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Case studies and forensic analysis of buildings collapsed recently in Bengaluru and review on foundation failures in Delhi

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ABSTRACT: In recent years Bengaluru city has witnessed a series of building collapses, unsurprisingly in monsoon. The majority of these collapses appear to be due to the failure of the foundation. The high cost of land in urban areas has motivated constructors to build in the vertical direction of the site rather than in the horizontal direction, even on the smallest piece of land to maximize the floor area. In an effort to save some money land developers have been ignoring proper Geotechnical investigation and Structural planning before starting construction. This lack of awareness of soil investigation's importance has led to many building failures in various modes. After studying the forensic research done on case histories of building failures in Delhi, the various modes of building failure have been identified as (i) Lateral soil movement (ii) Unequal settlement (iii) Draw down & heave (iv) Change in water level, etc.

This study aims at identifying the various reasons for building collapses in Bengaluru city through a forensic geotechnical approach and their remedial measures through suitable ground improvement techniques.

Keywords: Foundation failure, Forensic analysis, Geo-technique, Ground improvement, Soil investigation.

1 Introduction

The failure and collapse of buildings happen around the globe, and in most cases, they result in the loss of human lives and damage to surrounding civil structures. The majority of building failures are related to the foundation since it is the primary structure responsible for supporting and providing stability to the building. Foundation failure is very critical because even if a building has not failed, the foundation failure causes a redistribution of loads acting in a way that it was not designed and thus affecting the stability of the whole structure.

It is essential to identify foundation failures and their reasons to provide adequate remedies and undertake preventive measures. Common reasons for foundation failures are inadequate soil protection, improper geotechnical investigation, water level fluctuation, design errors, and improper construction practices.

Several building collapses were reported recently in Bengaluru, for example in Kamalanagar, Kempapura, and Poornachandra layouts. In the recent survey conducted by BBMP, 600 such buildings have been found across eight zones in Bengaluru. This study aims to classify the reasons and causes of foundation failures concerning

Bengaluru conditions, and then precautions and remediations will be addressed accordingly.

2 Bengaluru city and its construction practices

Bengaluru is the capital city of Karnataka state located almost in the centre of southern India. It lies about three thousand feet above sea level, on top of an east-west ridge in the Deccan Plateau. It is exposed to a tropical savanna climate with separate rainy and summer seasons. The primary rainy season here is from June to September which is when the rain is received from South-West Monsoon, and the secondary rainy season is from November to December which receives rain from North-East Monsoon. Being called the Silicon Valley of South Asia, Bengaluru is one of the most populated cities thus resulting in very dense construction in the heart of the city.

Every year heavy rainfall creates chaos in Bengaluru, with overflowing drains, knee-deep water levels in many parts of the city, houses getting submerged, many roads getting flooded, and trees being uprooted following a heavy downpour. This also causes sudden fluctuation in the Ground water table of the region.

Bengaluru was once called as 'City of Lakes' as the title indicates this city had hundreds of large lakes but as urbanization took off swiftly, lakes were polluted with sewage and industrial runoff. Rapid urbanization, the mass influx of people, and the resultant increase in demand for land contributed to the encroachment of lakes. Most part of the city now has been constructed on sites that were lakes at some point in the past. Due to the fluctuating water table these constructions possess high risks by the increase of pore water pressure in the soil. If the site constitutes sandy soil, its high permeability might have the possibility of Liquefaction, and Soil Settlement strongly exists. Clayey soil holds high porosity so, during water table fluctuation, Settlement will have more possibility.

Apart from that, most buildings in Bengaluru are not being built professionally. Many owners do not consult geotechnical and structural engineers for planning. Construction firms use low-quality materials to save money. Most importantly Soil investigation is not being done before building construction in common. Before the construction, proper soil testing needs to be done and the load-bearing capacity of the site needs to be analyzed. A lot of builders just submit the soil report of some other nearby sites to ge permits. Another major concern is that builders are not laying a foundation deep enough to support the building. An insufficient foundation increases the risk of the entire building collapsing.

3 Geotechnical investigation

Geotechnical Investigation is a process carried out on construction sites to verify if the properties of the soil are desirable. It requires a proper testing procedure and expertise. An engineer must know the nature of the soil before planning a building. A geotechnical report is a means to understand the site conditions, design, and construction directions to the structural designers and builders. The need for sufficient site investigation and detailed geotechnical reports cannot be ignored. The findings of the geotechnical survey have a strong impact on structural design, phasing the construction project, cost, and safety hence the report must be clear, concise, and accurate. Improper or inadequate geotechnical investigations can result in costly

budget, uneconomical design of foundations, unnecessary delays, disputes and project cost overruns.

