited to these only; a detailed survey will be made to outline other reasons why buildings fail.

The aim of this study is therefore to examine the incidences of collapsed buildings in Benin City with particular focus on analysis of the cause of two failed structures selected as case studies within the City.

CAUSES OF BUILDING COLLAPSE

There are several reasons why buildings collapse. Taiwo and Afolami (2011) observed that the type and complexity of the structure can complicate these reasons. Alutu and Anyata (2008) added that the causes of collapse are compounded by the fact that research focus is more on methodology and resources and construction rather than failure studies. As Parfitt and Parfitt (2007) put it, one remote cause of failure is the neglect of viewing and producing engineering designs from knowledge of failure studies. Whenever there is an incidence of building collapse, information obtained from structural investigations on the failed structure provide more insight into the actual and remote causes of the collapse. Some of the causes are somewhat linked to one another and as such can be carefully grouped or categorised into key factors.

According to Oyewande (1992), 50 per cent of the causes of building failures in Nigeria are attributed design faults, 40 per cent to fault on construction site and 10 per cent to product failure. Yussuf (2006) classified the causes as physical factors, ecological status of the site, composition of technical components, social factors, economic factors, engineering factors, human factors, government policies, and political factor. This is consistent with Akinpelu's (2002) view: environmental changes, natural and man-made hazards, improper presentation and interpretation in the design are major reasons for building collapse. An example of environmental/ ecological factors are deterioration of reinforced concrete resulting from chloride and calcium carbonate corrosion of the reinforcement, cracking caused by overloading, subsidence or basic design faults, and construction defects (Richard 2002).

In a report by Alutu and Anyata (2008), reasons given for the collapse of a number of infrastructural works like GSM masts, buildings, bridges and flyovers include lack of adequate supervision, lack of maintenance, lack of adequate design or no design at all. Analysis of wind-induced failure of a pavilion roof in Edo state, Nigeria showed that proper designs were not carried out to resist the prevailing wind speeds within the building site (Alutu, 2000). Therefore, buildings can come down as a result of sliding and overturning from heavy wind loads, roof uplift or sliding, and building sway (Merritt and Ambrose; Fredericks and Ambrose, 1989). They outlined other factors responsible for the safety and structural integrity of the pavilion: lack of structural design, lack of construction knowledge and procedures, poor workmanship and site supervision and arbitrary architectural specifications.

Another major category of causes of building collapse is human factors or as Dimuna (2010) suggested, man-made factors. These are summarised as: deficient structural drawings, absence of proper supervision, alteration of approved drawings, building without approved building drawings (Town Planning Authority), inefficient workmanship (labour), use of acidic and salty water for construction, the activities of quacks, clients' over reliance on contractors only for decision making on site, approval of technically deficient drawings, illegal alteration to existing buildings, client and contractor's penchant to cut corners and use of substandard materials. In a detailed analysis of these factors by Oloyede (2010) showed that non-compliance with specifications/standards by clients/ contractors; employment of incompetent and fraudulent contractor and use of substandard materials and equipment stood out as three remote causes of building collapses witnessed in Nigeria. He added that this could be ascribed to the parsimonious and arrogant attitude of clients who prefer to direct work on site in the manner that seems best to them which may be very detrimental to the overall project progress and quality of construction work. Apart from the opinion of the public regarding causes of collapse, he assessed the viewpoint of stakeholders in the academia but all three factors pointed out including falling standard of education; lack of continuing professional development and bribery and corruption were considered insignificant.

BACKGROUND TO THE STUDY

Structural investigation into the failure of two church buildings in Benin City is considered in this study. Failure analysis have been performed and presented below.

STRUCTURAL FAILURE OF CHURCH BUILDING I

Church building I, a standard church hall for religious worship, collapsed while the building was still under construction (Figs. 3.1, 3.2 and 3.3) due to failure of the roof truss resulting from professional and technical ineptitude of the site engineer during supervision. Principal as-built dimensions of the church building recorded on site visits revealed that the overall external dimensions of the building was 24m x 30m, the height of the roof truss alone was 6m to 13m and stood at an average height of 9.5mafter installation. The roof truss structure was purely constructed in steel. It was designed as a single span truss with a high pitch angle of 300at the midspan, each simply supported at column heads spaced at 3mcentres. Steel rafters were held firmly atop three shear walls (two at the ends of the building and one at the altar) having same pitch angle as the truss. U-shaped rag bolts were designed to be used in holding down the steel roof truss to the top of each column.

