ENGINEER - Vol. LVII, No. 04, pp. [55-66], 2024

DOI: https://doi.org/10.4038/engineer.v57i4.7666

Comprehensive Structural Assessment of Old School Buildings in Sri Lanka

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Abstract: The deterioration of old school buildings has become a significant challenge to the Sri Lankan Government and the educational system. This study investigated a total of twelve old school buildings, distributed across six distinct schools in Sri Lanka, all of which were constructed in the 1980s and 1990s. Visual inspection was carried out to detect the common defects of the structural elements. Non-Destructive Testing (NDT) and Destructive Testing (DT) methods were performed to determine the existing material properties of the identified deteriorated structural elements. Utilizing the SAP2000 software, a Finite Element (FE) model was developed to simulate a representative school building, considering the architectural and structural similarities shared with the examined old school buildings. Structural analysis was carried out for the typical concrete structural elements and their capacities were closely investigated based on variables such as concrete cover, effective steel area, and grade of the concrete. According to the FE modelling results and the capacity assessment, possible retrofitting methods such as Carbon Fibre Reinforced Polymer (CFRP) jacketing and Reinforced Concrete (RC) jacketing were suggested for these school buildings. For identified minor defects, appropriate repair methods such as Patch repair and Epoxy injection methods were suggested.

Keywords: School Building, Non-Destructive Testing, Retrofitting, CFRP Jacketing, Destructive Testing

1. Introduction

During the 1980s and 1990s, a significant number of government school buildings were incorporated into the Sri Lankan Educational System. These school buildings predominantly comprised two-story and three-story reinforced concrete buildings, characterized by comparable structural and architectural attributes. However, in recent years, a number of these buildings have exhibited a range of severe defects, and some situations caused school authorities to evacuate the children from these building premises due to safety concerns.

The National Building Research Organization (NBRO) of Sri Lanka is consistently being approached for inquiries regarding the examination and validation of the structural integrity of deteriorated school buildings. It has been observed that the structural capacity of these existing buildings tends to be significantly lower compared to newly constructed counterparts, while their durability and lifetime are adversely affected by age and exposure to environmental conditions. In addition, due to safety concerns, urgent measures need to be taken about these buildings, considering the impracticality of reconstructing a considerable number of school buildings within a short time frame.

This paper presents a comprehensive structural assessment of twelve defective old school buildings in Sri Lanka with potential retrofitting strategies to enhance the service life of these school buildings. To achieve this, visual inspections, destructive (core sample testing), and non-destructive testing methods were carried out to identify prevalent defects and determine the properties of the existing materials. Furthermore, a detailed vulnerable stability assessment of these school buildings was conducted using finite element (FE) modelling and capacity assessment.

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Ultimately, appropriate retrofitting methods, including Carbon Fibre Reinforced Polymer (CFRP) jacketing and Reinforced Concrete (RC) jacketing, were suggested. Patch repair and epoxy injection methods were proposed for the identified minor defects.

2. Literature Review

In the past few years, many research works have been carried out focusing on condition assessments and structural investigations of the deteriorated existing RC framed buildings, with reliable rehabilitation methods to enhance their service life. Most of these studies are integrated with non-destructive testing (NDT) and destructive testing (DT) methods for in-situ assessments of existing buildings, where these techniques play a major role in analysing existing concrete structures.

