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Detailed Engineering Assessment of Concrete Structures Using Cost Effective Inspection Techniques for Re-Strengthening

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Abstract

Before repairing and strengthening concrete structures to meet seismic design regulations, it is important to conduct a detailed engineering assessment (DEA) of the existing infrastructure. This assessment involves both destructive testing (DT) and non-destructive testing (NDT) methods to determine the safety of the structures. Modern technology has made these testing methods more efficient and cost-effective, allowing for rapid assessment without disrupting the functionality of the structures. In this study, four buildings were assessed using various non-destructive and destructive techniques such as Ferro-scanning, rebound hammer, ultrasonic pulse velocity tests, and mechanical core drilling. These tests were conducted at different locations within each building to determine the reinforcement details and assess the concrete's strength and elastic properties. The results showed that the quality of the concrete was subpar, and the selected structures lacked the necessary strength to withstand recent loads as specified by building codes (BNBC-2020). To address these deficiencies, a reinforced concrete jacketing technique was utilized to strengthen the buildings, significantly improving their seismic resistance and ensuring their safety in the event of earthquakes.

Keywords: *Concrete structures; Destructive testing; Non-destructive testing; DEA; Jacketing.*

1 Introduction

A detailed engineering assessment (DEA) is a thorough investigation and report that evaluates the structural integrity of a building. It is necessary when there is insufficient information to determine the safety of the structures. Assessing the strength of concrete is a challenging task when examining the quality of existing or new structures. The most crucial characteristic is the compressive strength of concrete, which describes its mechanical properties. Design codes typically consider the 28-day compressive strength as the minimum acceptable strength. The strength of concrete is usually tested during construction, and the results are relied upon by structural engineers, project managers, auditors, and quality assurance personnel (Breysse, 2012). Owners and maintenance managers of existing reinforced concrete structures often request a DEA report to prevent further damage to the structures. Modern non-destructive testing (NDT) and destructive testing (DT) refer to processes used to inspect and evaluate materials without affecting their functionality (IAEA, 2002). In Bangladesh, common non-destructive tests include iron scanning, Schmidt Rebound Hammer, and Ultrasonic Pulse Velocity. NDT technology can detect hidden cracks and voids in concrete that may impact durability (Malek & Kaouther, 2014). Advanced NDT techniques are used to assess strength properties, quality, surface absorption, hardness, and structural details of concrete without causing damage (Jones & Fącąoaru, 1969). However, in some cases, core samples may need to be extracted to evaluate the in situ compression strength of reinforced concrete structures (CPWD Handbook, 2002).

Cylindrical cores are typically taken from structural elements by drilling with a diamond-tipped core cutter that is cooled with water. The locations for extracting core samples are determined using a Ferro scanner, which identifies the most suitable areas for sampling (IS 13311, 1992). After the core samples are extracted, a series of tests are conducted to assess the strength, durability, and quality of the concrete. These tests also determine the presence of harmful materials and specific properties of the concrete that cannot be identified through non-destructive testing methods (IS 13311, 1992). In Bangladesh, there are many unplanned buildings that do not meet earthquake resistance standards. Conducting rapid non-destructive and destructive assessments can be a cost-effective way to evaluate the safety and quality of these structures. Therefore, the purpose of this study is to investigate the compressive strength, durability and quality of the concrete being produced without damaging any part of the concrete structure. The present paper focusses on condition assessment old existing building, built between 1972 and 1990 in Dhaka, the capital of Bangladesh. This papers also discusses techniques for strengthening the structures in accordance with current seismic design regulations to enhance their lifespan and safety.

2 Materials and Methods

2.1 Building Information

Four buildings in Dhaka, Bangladesh, constructed between 1972 and 1990, were chosen and evaluated. These buildings had a structural system consisting of beam-column reinforced concrete frames and an isolated column foundation system. The floors were constructed with concrete beams and reinforced concrete slabs.

2.2 Ferro Scan (FS) and Schmidt Rebound Hammer (RH) Test

Ferroscan is a portable system that uses electromagnetic pulse to detect steel rebar in concrete structures (Salman, 2011), determining position, a scanning depth of 180 mm for rebar between 6 and 36 mm in diameter (Mohshin et al., 2018) with accuracy within ±1 mm (Mohshin, 2017). Scanned data can be easily transferred and analyzed using a monitor (Fig. 1). The standard rebound hammer is a non-destructive testing method (Fig. 2) used to evaluate concrete quality (Amini et al., 2016), determining its strength by measuring the rebound number (Ansary, 2012). It is placed perpendicular to the surface and evened with a carborundum stone (Malek & Kaouther, 2014).

Figure 1. Hilti PS 200 Monitor and Scanner Device.