Figure 3.1: *Church building under construction just before failure*

Figure 3.2: *Failure of the roof truss*

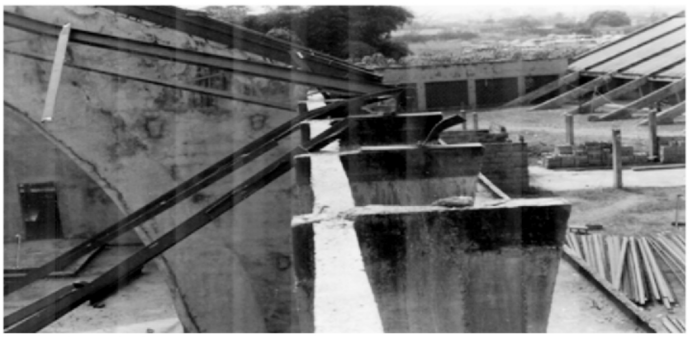

Figure 3.3: *Top of column after failure*

STRUCTURAL ASSESSMENT OF THE COLLAPSE

Following the failure of the church building, a committee of Engineers was set-up immediately to assess the main and remote causes and their findings were that:

1. The roof truss assembly and the substructure/superstructure were satisfactorily designed and detailed by a qualified structural engineer.
2. The professional service of a qualified practicing structural engineer was employed to supervise the construction. How-ever, before the rag bolts were cast and installed, a quack replaced the structural consultant with reasons undisclosed to the public and this act led to the following outcomes:
   - The use of short inverted T-shaped rag bolts tacked with weld at the T-junction instead of the U-shaped rag bolts for which the roof system was designed.
   - The T-portion of the rag bolt was placed parallel to the longer side of the column face and inside concrete with inadequate cover (Fig. 3.4). Rag bolts should have been positioned orthogonal to the longer face of the column to provide the required resistance to hold the truss down and transfer load through the load path down to the base.
   - Concrete cast atop the previously cast columns was shallow. From Fig. 3.5the two bolts shown after failure pulled out from the welded T-portion which was still embedded in concrete.
   - Concrete cast around the rag bolts where very poorly mixed and inadequately compacted; resulting in relatively weak concrete (Fig. 3.4).
3. While the steel roof truss was mounted and fixed to the rag bolts, horizontal reaction from the truss on the bolts in Fig. 3.5caused a large displacement resulting in translational movement of the bolts out of the shallow concrete hence the failure of the roof.

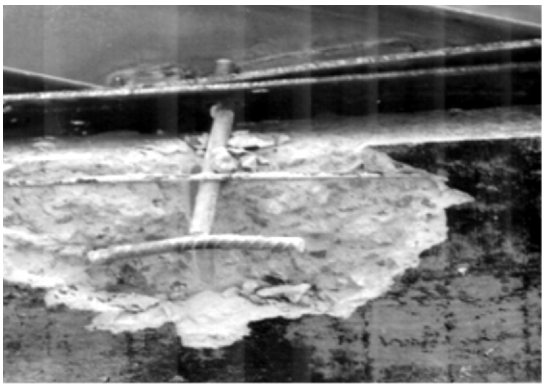

Figure 3.4: *Rag-bolt failure from the top of the column*

Figure 3.5: *Rag-bolt pull out from a very poorly compacted concrete.*

REMEDIAL MEASURES FOR THE COLLAPSE

On the basis of the lessons learned from the collapse of church building I, reconstruction work was proposed and implemented by correcting the ethical, professional and construction errors committed previously.