Ajitesh (2014) conducted a condition assessment for two existing multi-storied RC framed buildings located in a coastal area and somewhat away from the coastal region, using the rebound hammer test and Ultrasonic Pulse Velocity (UPV) test, respectively. The test results confirmed that there is a significant effect of coastal exposure on the durability of the structures. In addition, this study concluded that the rebound hammer test is more efficient in concrete strength predictions and the use of combined rebound hammer and UPV tests provide more reliable concrete strength estimation. Similarly, Venkatesh and Alapati (2017) conducted a condition assessment for a fifty-year-old existing hospital building using visual inspection and NDT techniques including UPV, rebound hammer, and half-cell potential tests to evaluate the status of its structural components. The results show that the structure is still in repairable condition and restoration measures were suggested including anticorrosive coating, column jacketing method, shotcreting, etc. In addition, the authors concluded that regular surveys and appropriate maintenance processes aid in restoring old RC buildings. Kumavat et al. (2014) have studied an evaluation of the concrete quality of an eight-year-old RC building by visual observation, DT, and NDT methods such as the UPV test, half-cell potential test, depth of carbonation test, cover meter test, and core test. According to the observed results of the study, the authors identified that the structure deteriorates due to temperature variations, aggressive chemical attack, and other physical causes, and poor maintenance rapidly increases the deterioration process. In addition, the authors stated that ultrasonic testing on core tests does not give accurate results due to some practical difficulties including air trapped between the concrete surface and the transducers. Furthermore, Ali (2018) evaluated the condition and the structural integrity of the existing six-storied RC factory building through DT and NDT. To assess the exiting material properties of the structure, NDT methods such as the ferro scanning test, cover meter test, UPV test, and rebound hammer test were performed. The concrete core test was the only DT that was conducted to determine the existing in-situ compressive strength of the different structural components. This study confirmed that the combined use of two or more testing methods would offer more reliable results. Moreover, a structural analysis was performed for the investigated building using the finite element software package ETABS and this study confirms that this building has sufficient structural capacity to withstand the standard loading requirements. Thomas and Ede (2019) presented an in-depth investigation of the NDT methods including the schmidt rebound hammer test, the UPV test, and the cover meter test. This study reveals that the rebound hammer can estimate the concrete compressive strength approximately equal to the destructive core test. Other than that, it highlights that the UPV test is not a reliable method to estimate the strength. Still, it is desirable to measure the uniformity and homogeneity of the concrete structures. Finally, the study concludes that, for the condition assessments of the concrete structures, the schmidt hammer, ultrasonic velocity tester, and the rebar locator should be used simultaneously for reliable results and proper investigation of structural integrity. Moreover, a detailed study of the estimation of the in-situ compressive concrete strength of an existing school building using an experimental testing program was presented by Minutolo et al. (2019). A series of laboratory-based DT methods were carried out on extracted concrete core samples of beams and columns of the examined building and the calibration procedure; NDTs were conducted for structural elements. They concluded that the DT methods give precise results, but the wider distribution of applied NDT methods led to imprecise results. In addition, this study recommended to carry out a large number of tests using NDT methods to obtain accurate concrete properties. Alwash (2017) has presented an evaluation of the concrete strength of old structures using NDTs and core tests. They analysed the current procedure of concrete strength estimation and suggested guidance for a more reliable estimation technique for DT and NDT methods. Mangrulkar et al. (2018) presented a case study of a 20-year-old existing building using various NDT methods including ultrasonic pulse velocity test, rebound hammer test, carbonation test, and half-cell potential test. This research study concludes that the structural components need repairing based on the observed testing data. In addition, Kukade et al. (2019) presented another case study of an existing 30-year-old RC-framed building through the NDT methods. The rebound hammer test, UPV test, and half-cell potential test have been conducted to assess the concrete quality structural stability of the building. The study recommended that the examined building needs proper repair and retrofitting techniques to enhance its condition and durability. Kumar and Alam (2020) studied the condition of an existing 2-story hospital building using NDT and DT methods including UPV test, concrete cure test, rebound hammer test, half-cell potential test and depth of carbonation test. This study reveals that the investigated building needs proper maintenance practices. They conducted numerical modelling analysis and suggested desirable retrofitting strategies for each structural element type including concrete beams, columns, slabs, and foundations.

Therefore, past literature confirmed that the proper use of DT and NDT methods on existing buildings provides appropriate results, and the rehabilitation of the decayed structures needs a comprehensive assessment to maintain their structural integrity. The defective buildings are common due to poor maintenance, showing the need for regular surveys and proper maintenance procedures. Apart from that, a coastal or corrosive environment can significantly degrade the durability of the building, leading to severe corrosive damages. Furthermore, those research findings stated that the use of combined DT and NDT methods provides more reliable results. Moreover, they highlighted that a significant number of tests can provide more accurate results. The importance of visual inspection as a preliminary assessment method and the contribution of detailed structural analysis through the numerical modelling approaches for selecting desired repairing and retrofitting strategies were discussed in case studies in the past literature.

3. Methodology

The examined old school buildings were deteriorated two-story and three-story reinforced concrete framed buildings with correspondingly similar structural and architectural characteristics. After the detailed visual inspections were carried out, appropriate NDT and DT methods were conducted for these selected school buildings. FE modelling and the capacity assessment were carried out to check the structural stability with the existing capacities of each type of typical concrete members. Ultimately, the necessary retrofitting and repairing methods were suggested for these buildings based on the test results and FE modelling results. Figure 1 represents the methodology flowchart that was followed in this study.

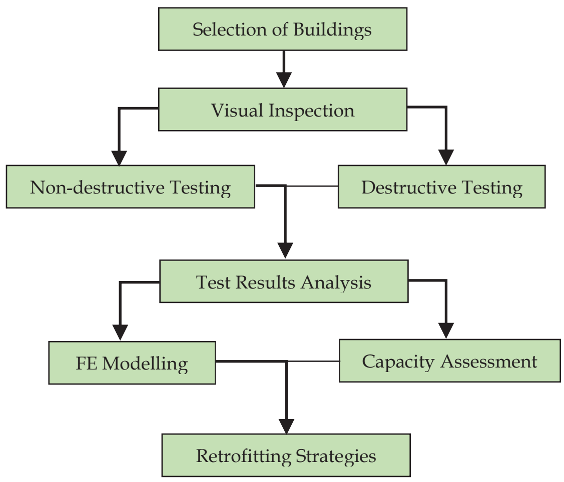

Figure 1 - Methodology Flowchart

3.1 Selection of School Buildings

Twelve old school buildings, distributed across six distinct schools in Sri Lanka, were selected for this study. All these buildings were constructed in the 1980s and 1990s and have started to show significant defects in structural and non-structural elements. The selected schools are mainly located in the wet zone of Sri Lanka, as per Karunaweera and Galappaththy (2014). In addition, these schools are away from the coastal region, so the effects of corrosion due to marine exposure can be ignored. For this study, the selected six schools are designated as A, B, C, D, E, and F. If multiple buildings were examined at a single school, they are labelled sequentially, such as A-1, A-2, etc.

