Case Study: The Strengthening and Rehabilitation of a School Building with Poor Construction Quality

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Abstract. Old infrastructure in most small islands developing states were built with poor construction quality leading to reduced concrete strength and load changes in these buildings are very common. Consequently, these structures have shown signs of premature damages and their service life remain elusive. This article deals with the inspection, assessment and strengthening of a reinforced concrete building, in Mauritius that is currently being used as a public school. The building was built in the year two thousand and is two storeys high. The establishment wants to add an additional storey on the existing building to increase student population. However, the building is showing signs of distress resulted from poor construction quality. The columns are misaligned on all three levels and the slab thickness is inadequate causing excessive vibration on the floors. The managements are not in favour of pulling down the existing building as they will have to abide by the new building regulations which will consequently decrease the allowable buildable area and will cause major disruption to the day to day activities. Therefore, the most feasible solution is to strengthen the load carrying capacity of members which have become structurally deficient over time to make the building safe and adopt to the addition of one storey above the existing building.

1. Introduction
Poor construction quality in old building is very common in small island developing states since the implementation of strict building guidelines is fairly recent. The most common and widely used construction material is concrete. This is because these states are vulnerable to cyclonic weather and concrete provides adequate resistance to weathering and other natural disasters. However, good construction practice and appropriate protection to the concrete is necessary for the building to survive its intended structural design life. Very often these concrete structures show sign of premature damages that may result from the aggressive environment or unplanned events such as fire or change of building use or inappropriate construction techniques or a combination of these scenarios.

There are various repair and strengthening techniques for reinforced concrete structures. These techniques are classified as primary strengthening and passive strengthening [1]. When the design service loads are greater than the load carrying capacity, primary strengthening is required to prevent the collapse of the structural member. Conversely, passive strengthening is required to reduce excessive deflection and crack propagation when additional loads are applied to a member that was previously designed for a lower design capacity. Among all the different techniques that exist, those involving restriction of movement in structural members are the most rapid and efficient in restoring damaged members [2].
In this particular research work, the intent was to look at the most appropriate method for strengthening an existing privately-operated secondary school, which is more than 20 years old. The management of the school had the intention of adding a new floor to the existing three-story high building. Information collected on the said building indicated that the construction was executed in several phases, no as made architectural or structural drawings were available to assess the structure. Furthermore, the different contractors involved in the construction were not graded contractors but a team of masons appointed by the client to supply labour only while the material, plants and equipment were procured by the client. Consequently, no supervision at all was done during the execution of the works.

The privately-owned secondary school is a three-story high building with a reinforced concrete skeleton cladded with cellular masonry blocks bonded altogether with cement mortar. Each floor is composed of three classrooms, each of internal dimensions 6.0 metres by 6.0 metres. The headroom within the classroom was constant across the floor but varied from floor to floor.

Hence, the main objectives of the study were to (i) assess the current state of the building, (ii) determine whether or not the building will be able to sustain another floor; and (iii) means and methods of ensuring the structural soundness of the building with the addition of one more floor.

2. Methodology
The proposed methodology adopted is as described in this section.

**Step 1: Structural Assessment of the existing building** – A visual inspection survey was carried out throughout the entire building to assess the condition of the structural members.

**Step 2: Non-Destructive tests** – The tests were performed on reinforced concrete columns, beams and slabs in order to assess the strength of the existing concrete.

**Step 3: Destructive tests** – Further investigation were required to assess and confirm the poor compressive strength of specific structural elements within the building.

**Step 4: Structural Design Checks** – Structural members were checked through design calculations to determine the feasibility of adding an additional floor to the existing structure.

**Step 5: Strengthening of the reinforced concrete elements** – A review of the existing strengthening and reinforcement methods and the selection of the most appropriate technique suitable for the school.

**Step 6: Implementation of the proposed system.**

3. Observations and discussions
3.1 Structural Assessment of existing building
A walkthrough visual inspection was carried out throughout the entire building. Cracks were observed in all classrooms as shown in figure 1 below, particularly at corners of openings [doors and window]. However, since the widths of the cracks varied between hairline and 1 mm, the resulting cracks were classified as cosmetic and consequently, had no incidences on the structural integrity of the existing building. Spalling of the floors were also observed during the survey and this occurred on all of three
floors but not in all the classrooms as illustrated in figure 2 below. Furthermore, the rebar in the slabs at the spalling points were in a state of advanced rusting.

![Figure 1. Error! No text of specified style in document. Crack over opening.](image)

![Figure 2. Spalling in slab.](image)

Based on the observations made during the survey, destructive tests were carried out to assess the strength of the existing reinforced concrete slabs.

### 3.2 Non-destructive testing

The Schmidt hammer or rebound hammer test is a non-destructive testing method of concrete which provide a convenient and rapid indication of the compressive strength of the concrete. The hammer, as shown in figure 3, consists of a spring-controlled mass that slides on a plunger within a tubular housing.