3.1 Advantages of Geotechnical Investigations

The proper geotechnical investigation includes a series of borehole drills, soil sample collection, and laboratory and/or in situ testing. The number of boreholes, their depth and location on site, soil samples, and tests depends on the structure's geometry, the loads imposed on the site, and the subsurface profile. There is currently no means available for determining the most accurate geotechnical report to quantify the risk of foundation failure, over-design costs, delays in construction works, and cost overruns. The following benefits to ease the engineer's work can be achieved by investigation

- Make use of latest techniques/technology available.
- Obtain surface and subsurface exploration of a site.
- Have complete data about the construction site.
- Establish parameters for the foundation
- Cost-effective services
- Prepares proper site investigation report
- Best soil treatments

4 Foundation failure

Foundation failure occurs when the foundation of a building is no longer capable of supporting the full load coming from the structure. It may be due to the movement of soil mass beneath the footings causing excessive settlement. In that case, the building might sink or topple over wholly because of inadequate soil-bearing capacity. Many building foundations fail just because of improper analysis of soil conditions of the construction site. In urban areas, the buildings are constructed on small plots due to a lack of suitable land.

4.1 Common causes of Foundation Failures in Urban areas:[5]

a) Changes in Water Table: The water content fluctuation in the soil can modify the dimensions and behaviour of soil mass underlying the structure. In some cases, groundwater is extracted to a level that it recedes drastically and resulting in foundation settlements with severe damage. In monsoon the sudden rise of the water table also affects the bearing capacity of the soil, resulting in liquefaction in sandy soils and differential settlements on clays.

b) Drag Down and Heave: In cases where the footing is placed on compressible soil, drag down and heave are chances of failure. In plastic soils, any settlement (drag down) often results in the upward movement of soil (heave) at some distance from the drag down. The differential settlement or heaving of the soil that supports the foundation is the most common cause for a foundation failure.

c) Lateral movement in soil: In any building when the side supports are removed suddenly or new overburden pressure is applied on the backfill, a lateral thrust is created on the retaining wall resulting in the lateral movement of soil. It may

also occur during earthquakes. Leaks in the drains adjacent to foundations can cause washout of soils causing foundation failure.

d) Unequal Support: Footing placed on a different type of soil that possess unequal bearing capacity will result in an unequal settlement which is called differential settlement. This causes tipping of the structure, the part of the structure resting on the weaker soil will tip away.

e) Load transfer: The basic function of a foundation is to transfer the load from the superstructure to the wider area equally onto the foundation soil. The design of the footings is done such that it uniformly distributes the pressure on the subsoil and the imposed load should never exceed the safe limit of the subsoil. The load transfer mechanism fails when the load transferring footings are not designed adequately for the load acting and accordingly to the nature of the subsurface soil.

5 Forensic observations of recently collapsed buildings in Bengaluru

Three buildings in Bengaluru that collapsed in recent years are selected by conducting a survey on media reports. Site visits are done to carry out Forensic observations and find the details of collapsed buildings, the nature of building collapse, and the causes of the failure.

5.1 Two buildings of Kamalanagar

Collapsed on October 13, 2021

Details of structure- Two buildings were constructed side by side in a 15 by 40 ft plot each, one building was G+3 and another G+1, building was constructed on an elevated plane with respect to the plot behind it. **Casualties**- None

Causes of failure

a) The Foundation of the building was in an elevated plane above the empty site behind it with inadequate support.

b) When it was raining heavily the soil under the foundation started to wash out towards the empty site.

c) The ground floor sank following the foundation failure.

Fig.1. Rare view of two buildings at Kamalanagar

Fig.1. Building falling back due to foundation failure

Forensic observations

a) There was a building in the plot behind, which was demolished recently. Both buildings had common walls on the adjacent sides.
b) After the demolition of the building behind, the adjacent building lost lateral support for the foundation at the back.
c) The stricture now had an unsupported floating wall on the back side, creating a risk of toppling at any given instance.
d) Due to heavy rainfall the soil under the foundation washed off. Thus, the foundation failed due to the rapid movement of land mass over the slope.
e) As soon as a building was demolished behind the plot, the soil slope should have been given the necessary support to hold back the foundation.

Fig.3. Elevation of collapsed building site

Fig.4. Soil movement from beneath the foundation

5.2 Building at Bengaluru's Hebbal-Kempapura.

Foundation failure on February 05 2020

Details of structure- A three-year-old, 5-storey building on a 20 x 30 sq. ft plot was being used as a hostel for boys.

Fig.5. Tilted building

Fig.6. Demolition of the building

Causes of failure

a) The building was built with 5 floors without approval from the BBMP.
b) It was identified that the owner of the adjacent plot carried out deep excavation of a 10ft x 10ft water sump using JCB.
c) A foundation pillar of the collapsed building was damaged during excavation and caused the tilting of the building.