3.2 Visual Inspection and Assessment

Visual inspection is the preliminary condition assessment that can be carried out to identify defects in the structural components including crack patterns, concrete spalls, deflections, presence of voids and corrosion, etc. In this study, a systematic visual inspection was carried out for each defective school building to identify the most common defects in concrete members with the degree of damage. Based on that data, the necessary NDT and DT methods that should be carried out for each school building were decided.

3.3 Destructive Testing (DT) and Non-destructive Testing (NDT)

The appropriate DT and NDT techniques were performed as in-situ evaluations in each defective school building to determine the existing material properties and ensure compliance with design requirements. The core test and the rebound hammer test were conducted to identify the existing compressive strengths of the concrete members. The depth of carbonation test was performed on extracted core samples, beams, and columns to determine their carbonated depths. In addition, the cover meter test was performed in some situations where the structural drawings were unavailable to determine the existing steel bar locations, diameters, and arrangements. The half-cell potential and the ultrasonic-pulse velocity tests were conducted to identify the possibility of corrosion and the concrete quality of the structure respectively.

Core Test

The core test is the only destructive test that was conducted in this study, and it was used to determine the in-situ compressive strength of extracted concrete core samples from concrete slabs in each school building. The test was conducted as per BS EN 12504-1: 2009 [7] and BS 6089:2010 standards. Core samples of 100mm diameter were extracted using a diamond drilling bit (Figure 2). The compressive strength was determined using the compressive test by applying corrections to the length-to-diameter ratio, the effect of reinforcement present perpendicular to the axis of the core, and excessive voidage. The average compressive strength value of three core samples was considered for each floor in the building.

Figure 2 - Extracted Concrete Core Samples

Rebound Hammer Test

The rebound hammer test was the other testing method that was used to obtain the in-situ compressive strength, based on the surface hardness of the concrete in each selected structural element in old school buildings. The test was performed as per BS EN 12504-2: 2001 standard. To determine an accurate rebound number for each selected 300mm x 300mm test area, a minimum of nine observations were taken. The result was recorded as an average value of all observations, which were corrected by considering the orientation of the rebound hammer according to the manufacturer's instructions. Figure 3 illustrates the rebound hammer test on an RC column.

Figure 3 - Rebound Hammer Test on a Reinforced Concrete Column

The regions that consisted of high porosity, honeycombing, rough texture, or scaling were avoided during the testing. The recorded readings which differed 20% or more from the calculated average value of more than six regions, were ignored. The carbonation factor was considered to estimate the compressive strength.

Cover Meter Test

The cover meter test was performed to determine reinforcement arrangement, concrete cover, and bar size in structural elements such as slabs, beams, and columns in the examined school buildings (Figure 4). The obtained cover meter results were preliminary data for some other tests when the rebars should be avoided or their arrangement is considered, such as core sample extraction and the UPV test.

Figure 4 - Cover Meter Test on a Reinforced Concrete Slab

The cover meter test was used to determine the locations, arrangements, and spacing of reinforcements when the drawings were not available for old school buildings. The test was conducted according to BS 1881-204: 1988 and Profometer 5+ was used to conduct the test.

Depth of Carbonation Test

This test was used to determine the carbonated depth of the extracted core samples, the carbonation depth of the beams and columns, and the internal voids of the core samples. A phenolphthalein solution was sprayed on the freshly extracted concrete core samples and the carbonated depth (uncoloured area) was measured four to eight points from the external concrete surface, and the median was recorded. Figure 5 shows the carbonated depth marking on an extracted concrete sample.

Figure 5 – Marking the Carbonated Area on an Extracted Core Sample

When the test was performed in a drilled hole, the dust was removed from the hole before the readings were taken, and the carbonated depth was recorded.

Half-cell Potential Test

The half-cell potential test was conducted as an NDT testing method to estimate the risk level of corrosion probability at a selected region and time. The test was performed per standard ASTM C876-91 [5]. This test is mainly used for the durability assessment of an existing structure considering the corrosion effect. The readings were taken using a grid pattern of a selected location and the spacing between each point was taken such that 100 mV difference between adjacent readings. A region with more than 150 mV generated was considered as a high corrosion activity.

Ultrasonic Pulse Velocity Test

The UPV test is a wave propagation test that was used to determine the uniformity of concrete components of the examined school buildings. In this test, the time taken for an ultrasonic pulse to pass through the concrete was measured. The test results show higher velocity if the concrete has good quality, density, homogeneity, and uniformity. UPV test was conducted as per BS EN 12504-4: 2004 and before starting the test, the surface was prepared properly. UPV test on a concrete column is shown below in Figure 6.