Figure 2. Schmidt Rebound Hammer Test.

2.3 Ultrasonic Pulse Velocity (UPV) Test and Concrete Core Extraction and Testing

The UPV method assesses material strength and quality using density and elasticity, using an electrical pulse generator, transducers, amplifier, and timing device (Jones & Fącąoaru, 1969). Higher pulse velocities indicate better concrete quality, while lower velocities indicate lower quality (Bogas et al., 2013). Figure 3 shows UPV testing with instrument. The structural integrity of a building was also determined by testing concrete strength using cores from twelve locations on different floors. Many cores failed in various modes.

Figure 3. Ultrasonic Pulse Velocity Test.

Figure 4. Concrete Core Extraction and Testing.

2.4 Geotechnical Investigation

A thorough investigation was conducted on the foundation system, bearing levels, bearing capacities, and the condition of a representative sample of underground elements to assess their size, corrosion, and condition.

2.5 Quality Standard of Concrete Based on NDT

The investigated results were compared with the quality standard of concrete suggested by GoI-UNDP (2007) for repairing and strengthening of concrete structures.

Table 1. Quality Standard of Concrete based on Rebound Number and UPV Value (GoI-UNDP, 2007).

Average Rebound Number	Quality of Concrete
>40	Very Good Hard Layer
30 to 40	Good Layer
20 to 30	Fair
< 20	Poor Concrete
0	Very Poor and/or Delaminated

UPV Value, V (m/s)	Quality of Concrete
V > 4000	Very Good
V = 3500 – 4000	Good, But may be Porous
V = 3000 – 3500	Poor
V = 2500 – 3000	Very Poor
V = 2000– 2500	Very Poor and Low Integrity
V < 2000 and Reading Fluctuating	No Integrity, Large Voids Suspected

2.6 Experimental Procedure

The investigation program is designed to determine the quality of built concrete for the selected structures and can be summarized in the following steps:

3 Results and Discussions

3.1 Assessment of Built-Concrete through RH Test

The study measured the strength of concrete in selected structures using rebound hammer tests, revealing an average rebound value of 16-35 for building-1, 24-32 for building-2, 25-33 for building-3, and 26-40 for building-4, with most values ranging from 20-30. Hence, the quality of concrete was considered fair according to the standard in Table 1.

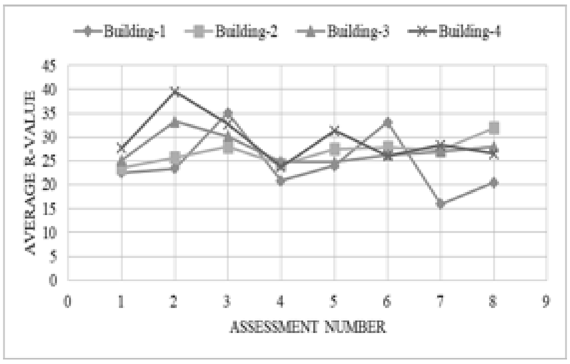

Figure 5. Quality Assessment of Built-Concrete through RH Test.

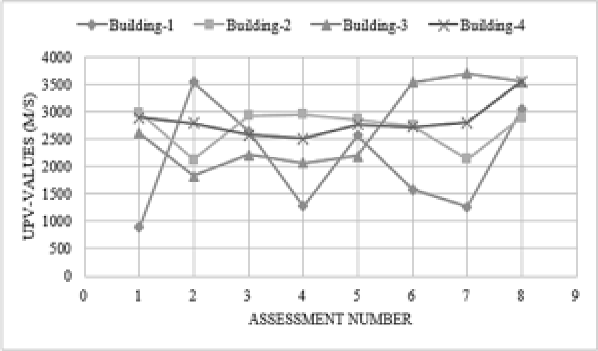

Figure 6. Quality Assessment of Built-Concrete through UPV Test.

3.2 Assessment of Built-Concrete through UPV Test

The UPV test evaluated concrete uniformity and compressive strength on various structures. Results showed buildings with low-quality concrete, with values ranging from 892 m/s to 3690 m/s. Building 1 had low-quality concrete, while buildings 2 and 4 had subpar concrete. All four buildings had very poor to poor quality concrete compared to standard UPV values.

3.3 Assessment of Built-Concrete through Concrete Core Test.

The compressive strength of concrete was tested in four buildings, ranging from 2683 psi to 3086 psi, revealing that the assessed buildings did not meet the minimum requirements set by the Bangladesh National Building Code (BNBC 2020), which requires a minimum compressive strength of 3500 psi for seismic resistant buildings.

The minimum strength for small-scale projects is 2500 psi, while seismic design requires 3000 psi, as per ACI 318-11 Section 21.1.4.1.