- The truss support system was reconstructed using properly well-compacted and properly mixed concrete cast to the correct depth as originally designed by the structural engineer (Fig. 3.6).
- U-bar rag bolts formed by bending rather than welding were properly installed by placing the bent bar orthogonal to the face of longer side of the column and held in position with longitudinal bars passing inside the U-bolts, top and bottom (Fig. 3.7).
- The steel roof truss was reconstructed and remounted on the column heads based on the original design and detail provided by the structural engineer. Supervision was done by a qualified and experienced site engineer (Fig. 3.8).

Figure 3.6: *Re-construction of the truss support system*

Figure 3.7: *Correct installation of the rag-bolt*

Figure 3.8: *Re-constructed truss*

STRUCTURAL FAILURE OF CHURCH BUILDING II

Church building II, a standard church hall for religious worship, collapsed while the building was still under construction due to failure of the roof truss resulting from inadequate design and poor construction supervision (Fig. 3.9). Weather was fair, just slight wind and rain. Principal as-built dimensions of the church building recorded on site visits revealed that the overall external dimensions of the building was 25m x 33m, the depth of the roof truss alone was 600mmand stood at a height of 9mafter installation. The average height of the columns is 6mand the roof sloped towards the eaves at 13.50 to the horizontal. The roof truss structure was purely constructed in steel. It was designed as a single span truss with a low pitch angle of 13.50 at the midspan, each simply supported at column heads spaced at 3mcentres. Steel rafters were held firmly atop three shear walls (two at the ends of the building and one at the altar) having same pitch angle as the truss.

Undesignedrag bolts were to be used in holding down the steel roof truss to the top each column.

Figure 3.9: *General view of the church building before failure.*

STRUCTURALASSESSMENT OF THE COLLAPSE

Visual inspection and defect diagnosis were performed on various structural elements of the collapsed building including columns, beams, roof truss and rag bolts. Findings from the assessment revealed that:

1. The service of a qualified and competent structural engineer was not employed in the design and construction instead, work was given to quacks.
2. Inadequate truss member sizes, depth, pitch angle and section were fabricated by the contractor to span 25m. Overall depth of truss was 600mm with 75 x 75 x 6mm top angle bars as top and bottom chords and 50 x 50 x 4mm angle bars as diagonal and vertical

bracings (Fig.3.10).

3. Roof slope is inadequate (13.50) compared to span resulting in sagging/ twisting of the trusses.
4. Concrete used to cast the beams and columns was poorly mixed and compacted resulting in weak concrete (Fig. 3.11 and Fig. 3.12). (Could the strength of this concrete be obtained?)
5. Short lap lengths were used for the bars in column and the position of the lap was 400mm above the beam instead of starting immediately 75mm on top of the beam (Fig. 3.11)
6. The rag-bolts were crudely formulated and fabricated(Fig. 3.13).
7. Rag-bolts were inappropriately embedded in the concrete column and as a result, the column reaction transferred to the rag bolts was not effective in providing adequate resistance to the end support reaction from the truss and wind forces, hence the roof truss collapsed.

Figure 3.10: Failure of the trusses

Figure 3.11: Failure of the side columns

Figure 3.12: Failure of other columns and beams

Figure 3.13: View of rag-bolt after failure

REMEDIAL MEASURES FOR THE COLLAPSE

Reinstatement plan of reconstruction was carried out by ensuring the following:

1. A qualified structural engineer was employed to make a proper design of the entire roof system i.e. roof truss, its rag bolts and the column for load transfer using appropriate codes of practice.
2. A qualified structural engineer with good site experience was appointed as supervisor to oversee all construction work and ensure all structural details were.
3. Failed column was demolished completely and reconstructed by ensuring that concrete of the right grade and quality was properly mixed and well compacted. Also, appropriate lap length and lap position for reinforcing bars was used.
4. The correct size of rag-bolts was designed by the structural engineer and placed properly, perpendicular to the face of the column's biggest cross-sectional dimension.
5. Truss was reconstructed to the depth and member section sizes provided in the design done by the structural engineer (what was the grade of steel used, provide some of these kind of information).