Figure 6 - UPV Test on a Reinforced Concrete Column

3.4 Numerical Modelling and Capacity Assessment

The examined school buildings were two-story and three-story reinforced concrete-framed buildings with similar architectural and structural characteristics. These buildings have rectangular-shaped floor plans with an average length of 27 m and a width of 7.5 m. The average floor-to-floor height is 3.0 m, and the building has nine bays along its length, as illustrated in Figure 7.

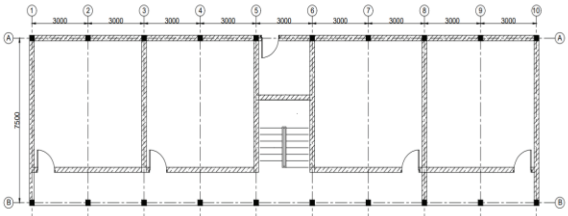

Figure 7 - Typical Floor Plan of the School Buildings

Hence, a typical three-story school building structure was modelled with SAP2000 software (v24.0.0) using the Finite Element (FE) modelling method to determine the critical structural members of the building and the forces that are acting on it. This procedure was selected because retrofitting measures designed for a three-story school building inherently account for the demands of a two-story school building, ensuring sufficient safety without the risk of under design. Additionally, the risk of over design is minimal, as the cost and material requirements for retrofitting a two-story school building based on a typical three-story model are not significantly higher, providing a conservative and efficient solution across both building types. Figure 8 shows the reinforcement details of typical RC beam and column sections.

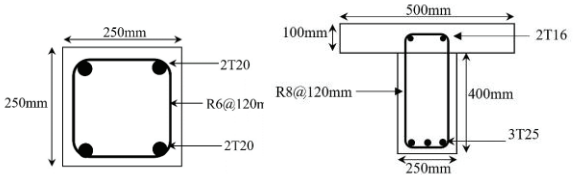

Figure 8 - Typical Reinforcement Details of RC Beams and Columns

Only gravity loads were considered in the numerical modelling part, and the building is assumed to be fully supported against lateral movement without accounting for the wind and seismic impact on the buildings. Floor slabs were modelled as rigid diaphragms, distributing loads uniformly to the supporting beams and columns. All the loads were applied as uniform loads, and the imposed loads were applied to the structure according to EN 1991-1-1 (2002). The numerical modelling considered various loads including an imposed load of 3kN/m² on the floor and 1kN/m² on the roof, along with the self-weights of both structural and non-structural elements, such as brick walls. In addition, two load combinations were used to address different loading conditions on the structure: the service state and the ultimate state. These combinations incorporated both variable loads (Q_k) and permanent loads (G_k), with the service state using $1.0G_k + 1.0Q_k$ and the ultimate state using $1.35G_k + 1.5Q_k$. Figure 9 displays the developed numerical model of the typical RC-framed school building in SAP2000 software (v24.0.0).

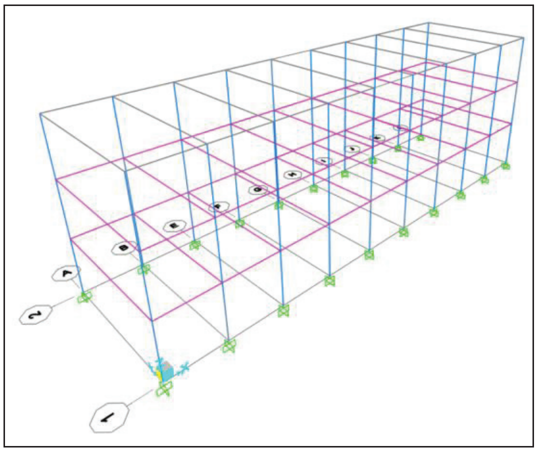

Figure 9 - Numerical Model of the Typical RC-Framed School Building

The capacity assessment was carried out for structural components including columns, beams, and slabs to study their existing capacities. The behaviour of those capacities with parameters such as concrete grade, effective steel area, and concrete cover was closely studied.

3.5 Retrofitting and Repairing Methods

This study discusses the feasibility of different retrofitting strategies for deteriorated concrete elements. For decayed RC columns, complete Carbon Fiber Reinforced Polymer (CFRP) wrapping is recommended to provide external confinement, which can increase the column's axial capacity and reduce potential cracking and concrete spalling. For defective concrete beams and slabs, external CFRP wrappings are suggested to enhance shear and bending moment capacities due to the deterioration of material properties.

In addition, RC jacketing method was suggested for decayed RC beams, columns, and slabs, specifying the required reinforcement and concrete. Appropriate designs were provided for each case, to enhance the structural performance of these elements and increase the durability of the structure. For the minor structural defects of the buildings, the applicability of the appropriate repairing techniques was reviewed including patch repair method and epoxy injection method.

4. Results and Discussion

4.1 Visual Inspection Results

Based on the visual inspection data, the cracking of concrete elements and spall-off concrete (Figure 10) due to the corrosion effect were identified as the most common defects in these studied school buildings.

Figure 10 – Defective Structural Elements in an Old School Building

4.2 Destructive and Non-destructive Test Results

According to the observed concrete core test data shown in Figure 11, the average compressive strength of the defective concrete slabs is around 15 N/mm^2, and it is significantly lower than the recommended value of 25 N/mm^2 in the original design considerations.