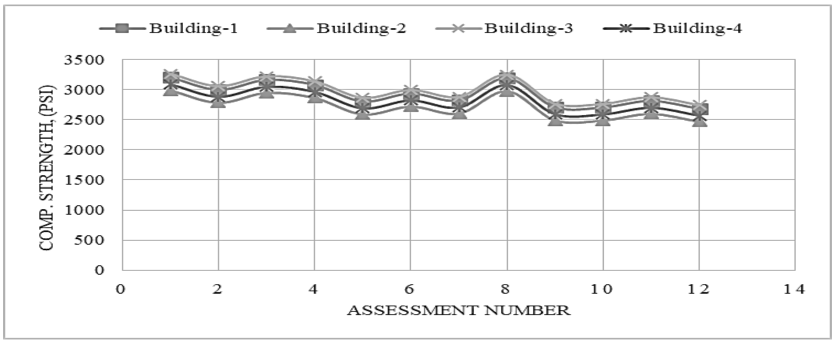

Figure 7. Quality Assessment of Built-Concrete through Concrete Core Test.

4 Checking Adequacy of the Buildings and Re-Strengthening Measures

The structural adequacy of selected buildings was assessed using CSI Etabs V18.0.2 software. Results showed sufficient deficiency in strength to resist recent BNBC loadings. Therefore, Re-strengthening with estimated earthquake resistance ratings and suitable RC jacketing measures are recommended. To extend the lifespan of these structures, suggestions have been made for reinforcing them with suitable RC jacketing measures.

4.1 RC Jacketing of Beams

Jacketing of beams enhances structural strength and stiffness, moderately enhancing flexural capacity, and creating strong joint connections. Top and bottom bars were inserted through orthogonal beams, using transverse steel bars in U and inverted U shapes with closely spaced ties near the joint area where the beam is expected to hinge (Fig. 8).

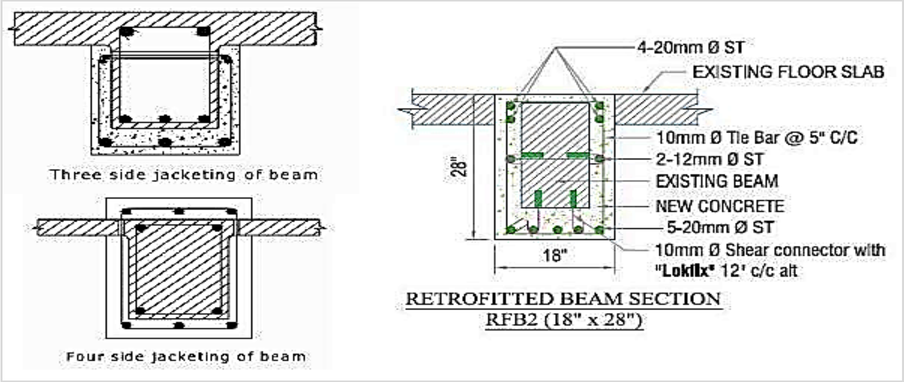

Figure 8. Construction Technique for Beam Jacketing.

4.2 RC Jacketing of Columns

Teran & Ruiz (1992) illustrated four major reinforcement patterns for RC jacketing of RC columns (Fig. 9). This study utilized the RC jacketing method to reinforce a column. The dimensions, reinforcement, and material properties of the column remained the same as found from DEA. The chosen reinforcement pattern, known as Model C, was found to be the most effective in terms of cracking load, stress-strain characteristics, and lateral displacements when compared to three other patterns (Mohshin et al., 2018).

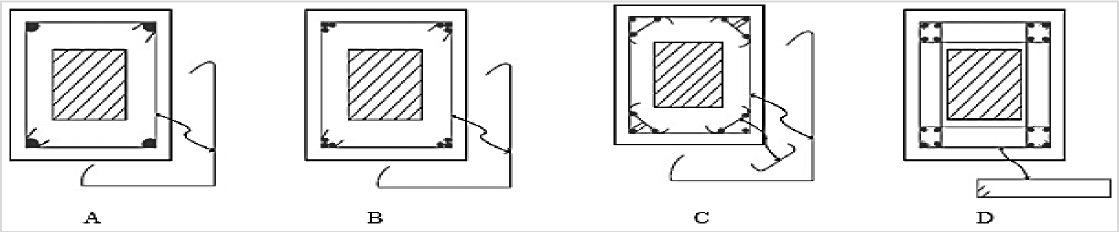

Figure 9. RC Jacketing of Columns.

4.3 RC Jacketing of Foundations

Strengthening foundations before or after an earthquake involves adding reinforced concrete strips to existing foundations. These strips connect wall footings and are inserted into existing footings, either above or at the same level. (Fig. 10). In either case, keys are inserted into the existing footing to connect it with the reinforced concrete strips and walls.