![Figure 3. Rebound or Schmidt hammer.](image)

![Figure 4. Rebound hammer testing positions.](image)

The test was done on the reinforced concrete columns, beams and slabs of the building under investigation and the following steps were adopted:

1. The concrete surface was smoothened, cleaned and dried.
2. Loose particles were rubbed off from the concrete surface with a grinding wheel or stone, before hammer testing.
3. Rebound hammer test was not conducted on rough surfaces as a result of incomplete compaction, loss of grout, spalled or tooled concrete surface.
4. The point of impact of rebound hammer on concrete surface was kept at least 20mm away from edge or shape discontinuity.
5. Ten readings of rebound number were taken at each point of testing and an average value of the readings is taken as rebound index for the corresponding point of observation on the concrete surface.
6. When carrying out the tests, the rebound hammer was positioned according to figure 4.

The results following the rebound hammer tests are illustrated in Table 1. It can be seen that the average value for the slabs are all less than 20 inferring that the concrete is of poor quality and strength, thus requiring further investigations. For both beams and columns, the average value was between 28 and 30 inferring that the quality of concrete is fair. Compressive strength of both reinforced beams and columns were in the range of 25 to 30 MPa.

**Table 1. Rebound hammer test results.**

| Test # | Element | Floor level | Slab | Beam | Column |
|--------|---------|-------------|------|------|--------|
| 1      | 1       | 1           | 1    | 1    | 1      |
| 2      | 2       | 2           | 2    | 2    | 2      |
| 3      | 3       | 3           | 3    | 3    | 3      |
| 4      | 4       | 4           | 4    | 4    | 4      |
| 5      | 5       | 5           | 5    | 5    | 5      |
| 6      | 6       | 6           | 6    | 6    | 6      |
| 7      | 7       | 7           | 7    | 7    | 7      |
| 8      | 8       | 8           | 8    | 8    | 8      |
| 9      | 9       | 9           | 9    | 9    | 9      |
| 10     | 10      | 10          | 10   | 10   | 10     |
| Total  | 136     | 127         | 147  | 132  | 130    |
| Average| 13.6    | 12.7        | 14.7 | 13.2 | 13.7   |

3.3 Destructive testing

After performing the non-destructive rebound hammer test, it was found that the compressive strength of the reinforced concrete slab for all the different floors in the building was poor, around 10 MPa. This strength is by large below the normal design concrete strength (25 MPa) that was used for the design of such slab in the past. Hence, there was a need to confirm the poor concrete strength through destructive tests.

Coring, which is the process of removing a cylindrical sample, or core, from the existing reinforced concrete slab, was performed. The apparatus used was portable as shown in figure 5. The core samples were then sent to the laboratory for the determination of the compressive strength of the slab. Table 2 illustrates the compressive strength of the reinforced concrete slab.

**Table 2. Core test results.**

| Ref.       | Thickness (mm) | Area (mm²) | Weight (g) | Force at failure (kN) | Correction factor | Compressive Strength (MPa) |
|------------|----------------|------------|------------|-----------------------|-------------------|--------------------------|
| First floor-Corner | 139       | 7080      | 2310      | 46.93                 | 0.96              | 6.4                      |
| First floor-Middle | 111       | 6700      | 2280      | 70.29                 | 0.93              | 9.8                      |
| Second floor-Corner | 101       | 6990      | 1700      | 95.44                 | 0.87              | 11.9                     |
| Second floor-Middle | 89        | 6740      | 1650      | 47.45                 | 0.87              | 6.1                      |
| Roof-Corner   | 123       | 6900      | 2060      | 115.4                 | 0.93              | 15.6                     |
| Roof-Middle   | 113       | 6900      | 1990      | 97.24                 | 0.93              | 13.1                     |
Figure 5. Core drilling machine.

The values obtained confirmed the poor quality and strength of the reinforced concrete slab across all the different floors of the building. Furthermore, it was also found that the thicknesses of the slab were below the norms and need to be strengthened.

3.4 Design Checks

Since no as-made drawings of both architectural as well as structural plans were available, some additional investigations were carried out as detailed hereunder.

- The reinforcement to the columns, beams and slabs were exposed at specific places in order to confirm the size and reinforcement used.
- The middle and one edge of the column foundation of the building were exposed in order to determine firstly the size of the bases and then the reinforcement to the bases.

These sizing were then used to check the suitability of the existing elements for the addition of another floor. However, during the course of this particular exercise it was found that the columns at the different floors were not aligned. Further investigation revealed that the building was constructed in phases, level by level and each time a different contractor was appointed for the execution of the works.