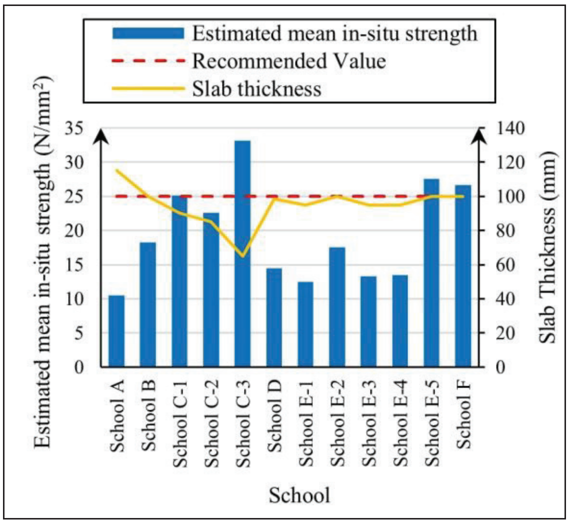

Figure 11 - Compressive Strengths of Concrete Slabs

Depending on the requirement, the rebound hammer test was conducted in some of the school buildings. The obtained test results show the existing average compressive strength values of beams and the columns were approximately 13 N/mm^2 and 18 N/mm^2, respectively, which is considerably less than the recommended value of 25 N/mm^2 in the original design considerations. The depth of carbonation test results illustrated in Figure 12 show that tested concrete members have significantly higher carbonated depths than the recommended value of 10 mm, and in most cases, the concrete sections are carbonated up to the rebar.

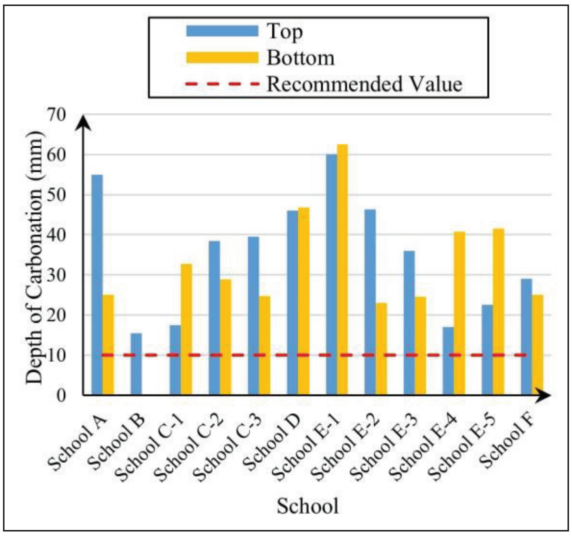

Figure 12 - Depth of Carbonation Test Results

According to Figure 12, the average carbonated depths of the slab top and slab bottom are 35.2 mm and 34.1 mm, respectively. Moreover, the half-cell potential test results show that tested concrete members have a considerably higher possibility for corrosion. Figure 13 highlights that the half-cell potential values are considerably higher than the 200 mV, which indicates a 90% probability that no corrosion is occurring (ASTM C876-91) [5]. The average value of the obtained test results was around 351 mV.

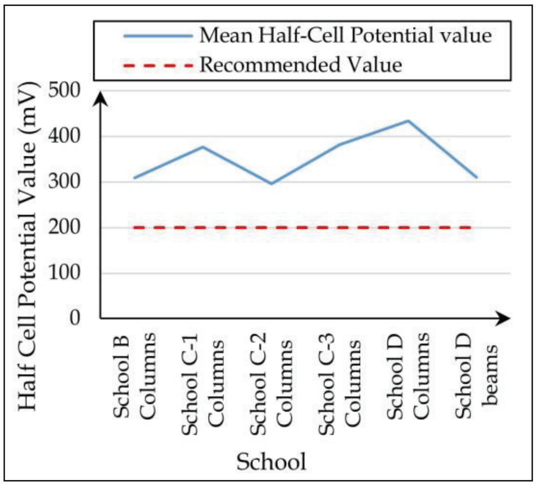

Figure 13 - Half Cell Potential Test Results

The UPV test results of several school buildings are shown in Figure 14, and they reveal that the concrete quality of those examined buildings is between the good and medium level (IS13311: part 1, 1992). Therefore, the concrete quality of the members remains in the safe zone, but it has the potential to deteriorate without proper repairing and maintenance works under engineer supervision.

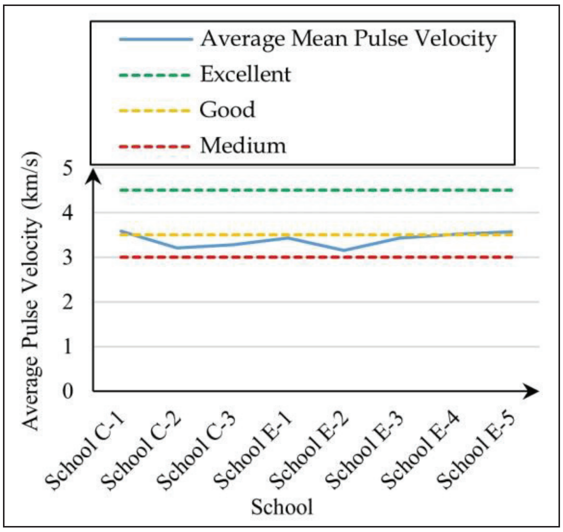

Figure 14 - UPV Test Results

4.3 Numerical Modelling and Capacity Assessment Results

Figure 15 shows the bending moment distribution of the frame elements of the modelled typical three-story school building. The maximum axial force of a column was around 530 kN, and the maximum bending moment and the shear force of an RC beam were 180 kNm and 145 kN, respectively.