Forensic observations

a) It is observed that the building was not constructed according to the building bylaws, and adequate setbacks were not maintained.
b) The JCB operator while excavating in the adjacent plot had damaged parts of the foundation column of the building causing the weakening of the structure.
c) A sump in the adjacent plot developed cracks and water began to seep into the foundation. As we know the rising and fall in the groundwater level affects the sol behaviour. The water level rise in the ground reduces the bearing capacity of soil and receding water cause sinkhole formation due to overburden pressure.
d) The weakened soil and damaged foundation pillar together has caused the failure.

5.3 Building in Poornachandra Layout

A 6-year-old G+3 storey building on a 10 x 20 sq. ft plot was tilted after a heavy downpour in Bengaluru in October 2021.

Fig.7. Failed structure at Poorna-chandra layout

Causes of failure

a) Insufficient foundation, Poor structural design.
b) Constructed by violating the building By-laws.
c) The building was built next to the stormwater drain.
d) Storm water drain runs deeper than the foundation of the building.
e) The building tilted backwards following the rain in the city.
f) Cracks were developed in the staircase, walls, and concrete flooring in front of the building.

Fig.8. Building constructed adjacent to the storm drain side wall

Forensic observation

a) It was observed that the building site is very small and right next to the stormwater drain.
b) The foundation of a building is supposed to transfer the load to the soil through a wider area but here the foundation area was equal to or smaller than the built-up area of the outer walls

c) Although the building owner realized the threat of this unsafe structure instead of demolishing it or getting help from professionals, he tries to repair it by himself giving an iron rod support behind the building.
d) Since the stormwater drain was flowing deeper than the foundation of the building, the building loads through the foundation were acting on the sidewalls of the drain which was adjacent to the foundation.
e) Due to the rains and rise in the water table affected the dimensions of supporting soil strata and increases the effective lateral pressure on the sidewalls of the drain.
f) The sidewall which was old and weakened over the course of time failed under the building load and increased lateral pressure.
g) This made the foundation lose support in the backside of the building and caused the partial sinking of the foundation.
h) This is a classical geotechnical failure called the differential settlement that is usually caused by unequal load distribution resulting in unequal settlement of the foundation.

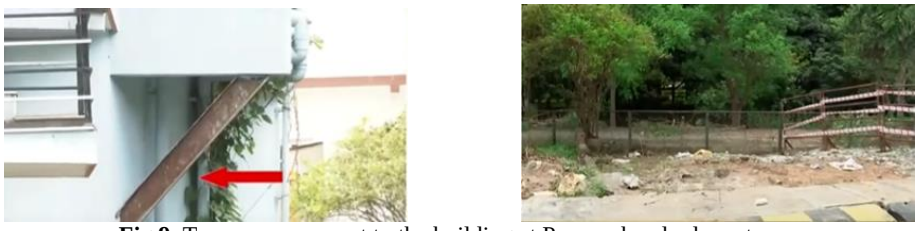

Fig.9. Temporary support to the building at Poornachandra layout

6 Remedial measures for different kinds of failure

6.1 Load Transfer Remediation

For load transfer failures, the most commonly adopted remedial measure is underpinning. It is done by strengthening and stabilizing the foundation of an existing building. Underpinning is done by increasing the depth or width of the foundation so that it gets more support from the soil stratum and makes the load distributed on a wider area. The process of underpinning is usually made by using steel piers, helical anchors, and micro piles.

6.2 Lateral Movement Remediation

Preventive measures for avoiding lateral movement can be through, (i) well-planned soil exploration (ii) Proper analysis and design of supports and (iii) Controlled quality in construction and careful supervision.

6.3 Unequal Support Remediation

The grouting technique can be used to stabilize the foundation. Other methods are soil extraction from beneath the foundation.

6.4 Remediation for Drag-Down and Heave

Preventive actions for controlling Drag Down and Heave are to compact the soil on the wet side of OMC, resist the direction of soil expansion and control moisture contact with soil using plastic fabric under the foundation. etc. Heaving is the most common cause of foundation failure. As a preventive measure, water coming from rainwater drains, and rooftops should be prevented from coming in contact with the foundation soil.

6.5 Change in Water Level

It is important to prevent any potential sinkhole formation by controlling the dewatering process to avoid damage to property due to water table fluctuation under the foundation area. [6]

7 Review on foundation failures in Delhi

Research on the foundation failures that happened in the past is studied to get some knowledge about the classical geotechnical failures and traditional remediation that is being practised in such cases.

Devendra Sharma (1988) [1] has reported the case of St. Thomas church of Delhi which was built in the year 1933. It had a tower of about 61 feet. Following heavy rains in 1958, the structure was subjected to differential settlement and tilting of the tower.

Forensic investigations revealed the presence of old burial pits at about 2m and 2.6m depth below the ground level, which means the site on which the Church is constructed was on a filled-up ground. Chances are that constructors would have mistaken the top Yellow-greyish soil with mixed Kankar as Virgin ground.