IMPLICATIONS FOR STRUCTURAL DESIGN AND CONSTRUCTION

The following factors have been considered as the main reasons for the failure of both church buildings:

LACK OF STRUCTURAL DESIGN

Structural designs provide details of the most suitable member sections and materials that can support the estimated loads on a structure without failure or collapse. If a proper design is done, economy of materials is achieved. Some clients however prefer to circumvent the use of qualified structural engineer in order to save consultancy fees. In reality however, the work of the structural engineer in the design of structures lead to an overall reduction in cost since they design to obtain the best alternative structural scheme that would safely transfer all loads on the structure to the base while achieving an economical design.

It is not advisable to solely rely on the services of the architect in the design of building because the architect is not as concerned with the structural integrity and stability of the building as he is with the aesthetical appeal and space functionality. Church building I was designed by a qualified structural engineer but was not adequately supervised by a qualified and experienced site engineer. This was not a fundamental problem of structural design. However, Church building II was not designed at all. The most critical point from where most roof failures will originate is at the connection between the roof members and the supporting columns, beams and load-bearing walls. Construction was carried out by quacks using member sizes, section dimensions and materials chosen arbitrarily or by assumption. As a result, the material strength of the rag-bolt connection between the roof truss and the columns was inadequate for the loads and reactions from wind, truss weight and live load, hence the connection could not transfer the loads to the base through the column and this led to the collapse of the roof truss. This suggests that lack of structural design is a major factor responsible for the collapse of the roof truss. Hence, the service of a qualified structural engineer is inevitable in design and construction process for any building.

POOR CONSTRUCTION KNOWLEDGE

Fabrication and construction work on site is expected to be carried out to the specifications and details provided by structural engineers. Some contractors who bid for projects are not qualified or even experienced and as such do not understand the implications of applying the wrong construction procedures, but have secured the projects due to influence or finance. These non-engineers or quacks cannot even interpret drawings or structural details and hence instruct artisans to cast columns and fix connections by using arbitrary truss member sections, depth and materials. Even though Church building I was designed, it was not supervised by a qualified site engineer. However, Church building I and II was neither designed nor constructed. In the former case, U-shaped rag bolts were designed to be used and placed in a direction orthogonal to the face of the column's biggest side, instead the quack decided to use T-shaped bolts welded together and placed in a parallel orientation without reinforcing bars to hold bolts in position. In the latter case, incorrect rag-bolt sizes were used and unreinforced. Also, roof truss was fabricated on site to an arbitrary depth. The truss in both cases failed as a result of its inadequacy of the capacity of the constructed truss section sizes and connection. This implies that poor construction knowledge is a factor responsible for the collapse.

POOR WORKMANSHIP AND SITE SUPERVISION

Poor workmanship results from the manner in which construction materials e.g. steel and concrete are handled, placed and finished during fabrication or casting. From the two cases studied, concrete columns and rag-bolt supports were cast with poorly mixed and inadequately compacted concrete. Also inadequate lap lengths and lap position of column reinforcing bars were used in construction. These led to failure of the concrete columns that supported the roof truss. Proper site supervision should be done to ensure concrete of the right grade is mixed to the correct proportion of aggregate by a design mix and well compacted by vibration to improve the structural performance of these members under loads.

RECOMMENDATIONS

The following recommendations are proposed on account of lessons learned from the study:

1. Qualified structural engineers should be employed to carry out structural analysis and design of all structures.
2. Qualified and experienced contractors should be engaged in the construction of all structures.
3. All contractors should carry out their work in strict adherence to construction procedures, working drawings and specifications as detailed by the structural engineer.
4. Good workmanship can be achieved by ensuring that all works carried out by contractor is adequately supervised by qualified structural engineer.
5. Any drawing used on site should be duly signed by a qualified structural engineer.

CONCLUSIONS

From the findings of the study, the following deductions are drawn:

- The major cause of building collapse stems from human factors i.e. negligent attitude of stakeholders of the building project. For example, a client may decide not to employ the services of a structural engineer in a bid to save cost of consultancy fees and therefore relies on the decision taken by quacks which he has appointed as contractor for the project. This includes disregarding the activity of getting appropriate approvals from the Town Planning Authorities for all drawings to be used in construction.

- The critical point of a roof truss system is the connection. Rag-bolts at the connection which transfer loads from the truss through the columns to the base should be adequately designed and placed in position according to specifications or else failure is certain.

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