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EVALUATION OF CONCRETE COVER DEPTH OF SELECTED INSTITUTIONAL BUILDINGS USING PROFOSCOPE

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Abstract: The importance of concrete cover depth to reinforcement bars cannot be over emphasized in reinforced structures. Investigation of cover depth in reinforced concrete buildings help to detect and prevent the so-called corrosion of rebars and cracking. This paper reports a non-destructive investigation of two existing reinforced concrete institutional buildings. Though, there are several methods of non-destructive testing techniques for measuring cover depth such as ground penetrating radar (GPR), cover meter, infrared thermography, etc., the type used for this research is Profoscope by Proceq. The reliability and accuracy of this equipment was first tested on six newly cast reinforced concrete block specimens of 250 mm x 300 mm x 300 mm with varying cover depths and re-bar diameters. The concrete is made up of grade 20 with water cement ratio of 0.5. The Profoscope was used on the field to locate and estimate the cover depth of the structural beam and column elements of the selected buildings. The results of the calibration show that the Profoscope is a relatively reliable equipment for estimating cover depth, but with its ease of use, durability, compactness, lightweight and robustness, it has the limitation of measuring the cover to reinforcements up to only a maximum depth of 80 mm. The analysis of the field data shows that about 7% of the columns and 5% of the beams in one of the buildings, and 2% of the columns and 7% of the beams in the second building fail to meet the minimum requirement of 20 mm as specified in Table 3.4 of BS 8110-1:1997 under any condition of exposure. It is noted that the total number of structural members that fail to meet the minimum requirement is seemingly insignificant, but the consequence of abnormal loading or exposure of the affected members may be substantial depending on their locations in the main structural system. The need for proper and prompt maintenance strategy on the examined buildings is advised.
Keywords: reinforced concrete, non-destructive techniques, rebars, cover depth, profoscope

1. INTRODUCTION

Cement, fine aggregates, coarse aggregates and water are very common constructional materials. When these are mixed together in the correct proportions, they form a very important material termed concrete (Hirschi *et al*., 2005). The cement is the binder while the aggregates are the inert materials. When the concrete components are mixed together, through the process called hydration, the paste turns into solid called concrete. However, the concrete is very good in its compressive properties but weak in tension when loaded. The aftermath effect of this weakness is that concrete begins to develop cracks at the tension side when the load exceeds the tensile strength. Therefore, when reinforcement is added, it will supply the tensile strength needed. The combination of concrete and reinforcement is termed reinforced concrete. When the reinforcement in the concrete does not have adequate cover, there is tendency for the rebars to get exposed and become vulnerable to corrosion. The corrosion of rebars in concrete can adversely affect the strength of any reinforced concrete structure. This is the reason why there must be periodic assessment of the structural element of all reinforced concrete structures. One of the commonest techniques is the non-destructive tests. Non-destructive technique (NDT) is a process of determining the integrity of a structure without destroying its components (Gupta, *et al*., 2015). The tests are used to determine the strength and durability of structures. The use of any methods of NDT depends on the types of properties desired. Some of the NDT methods are penetration test, radiography test, ultrasonic pulse velocity test, magnetic particle test, liquid penetration test, ground penetration radar test (GPR), rebound hammer test, etc. (Shankar and Joshi, 2010, Sakshi, 2018, Schabowicz, 2019, Jedidi & Machta, 2014). All these tests can be used for both old and new structures. However, it is always good to monitor the depth of concrete cover to reinforcement in reinforced concrete buildings. This will give us the propensity of the embedded reinforcement to corrosion. As the name implies, concrete cover is the distance between the embedded reinforcement in the concrete and the outside of the concrete in which its inadequate provision may impair the structural integrity of the structure (Steel Detailing and Drafting Services, 2019). Apart from concrete cover providing resistance to reinforcement corrosion and deterioration, it also helps to resist fire in case of exposure to fire (Engineering Basic, 2019). Table 3.3 of BS 8110-1:1997 gives the specified nominal cover to all reinforcement (including links) to meet durability requirements, while Table 3.4 of the same document gives the specified nominal cover to all reinforcement to meet specified periods of fire resistance. These specified cover depths should be maintained throughout in the concrete irrespective of any factor such as reinforcement lapping. However, for both old and new structures, in order to ensure that adequate cover has been provided, there is the need to conduct structural integrity tests using appropriate NDT devices. The two main NDT devices commonly available is cover meter and ground penetrating radar (GPR) (Bhaskar and Ramanjaneyulu, 2015, Ambika and Alfa, 2017, Rathod *et al.*, 2019). These equipment are relatively useful for locating rebars and for estimation of cover depth in reinforced concrete.