Table 3 illustrates the required sizes of the different elements upon addition of one more story. The new floor layout will be the exact replica of the previous ones, that is will accommodate three classes of same dimensions.

| Element    | Actual | Required for addition of one more level |
|------------|--------|----------------------------------------|
|            | Size   | Cover | Reinforcement | Size   | Cover | Reinforcement |
| Middle     | 2000   | 2000  | 300 30-35 T12-150 B1 and B2 | 2500   | 2500  | 500 50 T12-150 B1 and B2 |
| Middle Edge| 2000   | 2000  | 300 30-35 T12-150 B1 and B2 | 2500   | 2500  | 450 50 T12-150 B1 and B2 |
| Columns    | 300    | 300   | 400-280 4T16 + T08-200 | 300    | 300   | 2800 30 4T20+4T16 + T08-150 |
| Beams      | 6000   | 200   | 400-425 4T20 + T08-150 | 6000   | 200   | 450 30 4T20 + T08-150 |
| Slabs      | 6000   | 3000  | 89-139 15-20 T10-200 B1 and B2 | 6000   | 3000  | 175 30 T10-200 B1 and B2 |

Major issues that required further consideration for ensuring a structurally safe and sound building upon the addition of one more level are:

- Inadequate bases
- Misalignment of columns
- Inadequate reinforcement to columns
- Inadequate thicknesses of the existing slab

3.5 Strengthening of the bases, columns and slabs

From the literature there exist a number of means and methods for the structural strengthening of the above-mentioned elements.
Jacketing method can be used for both concrete and steel reinforcement. In concrete jacketing the structural members gain additional strength from the monolithic behaviour created by the bonding of the old and new reinforced concrete. It is noted that the effectiveness of the composite is independent of the surface roughness [3].

According the Xiao and Wu, steel Jacketing method is mostly effective in increasing the ductility of columns [3]. Moreover, it is the most affordable techniques where steel angles and strips are glued to the concrete column and the ends are welded to form a cage around the column as shown in figure 6 below [4].

![Figure 6. Steel jacketing of column [3].](image)

In addition to the gain in axial resistance produced by the angle bars, steel jacketing also increase the shear strength of concrete. The effectiveness of this technique is dependent on the bonding strength between the concrete and the steel. However, little gain in flexural stiffness of members is observed [3]. Several researches have been carried out to investigate the effects of the size of steel angles and strips, the spacing of the strips, the bonding techniques in view to optimize the method. Cirtek concluded that the size of steel angles and strips can increase the load carrying capacity of the columns by about 55% [4]. Badr also concluded that the load carrying capacity can be increased by 16% when anchor bolts are on the strips [4]. Gimenez et al.[4] found out that premature failure of columns that are strengthened by steel angles and strips can be prevented by decreasing the strip spacing at the ends. This method will also result to an increase in load carrying capacity [4].

**Reinforcing the base** - For our study, the bases, being inadequate to sustain the resulting load, had to be enlarged and the method of jacketing as shown in figure 7 (a) below was adopted using the proposed methodology.

1. All floors were propped using diameter 65 mm steel hollow pipes at a spacing of 1 meter by 1 meter.
2. After setting out the new bases, the existing surface bed was cut. The existing bases were exposed.
3. Reinforcements were dowelled into the existing concrete bases using approved epidermix and the specified procedures of the manufacturer were followed.
4. Cover block of thickness 50 mm were used
5. Concrete of compressive strength 35 MPa was used to cast the foundations.
6. Cubes were taken for testing at both 7 and 28 days.
Reinforcing the concrete columns – Though the size of the existing reinforced concrete columns were adequate, unfortunately design calculations showed that the existing reinforcement were not sufficient. Furthermore, to cater for the misalignments, the only possible solution was to again adopt the jacketing principle as illustrated in figure 7 (b). The following steps were adopted:

1. Rendering to the existing columns were removed
2. Honeycombing were spotted at a number of places along the columns
3. The observed defects were treated
4. Additional reinforcement was dowelled into the existing columns using approved epidermix using the specified procedures of the manufacturer.
5. Cover block of thickness 30 mm were used
6. Concrete of compressive strength 30 MPa was used for casting.
7. Cubes were taken for testing at both 7 and 28 days.

The resulting column was of dimensions 800 mm by 800 mm as it had to account for the misalignment of the existing columns occurring at the different levels.

Figure 7. (a) RC jacketing of base, (b) RC jacketing of column [3].

Strengthening of existing slab – The existing slab thicknesses, ranging between 89 mm and 139 mm, are all below minimum design standard. The option of pulling down and reconstruction of the slab was discussed with the client, but this option was declined.

One technique that was highlighted by Stuart to reinforce concrete slab is to fit new steel sections underneath the slabs connected to the existing beams [5]. The composite action of the steel channel and the concrete slab increased the load carrying capacity. Due to its simplicity, no in-depth investigation was carried out.

Therefore, due to its effectiveness and ease of construction, new steel channel sections were used to strength the weak slabs as shown in figure 8 below.
Figure 8. Plan and section across slabs being strengthened.
4. Conclusions

After reviewing the designs, instructions were given to the contractor for implementing the different tasks. Bases and beams were strengthened through jacketing and the existing slabs were strengthened through the addition of steel channels. After the execution of the works, two coats of white paint were applied to the internal faces of the building and on a weekly basis cracks development were monitored. During the monitoring period, only hairline cosmetic cracks were observed. With no increase in the concentration and propagation of cracks it was concluded that the strengthening techniques adopted were appropriate.

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