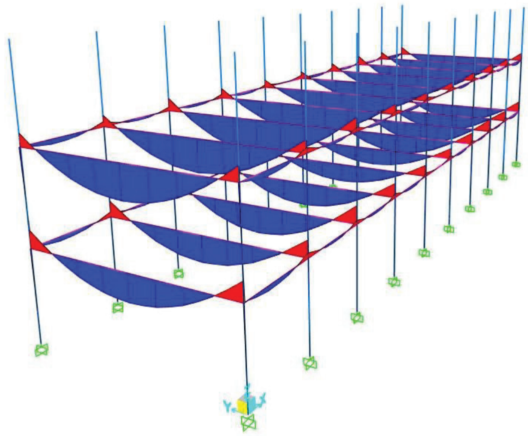

Figure 15 - Bending Moment Distribution of the Frame Elements

The bending moment-axial force (M-N) interaction diagram was developed for the typical RC column member, and the ultimate axial and bending moment capacities were compared with the required capacities obtained by the FE modelling results. Figure 16 illustrates the M-N interaction diagram of a 250 mm x 250 mm typical RC column member with its initial ultimate axial and bending moment capacities before the building deteriorated. The grade of the concrete and yield strength of the steel rebars were considered as 25 N/mm² and 460 N/mm², respectively. The required capacity in Figure 16 represents the axial and bending moment demands extracted from the FE model.

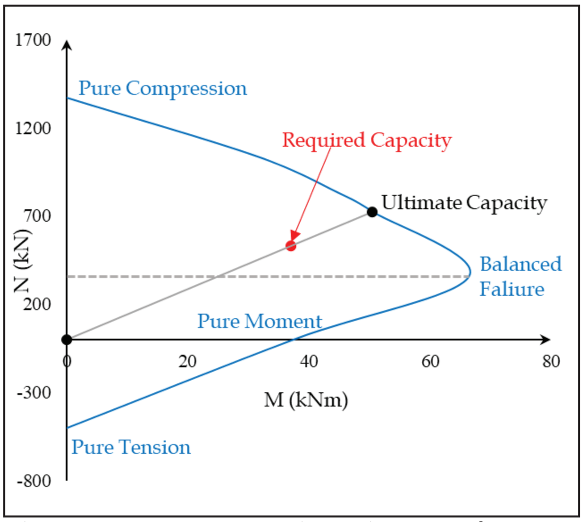

Figure 16 - M-N Interaction Diagram of a Typical RC Column Member

The behaviour of axial and bending moment capacities with the reduction of effective steel area due to corrosion in the decayed column member is shown below in Figure 17. The existing compressive strength of the decayed concrete was taken as 13 N/mm² based on the testing results, while the yield strength of steel was taken as 460 N/mm². The M-N interaction curves were developed for 10%, 20%, and 40% effective steel area reductions, which were compared in this analysis.

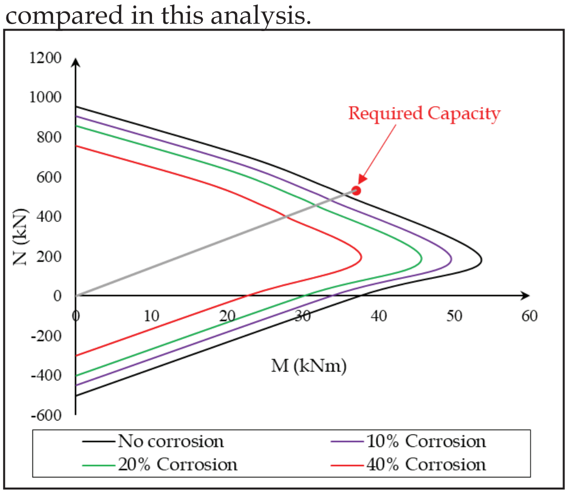

Figure 17 - Behaviour of Axial and Bending Capacities Under Corrosion

The initial bending moment and shear capacities of the RC beams and slabs were compared with the required demands from the

FE model. Subsequently, the reduction in capacity due to the building's deterioration process was considered, and changes in capacity related to concrete grade, effective steel area, and concrete cover were studied.

