Building Structural Safety Audit of 426 buildings situated in Village Shahberi Area

Greater NOIDA Industrial Development Authority, henceforth referred to as the client, had concerns regarding the structural condition of residential buildings situated in village Shahberi, greater NOIDA, Uttar Pradesh. The client contacted Prof. Shashank Bishnoi, Associate Professor, Department of Civil Engineering, Indian Institute of Technology Delhi, henceforth referred to as the consultant, to advise on the condition of these buildings. This report discusses the findings and recommendations of the consultant on the matter.

1 Scope of the work

The scope of this work was decided to be:

- To carry out a visual inspection of the buildings above,
- To advise on any testing work that may be required for the buildings,
- To analyse the test results,
- To categorise the buildings into four classes: 1) ones where no action is required, 2) ones where minor repairs or strengthening may be required, 3) ones where a further detailed analysis may be required to decide if they can be repaired or not and 4) ones that must be demolished.

A detailed analysis was not a part of the above scope of work and was decided to be added if required afterwards. Only the residential buildings that had a total of at least 4 stories were included in the survey. A list of the buildings to be included in the inspection was provided by the client. Some of the buildings that were provided in the list by the client could not be located at the time of the visits, while additional buildings that fit the criteria for the inspection and were not listed have been included in the report.

2 Observations and information obtained during site visits

The key observations made at the time of the visits are listed below.

1. There were some additions and deletions to the list of the buildings to be inspected on the basis of the presence and size of the buildings.
2. It was informed that most of these buildings were built between 2011 and 2018.

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3. Most of the buildings inspected at the location were found to be of the reinforced concrete frame type. Most buildings were found to have stilts for parking purpose on the ground floor and 4.5 inch brick infill walls on the upper floors.
4. The buildings inspected were found to have three to six floors above the ground floor and some of them also had one or two basements.
5. One of the buildings was found to have a mobile phone tower on its top.
6. In most of the buildings, each floor was found to have several independent apartments. While some buildings were found to be occupied (O), some were found to be completed (C) but not occupied and others were found to be under construction (UC).
7. Most buildings were found to have 1 m to 1.5 m long projecting cantilevers on the sides facing the roads. Many of these buildings were found to have bathrooms built over these projecting cantilevers.
8. Although, further analysis is required, at the first look, the size of the columns in most of the buildings was observed to be smaller than that is usual for buildings of such size. In many of the buildings, columns were of 230 mm by 230 mm to 230 mm by 450 mm in size. The spans between the columns were found to be around 6 m in many buildings, which is longer than what is common for such buildings and such column sizes.
9. In order to obtain an initial idea of the quality of the materials used, visual signs of structural distress were observed and measurements of surface hardness of exposed concrete were made using a rebound hammer. Structural cracking was not visible in any of the buildings inspected. Additionally, bar locators were used to locate steel reinforcement in reinforced concrete elements that were not visible due to tiles, plaster or other forms of cladding on their surface. This helped in identifying structural members and to estimate their sizes without causing any damage to the buildings. It must be noted that the surface hardness measurement does not directly indicate the strength of concrete and is only an indirect and approximate measure.
10. From the observations and measurements made on the site, it was apparent that conventional and rudimentary construction practices had been used. For example, despite the relatively taller height of the structures, no shear-walls were used in the buildings. Also, from the details visible in the buildings under construction, ductile detailing, which is recommended in the Indian Standards for the design of buildings in seismic conditions, was not observed to be practiced. In order to make the behaviour of a building more ductile during an earthquake, additional confinement is provided to

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concrete near the joints and special care is taken to bend the ends of shear rings of reinforcement to angles of 135°. However, these details were found to be absent in the buildings where construction was ongoing and the reinforcement details could be seen.

11. While tilting was observed in some of the buildings, since no cracks that are usually associated with such tilting were observed, it was not clear if these buildings were tilted from the time of construction, or if the cracks that formed due to any later tilting were covered at a later stage. The buildings that were found to be tilting were marked to be dangerous, requiring immediate attention.
12. It was observed that most buildings had their own septic tanks from where the waste water flows onto unlined open drains on the road-side. It was also found that all buildings drew ground water using bore-wells for household use. Although it is expected that both these practices would be causing damage to the foundations of the buildings, in most buildings, except those where tilting was observed, signs of foundation failure were not currently visible.

3 Categorisation of buildings

On the basis of the condition of the buildings that were inspected, the categories into which these buildings were divided are listed as below:

- Category 1: Buildings where no action is required,
- Category 2: Buildings where minor repairs or strengthening is required,
- Category 3: Buildings where a further detailed analysis is required to decide if they can be repaired or not, and
- Category 4: Buildings that must be demolished.