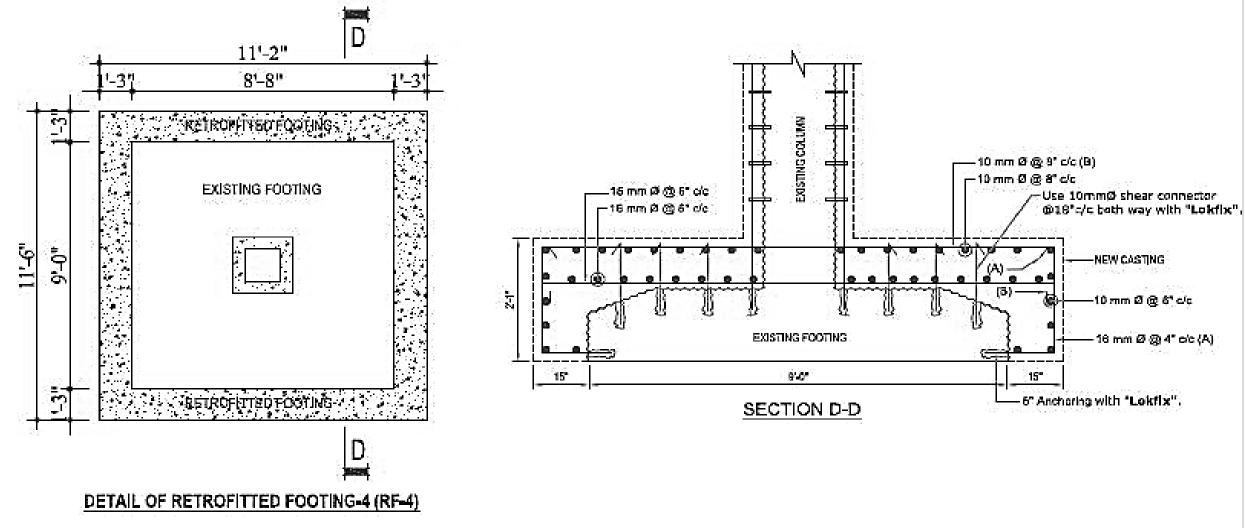

Figure 10. Construction Technique for Foundation Jacketing.

4.4 Provision of Shear Connectors

Shear connectors with a diameter of 10 mm were installed in 16mm diameter holes, 300mm apart, staggered pattern. They were cleaned with compressed air or water jet, and secured with Master Flow 935 AN bonding agent.

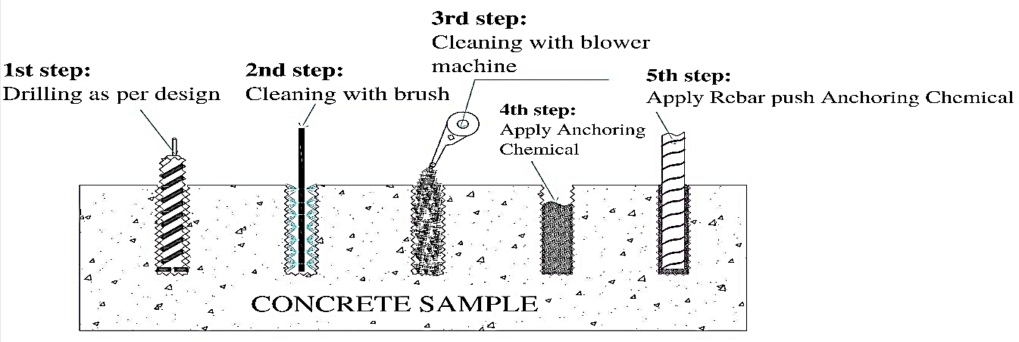

Figure 11. Shear Connectors Provided for Strengthening.

5 Conclusions

Assessing the seismic stability of old buildings in Bangladesh is crucial due to its location in a seismically active area Close to the border of the Indian plate and Eurasian plate. By conducting detailed engineering assessments using cost-effective testing methods, such as DT and NDT, the condition of aged existing RC buildings can be evaluated and necessary repairs can be made to extend their lifespan. This approach aligns with the BNBC 2020 and considers the economic feasibility of retrofitting measures. By following this approach, building owners and engineers can ensure the safety and resilience of their buildings in the face of potential earthquakes, contributing to the overall safety and well-being of society.

Recommendations

Regularly conducting engineering assessments using cost-effective DT and NDT methods is crucial, particularly in buildings where component failure could result in danger or financial loss. These assessments are also important for preserving historical, artistic, social, and human significance of structures and complying with updated code regulations.

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