The water table during the soil investigation was 5m but during the rainy season, it raised to 1.8 m. The burial pits acting as hollow spaces seem to be the reason for the raise in the water table, seasonally the water filled up in the hollow spaces and while receding it caused the collapse of these empty spaces which was also observed during the penetration test showing little or no resistance at certain depths.

As remediation engineers tried to underpin the structures at places of damage. Shoring was done to support the outer sides of the tower. Even though the problem seemed to be addressed, the structure experienced similar damages due to the rains of 1964.

[3] In 2010, a 5+ storey building near East Delhi suddenly collapsed killing 71 people and injuring over 65 people. The building was about 20-year-old with cantilever projections on all sides. The basement had 12 columns placed at the boundary of the plot, this indicates that all these columns were eccentrically loaded.

The entire colony comes under the Yamuna flood plain but no attention was given to the seepage protective measures. The building height (20.5m) was more than 4 times

the plot width (4.7m). In addition, the overhang from the ground floor to full height was almost 50% of the base width, thus making it vulnerable to structural instability.

The post-failure investigation revealed that the size of the supporting columns was hardly 0.5 x 0.6 m^2 but the actual load that was imposed is 108 tons which required a minimum of 3 x 3 m^2 columns. The slender columns were oriented along the plot length, which should not be the case for normal buildings. This building had a weak column-strong beam-type structure. It was observed that the silty sand under the foundation might have undergone densification by the sustained loading for a very long period. Water logging also weakened the soil around the foundation walls and slab. The owner occasionally pumped the water out creating cervices and thus making way for piping and sand boiling.

This problem arises every monsoon as several buildings used to get affected due to water logging. The city municipality except for giving notices to the owners, no other remedial measures taken. Some building owners filled the basements with rubble waste as a self-remedy, but this in turn increased the load on the foundation and increased the dampness in the area.

7.1 Inferences from the review

The current review is focused on the major foundation failures of India that happened in the past. We understand the common reasons for the failures and remedies that are being followed in the country.

The case history of the St. Thomas Church stresses on the importance of proper soil investigation before starting construction. Also, while providing remediations such as underpinning the damaged structure, it should be done for complete structure once for all such that it provides uniform support overall. If not, there will be chances of untreated parts to sink later.

Also, in the cities like Delhi where multistoried buildings are built around any river basin plains, it is desired to investigate all buildings with basements, primarily to check the dampness for which proper treatment may be done as per prescribed standards.

8 Conclusions

1. In the case of St. Thomas church, we understand that soil investigation must be done deep enough using boreholes to know if there are any cavities like old graves and the underpinning should be made such that it provides uniform support to the whole structure and hence avoid the sinking of other untreated portions in the future.
2. The residential building failure in Delhi shows that improper structural design of foundation columns eventually fails by weakening due to rains and waterlogging. The foundations must be taken care of such that no waterlogging happens during monsoon season by proper treatment to avoid dampness around the basement.
3. The building in Kamala Nagar failed due to soil movement from underneath the foundation to the open space behind the plot, so to protect the building in

such cases the slope behind any foundation must be given proper support by retaining walls.

4. The Kempapura building failure shows that while excavating the site, care should be taken to not disturb the foundations of adjacent plots below ground level and the foundation columns should have a prescribed setback behind the site boundary.
5. The plot of the building in Poornachandra layout was very small for construction. Even after encroaching the stormwater drain land, a proper foundation couldn't be provided. The owner's self-styled remediation couldn't save the building from failure. Hence, it is recommended to follow all the by-laws while constructing a building in a city.
6. The importance of proper site investigation and detailed geotechnical reports should not be ignored.

References

1. Devendra Sharma (1988) Foundation Failure of the St. Thomas Church, New Delhi Foundation Failure of the St. Thomas Church, New Delhi. International Conference on Case Histories in Geotechnical Engineering.
2. Foundation Analysis and Design -Joseph E. Bowles McGraw-Hill Science Engineering Math (1995).
3. Ghosh, Chandan. (2011) Forensic investigation of the collapsed building at Lalita Park, Laxmi Nagar, Delhi (East), A report submitted to the Commission of Inquiry, Delhi Govt., New Delhi, India.
4. Ghosh, Chandan. Investigation of a Building Collapse in Delhi. (2011). Proceedings of Indian Geotechnical Conference December 15-17, 2011, Kochi (Paper No. Q-385)
5. Srivastava, Dr. Amit et al. (2012). Review of Causes of foundation failures and their possible preventive and remedial measures. 4th KKU – International Engineering Conference, (KKU-IENC2012)
6. Zaidan, Samer. (2021). Typical Foundation Failures and Remediations. (researchgate.net)