After visiting the location, it was found that while only a few of the buildings could be classified under category 1, there was no building that could be classified under category 2. Most of the buildings could be classified under category 3 and there was no building that was classified under category 4. Due to the large number of buildings under category 3 and to help in prioritising the work, the buildings under this category were classified under the following 3 sub-categories:

- Category 3a: Less critical
- Category 3b: Medium critical
- Category 3c: Highly critical

While immediate action is required for buildings under category 3c, those under

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category 3a can be handled after the categories 3c and 3b are completed.

A list of the categorisation of the buildings that have been inspected is enclosed for reference, along with any additional comments. As mentioned above, some of the buildings that were provided in the list by the client could not be located at the time of the visits, while additional buildings that fit the criteria for the inspection and were not listed have been included in the enclosed list.

4 Procedure for detailed analysis of buildings under category 3

For buildings under category 3 (a, b, & c), the procedure for checking the structural adequacy of the buildings is discussed below. Given the large magnitude of the verification to be carried out, simplified procedures for verification of the structural adequacy of the buildings is being recommended here. Detailed testing and analysis procedures may be followed in cases where ambiguous results are obtained from the procedure described below. However, it is expected that in most of the cases, the procedures listed below will be sufficient to evaluate the structural adequacy of the buildings and to decide upon the corrective measures to be taken, if any. There are four main steps in this process. In the first step, the structural arrangement of the buildings must be studied in order to establish their structural designs. In the second step, a simplified structural analysis of the buildings must be carried out to assess the safety of the building and to understand the minimum grade of materials required in order for the buildings to meet the requirements of the relevant standards. In the third step, only for the buildings where it is found that it is critical, the strength and quality of the structural materials used for construction may be measured. In the fourth step, once again only where required, methods for strengthening of the buildings must be designed.

It is pertinent to mention that in most cases, the testing of strength and quality of materials is usually carried out before the analysis is carried out. However, given the large number of buildings to be assessed and the fact that many of these buildings are occupied, it is felt that carrying out the structural analysis first will significantly reduce the number of tests to be carried out on the site and minimise the inconvenience to the residents. Also, since in many cases the buildings may be dangerous, testing may further increase the risk. Therefore, in such cases where the analysis shows that in order for the building to meet the requirements

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of the standards, the grades of the materials required are inordinately high, the strengthening of the parts of the building that are the most at risk can be directly focussed upon.

The steps to be followed are discussed in the sub-sections below.

4.1 Measurements and verification of structural arrangement

The steps below must to be followed to establish the structural arrangement for each of the buildings. First, the owner and/or the occupants of the buildings must be notified and provided time of 2 weeks to submit architectural and structural drawings of the building. In case the owner or occupants submit drawings of the structure, the same must be verified through measurements and testing at the location. The following procedure must be followed for the verification of the drawings:

- The outer dimensions of the buildings must be measured and compared with the drawings.
- The number and approximate locations of the columns must be compared with the drawings. The sizes of around 20% of the columns at the ground floor level and the lowest basement (if present) in the building must be verified and compared with the drawings. It must be ensured that if there are columns of different sizes, then at least one column of each size is included in the survey. The reinforcement in each of the columns being verified must also be checked using a cover-meter.
- The approximate locations and arrangement of the beams must be verified with the drawings.
- The number of the floors in the buildings, including the basements must be verified with the drawings.
- The general arrangement of the walls and the rooms in the drawings must be verified with the arrangement at the first floor of the building.
- The location and size of water-tanks and the presence of any other features such as mobile-phone towers, etc. must be checked and verified with the drawings.

In case the owner or occupants are unable to submit architectural and structural drawings of the structure, or they submit incomplete drawings, the following survey must be carried out at the location:

- A detailed geotechnical investigation must be carried out in the village in order to assess the soil condition at the location. The investigation must include sufficient

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number of bore-holes in each of the blocks and must be at least 20 m deep. As is usual, the soil profile, grain size distribution and the NPT values must be reported as a function of depth for each of the bore-holes. An expert in Geotechnical engineering must be consulted to arrive at the safe bearing capacity values at each of the locations.