4.4 Feasible Retrofitting and Repairing Methods

The CFRP jacketing method is suggested for the RC column strengthening and the partial bending moment-axial force (M-N) interaction diagrams for unstrengthened and strengthened RC columns were developed. According to the Standard ACI 440.2R-17, 2017, the FRP systems should not be applied when the concrete section has a compressive strength lower than 17 N/mm². Therefore, a minimum of 17 N/mm² existing compressive strength is taken into the design purpose with an effective cover of 30 mm. The longitudinal steel reinforcement area reduction was assumed as 25% of its initial steel area due to corrosion. Table 1 represents the CFRP sheet properties (ACI 440.2R-17, 2017) that were considered in the design.

Table 1 - CFRP Sheet Properties

Thickness per ply (t_f)	0.33 mm
Ult. tensile strength (f_{fu}*)	379 2N/mm²
Rupture strain (ε_{fu}*)	0.00167 mm/mm
Modulus of elasticity (E_f)	227,527 MPa

The ultimate capacities of the deteriorated RC column member (unstrengthened member) and CFRP retrofitted RC column member (strengthened member) were compared with their initial design conditions. The axial and bending moment capacities of both the deteriorated member and the retrofitted member were calculated as per ACI 440.2R-17, and Figure 18 represents the developed partial M-N interaction diagrams. Here, the existing capacity represents the capacity of the deteriorated RC column member, while the required capacity was obtained based on the gravity load demands obtained from the FE modelling. In this design, complete CFRP sheet wrapping was suggested and Figure 18 shows the enhanced M-N capacity curves with the number of CFRP plies (n) applied. Applying five plies shows good agreement with the column’s initial design capacity, while four plies also provide a reasonable capacity enhancement compared to other options.

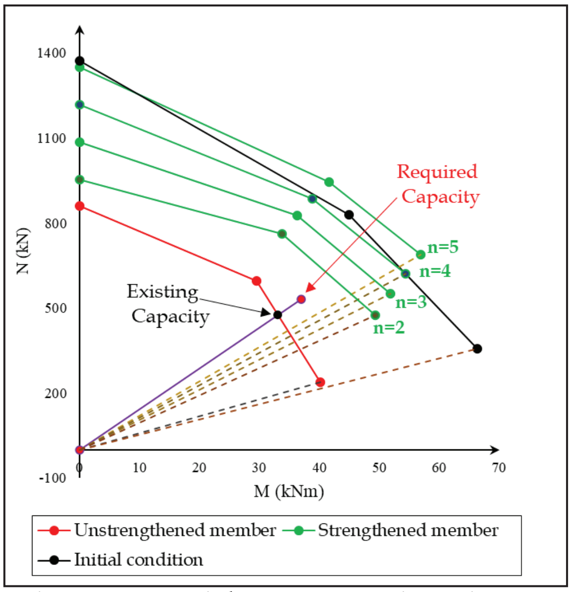

Figure 18 - Partial M-N Interaction Diagram

The RC jacketing design is suggested for defective columns (IS15988, 2013). For the design purpose, 25% of longitudinal steel reinforcement area reduction due to corrosion effect was taken into account, and the grade of the decayed concrete was considered as 13 N/mm² with an effective cover of 30 mm. Figure 19 shows the cross-section of the jacketed reinforced concrete column with the necessary reinforcement requirement. The RC jacketing of defective RC columns can be connected to the existing foundation using the chemical anchoring method or the appropriate method of connecting newly added reinforcements.

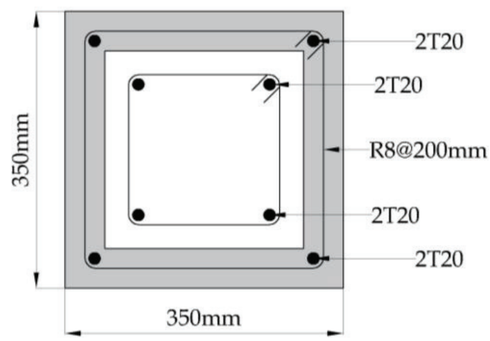

Figure 19 - Cross-section of the Jacketed RC Column

The CFRP strengthening designs for decayed RC beams were suggested based on the additional bending moment demands. Table 2 shows the properties of the external CFRP laminate considered in this design ACI 440.2R-17, 2017.

Table 2 - CFRP Laminate Properties

Thickness per ply (t_f)	1.02mm
Ult. tensile strength (f_{fu}*)	621N/mm^2
Rupture strain (ε_{fu}*)	0.015mm/mm
Modulus of elasticity (E_f)	37,000MPa

The design was carried out as per the wtqndard ACI 440.2R-17 (2017), and the grade of the decayed concrete material was considered as 18N/mm^2 with an effective cover of 30mm. In addition, 25% of longitudinal steel rebar area reduction due to corrosion effect was considered. Figure 20 shows the CFRP design for the flexural strengthening of decayed RC beams, where one ply of external CFRP sheets was applied.