- The number of floors in the building, including the basements, must be noted.
- The foundation of the buildings must be partially exposed at a minimum of three locations to measure their size and thickness. One of the foundations exposed must be at the corner of the building, the second one along the edge of the property and the third one in the middle. The foundations may be exposed at more number of locations for larger buildings. The foundations must be covered with soil immediately after the measurements. All the foundations at the corners of the building may be assumed to be similar to each other, those not at the corner but along the edge may be assumed to be similar to each other and those inside the building may be assumed to be similar to each other.
- Measurements of sizes and locations of all columns and beams on the ground floor must be carried out, after the removal of plaster, tiles or any other cladding that may have been used.
- Measurements of the floor plan of the building on the ground floor, including the layout of each of the columns on the ground floor must be made. Measurements of any cantilevers extending on the higher floors must be made. It must be verified that the layout of the columns on the upper floors is similar to that on the lower floor.
- The location, thickness and length of the brick walls must be measured on the first floor. Since the weight of the bricks depends on the type of the bricks used, this must be ascertained by drilling two to three holes in the walls of each building and visually observing the bricks. This may not be necessary in buildings where at least one exposed, un-plastered wall is visible.
- The reinforcement details in the columns must be verified using a bar-locator. Both, the number and the size of bars in the columns must be verified. The reinforcement details may be verified in each of the columns up till the first floor.
- In case the design of the upper floor of the buildings is visibly different than the design of the lower floors, the differences between the designs of the two floors must be measured and recorded.

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- The verticality of the building must be checked and the amount of tilting at different levels in the buildings must be recorded and be reported to the client for immediate action.
- The thickness of slabs and finishing must be measured in twenty of the buildings to arrive at the usual value being used in the region.
- The location and approximate size of the mumty on each of the buildings must be noted.
- The number, capacities and locations of any water tanks above the buildings must be noted.
- The complete information from the above measurements must be recorded in the form of architectural and structural drawings that can be conveniently used to input information required for structural design.

4.2 Simplified structural analysis

A simplified structural analysis of the building must be carried out as described below.

- A computer model of each of the buildings must be prepared and a structural analysis must be carried out to assess if the building meets the requirements of the standards.
- For the preparation of the computer model, the column and beam layout may be assumed to be the same for all floors of the building, unless it has been found during the site measurements that the layout is visibly different on different floors. In case, it has been found that the layout on the first floor is not the same as the ground floor, then the layout on all floors above the ground floor may be assumed to be the same as that on the first floor. In cases where the layout of the top floor or the terrace are visibly different, the differences may be included in a simplified manner in the computer structural model.
- The average values of self-weights and dead loads measured above may be used on the basis of the average thickness of the slabs and the finishing in the analysis.
- For this analysis, wall-loads must be applied to all floors on the basis of the wall-dimensions and locations measured on the first floor of the building.
- Any additional loads on the buildings, such as any mobile phone tower, water tanks, etc., must be included in the loads.

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- In the initial analysis, the grade of concrete can be assumed to be M20 and the grade of steel can be assumed to be Fe500.
- The structural analysis should include seismic loads, for Seismic Zone IV and a response reduction factor of 3, unless evidence of ductile detailing are found in the building being analysed, in which case a response reduction factor of 5 may be used.
- The structural analysis must include information about any tilt measured in the buildings. In order to understand the influence of the tilt, the displacements in the structural members measured in the tilting buildings must be included in the respective structural members in the structural analysis model.
- Considering the age of most of the buildings, standards that existed at the time of the start of their construction may be used as reference. IS456:2000, IS1893:1984 (reaffirmed 2003) and IS875:1987 may be used for reinforced concrete design, seismic design and wind loads respectively.
- The safety of the foundation must be checked on the basis of the safe bearing capacity recommended on the basis of the geotechnical investigation. In case the calculated soil pressures exceed the safe bearing capacity of the soil, ground improvement measures, such as piling, grouting, etc., must be undertaken after taking recommendations from an expert in Geotechnical engineering.
- The safety of each of the structural members must be checked by comparing their capacities with the expected loads in these members. The members where the load in the member exceeds the capacity of the member must be identified. Members that have a capacity of up to 5% below the calculated requirement may be ignored.
- In case only a few of the members are found to not meet the requirements of the relevant standards, and the arrangement of these members does not render the building unstable, the structural designer may identify possible means of strengthening these members.
- If any of the members of the building are found to not meet the requirements of the standards with the assumption of M20 concrete, the minimum grade of concrete required for these elements to be safe must be calculated. Based on the expected type of construction carried out, M40 may be the highest grade assumed to be possible in this construction. If there appears to be a reasonable possibility that this required grade of the concrete could have been used in the building, the procedure described in section 4.3 must be followed.

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* For buildings that are found to have several members whose capacity is below the required capacity and those buildings that are found to be unstable due to either their structural arrangement or due to the low capacity of its structural members, the possibilities for strengthening discussed in section 4.4 must be considered. Through a structural analysis, the most practically and technically viable means of strengthening must be chosen.
* For buildings that are found to be unstable or not meeting the requirements of the standards and where none of the strengthening schemes above is found to be possible may be deemed to be grossly inadequate and appropriate action may be taken. The action taken must consider the possibility of damage to, or even complete collapse of adjoining buildings, in case there is a collapse in any of the buildings being considered.

4.3 Verification of grade of concrete (where required)

Testing of the grade of the concrete must be carried out for buildings where a reasonable grade of concrete, which is higher than the assumed minimum grade of concrete, must be assumed in the structural analysis described in section 4.2 in order for the building to meet the requirements of the relevant standards. The following steps must be followed for these tests.

* Three reinforced concrete members where the strength of the concrete is found to be critical must be first identified. These members must preferably be columns, but, in the interest of safety, the chosen columns must not be adjacent to each other.
* Supports using jacking props must be provided to all members adjacent to the one from where a core is bring drawn. Care must be taken to ensure that the props provided are sufficient to take the entire load of the member from where the core is being drawn.
* Cores of at least 65 mm diameter must be drawn from the chosen reinforced concrete members. Before the cutting of the core, the location of the reinforcement in the reinforced concrete member must be checked using a rebar locator in order to prevent the cutting of any reinforcement during the coring process.
* Immediately after the removal of the core, the cavity must be filled with a shrinkage compensated repair mortar with bonding agent and must be suitably cured. The jacking props may be removed once the repair mortar has reached sufficient strength.

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- The core drawn must be visibly observed and any observations regarding the presence of honeycombing, pin-holes, discolouration, etc. must be recorded. The density of the concrete in the core must be measured and the compressive strength of the core must be calculated according to the procedure described in IS516.
- The grade of concrete must be calculated to be the highest grade of concrete for which the obtained strengths of the cores are found to be acceptable according to the provisions of IS516.
- In cases where the assessed strength of concrete is found to be lower than the grade required according to the structural analysis carried out in section 4.2, methods for strengthening may be designed, as described in section 4.4.

Given that the drawing of cores can reduce the strength of structural members, it is important to take all safety measures during the measurements and testing. It is recommended that the buildings from where cores are to be drawn must be vacated during the process, until the repair mortars have suitably hardened.

4.4 Methods for strengthening (where required)

In the case where buildings classified under categories 3a, 3b or 3c are found to be structurally inadequate, the following possibilities may be considered by the structural designer, in the order listed below.

- The possibility of enlarging the existing columns and beams through jacketing must be evaluated. For this, the critical members in the building must be identified and the effect of enlarging the size of the members on the compliance of the building with the relevant standards must be checked.
- In cases where the structural analysis predicts that there is a risk of failure of a building due to seismic or wind loads, the possibility of the addition of shear walls to the structure must be evaluated. Locations where the addition of shear-walls can be feasible must be considered. The locations must be chosen in a manner that the excavation for the construction of the foundation for the shear wall must be possible and such that the shear wall acts integrally with the entire structure. In the structural analysis, the shear wall must be added one floor at a time in order to calculate the minimum height of the wall required so as to ensure the safety of the building.
- If neither of the above two options are found to be possible, the possibility of removal of floors starting from the top of the building may be evaluated. One floor of the

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building may be removed at a time in the structural analysis, until it is found that the remaining building complies with the relevant standards.

- In cases where the structural design of the building is found to meet the requirements of the standards, without or with any of the strengthening measures above, and the expected soil pressures are found to be higher than the safe bearing capacity, a Geotechnical Engineering expert must be consulted for designing soil-strengthening measures for the safety of the buildings.
- In cases where both, the structural design of the building is found to be inadequate and the soil pressures are found to be higher than the safe bearing capacity, the measures for structural strengthening must first be evaluated. The soil pressures must be calculated again after the structural strengthening measure is decided upon. If the soil pressures are still found to be higher than the safe bearing capacity, a Geotechnical Engineering expert must be consulted for designing soil-strengthening measures for the safety of the buildings.
- In case none of the above options is found to be feasible, the building being considered must be demolished.

5 Final recommendations

Finally, it is recommended that the structural survey, analysis, testing and strengthening programme be followed for the buildings categorised as 3a, 3b or 3c, as discussed above. Utmost care must be taken to ensure the safety of the occupants of the buildings and the survey and testing team while the above programme is executed. Buildings must be evacuated and sealed in cases where signs of structural distress, including tilting and cracking, are visible, especially for category 3c.

In addition, it is recommended that lining of the open drains in the area be carried out to prevent failure of foundations. If it is planned to lay sewer lines or to carry out excavation for any other purpose in the area, a detailed survey of the foundations must first be carried out and it must be ensured that any excavation work carried out must not cause any disturbance to the foundations of the buildings and to the soil lying in the zone of influence of the foundations. A Geotechnical Engineering expert must be consulted for this purpose.

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6 Summary

Residential buildings in the Shahberi village of Greater NOIDA were visited and visually inspected. The buildings have been categorised according to their structural arrangement and condition. A structural survey, analysis and testing programme has been recommended to be followed in order to decide the further course of action for each of the buildings. The current scope of work of the consultant is completed with this report.

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