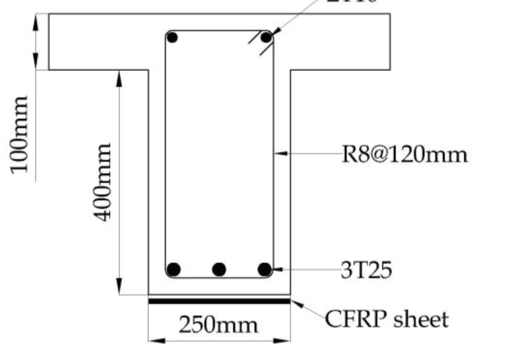

Figure 20 - Cross-section of RC Beam Strengthened with CFRP Sheet

RC jacketing was suggested as another retrofitting option for the decayed concrete beams. This can overcome both the flexural and shear demands of the beam. The grade of the deteriorated concrete material was considered as 18N/mm^2 with an effective cover of 30mm. In addition, 25% of longitudinal steel rebar area reduction due to corrosion effect was considered. Figure 21 shows the cross-section of the jacketed reinforced concrete beam with the appropriate reinforcement requirement.

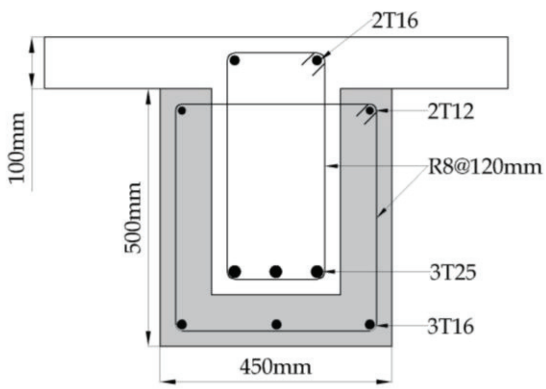

Figure 21 - Cross-section of the Jacketed RC Beam

In addition, RC jacketing for defective concrete slabs was presented here as a retrofitting solution. The decayed concrete material was considered 15N/mm^2, and the reduction of the effective steel area by 25% due to the corrosion effect was taken into account. Figure 22 illustrates the RC jacketing design for the defective concrete slab.

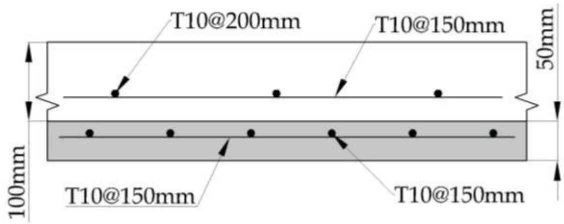

Figure 22 - Cross-section of the Jacketed RC Slab

For the identified minor defects on the structural elements during the visual inspection, repairing methods such as the patch repair method and epoxy injection method were suggested.

5. Conclusions

In this study, twelve old school buildings were evaluated, and these buildings were identified as two-story and three-story RC-framed buildings that have similar structural and architectural aspects. Most of the reinforced concrete members of these buildings have exposed and corroded reinforcements, due to the spalling of the concrete cover, and concrete cracks in the structural elements were recognized during the visual inspection.

According to the core test and the rebound hammer test results, the average existing compressive strength of concrete members was considerably less than the recommended value (25N/mm^2) in the design phase of the buildings. The concrete slabs display an average compressive strength that is approximately 40% lower than the recommended value. The rebound hammer test was conducted in some selected school buildings depending on the requirement of the test and the obtained results reveal that RC columns and beams have significantly lower compressive strengths, approximately 44% and 28% lower than the recommended value, respectively. Most of the concrete slabs were carbonated up to the rebars showing higher carbonation depths at both the top and bottom of the slab. It shows that the possibility of cracking concrete and rebar corrosion is high in these slab panels. Moreover, several examined school buildings showed a higher possibility of corrosion in concrete beams and columns as per the obtained results of the half-cell potential test. Therefore, the corrosion impact and the cracking due to the reinforcement corrosion are noticeably high in concrete beams and columns. In addition, the concrete quality observed from examined old school buildings was between the good and the medium level according to the UPV test results and the buildings are currently in a safe range of concrete quality but there is potential for quality degradation.

Most of the examined school buildings were identified as poorly maintained buildings and there were observable poorly repaired structural defects in the concrete elements. Nevertheless, these buildings are still in a repairable condition, and it might be more cost-effective than replacing these buildings with new buildings. To overcome the severe corrosion effects which can lead to the structural deterioration of the building appropriate regular inspections and maintenance procedures are required under engineering supervision. Other than that, these tested buildings need proper protection to keep the concrete quality of the structural members which might directly affect the durability of the structure. The suggested CFRP jacketing and RC jacketing strengthening techniques can be applied to the deteriorated RC elements to enhance their structural capacity.

In this study, the effect of the coastal environment was not considered, as the investigation did not include coastal-affected conditions. In addition, the observed defective RC beams did not exhibit shear failures during the inspection, but the possibility of shear failure due to the decay of shear reinforcements in the beams still exists. Therefore, further structural assessment is needed to accurately measure the amount of corroded steel in the decayed RC elements. Ultimately, this study provides a general retrofitting procedure based on the average condition of the examined old school buildings and suggests possible further assessments.

Acknowledgement

We would like to express our appreciation to the National Building Research Organization (NBRO) in Sri Lanka for granting us the opportunity to participate in their testing activities and for their grateful guidance throughout this study. We are truly grateful for this opportunity and look forward to continued collaboration with such a distinguished organization.

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