2. COVER METER

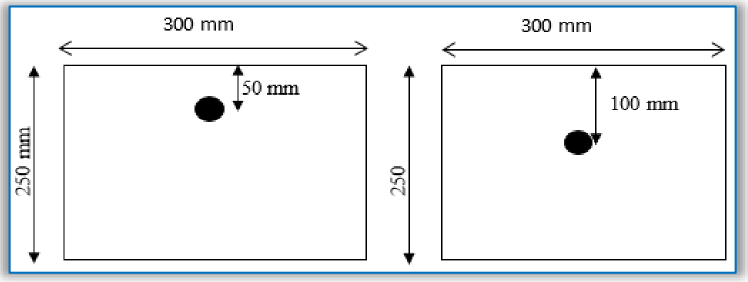
As the name implies, cover meter is an instrument used to locate rebars, identify rebar diameters and estimate cover depth. It is based on electromagnetic pulse induction principle to perform its operations. In the market, several types of cover meter are available viz. Cover Master, NOVOTEST, Pachometer, Micro-cover meter and Profometer (The instructor, 2019, Engineers' Forum, 2019). For this research, Profoscope from Proceq was used (Figure 1). The equipment is versatile, fully-integrated rebar detector, real-time rebar–visualization, in addition to rebar-proximity indicators and optical and acoustic locating aids.

Figure 1: Profoscope (Gilson, 2019)

Apart from these features, the equipment is easy to use and durable. It possesses memory functions which can be used for data export and analysis. As well, it is compact, robust, very light, and battery powered. To use this equipment, it must be switched on in the switch-on button. It is then placed on the test surface and move gently in a direction where rebar is supposed to be located. The Rifle Scope of the equipment moves in the opposite direction. With to and fro continuous movement, the equipment is made to rest when the Rifle Scope is directly at the centre line. At this position, flash of light is produced by the LED indication. The reading can then be taken and documented. If the rebar diameter setting is accurate, the result of the cover depth also will be accurate (Profoscope Operating Instructions by Proceq, 2015).

3. CALIBRATION OF THE PROFOSCOPE

The Profoscope was calibrated using six blocks of concrete prepared with grade 20 and allowed to cure for 28 days after casting according to the method used by Sivasubramanian *et al.*, 2013. The size of each concrete blocks was 300 mm x 300 mm x 250 mm. Two 16 mm bars were placed at distances 50 mm and 100 mm from the top into each of the mould before casting. This also goes for 20 mm and 25 mm thereby making the total concrete blocks made to be six numbers. Figure 2 (a-b) shows the specimens' sides indicating the position of the rebars. After 28 days, the equipment is then placed at the top of the block and performs the testing to locate the rebars and the cover depth (Figure 3).



(a) (b)

Figures 2: Specimens side showing the position of rebar and cover depth at (a) 50 mm; (b) 100 mm


Figure 3: Testing a concrete block sample


Figure 4: Site measurement

4. SITE MEASUREMENT

The field measurements using the Profoscope were done on two hostels on one of the Campuses of the Universities in Nigeria. Measurements were taken on the structural elements (beams and columns) (Figure 4). The layouts of the beams and columns are shown in Figures 5 and 6. Accessible structural elements that were measured were 72 columns and 44 beams in Hostel A, and 161 columns and 89 beams in Hostel B.

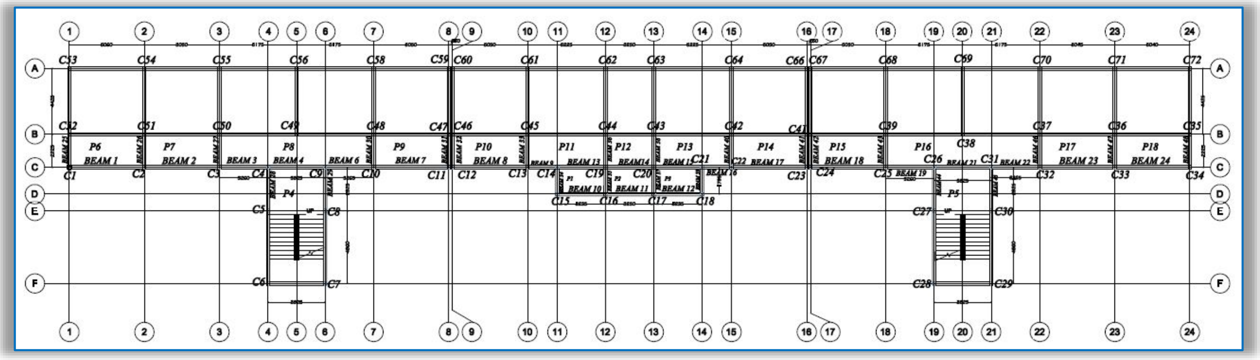


Figure 5: The structural layout of the building Hostel A

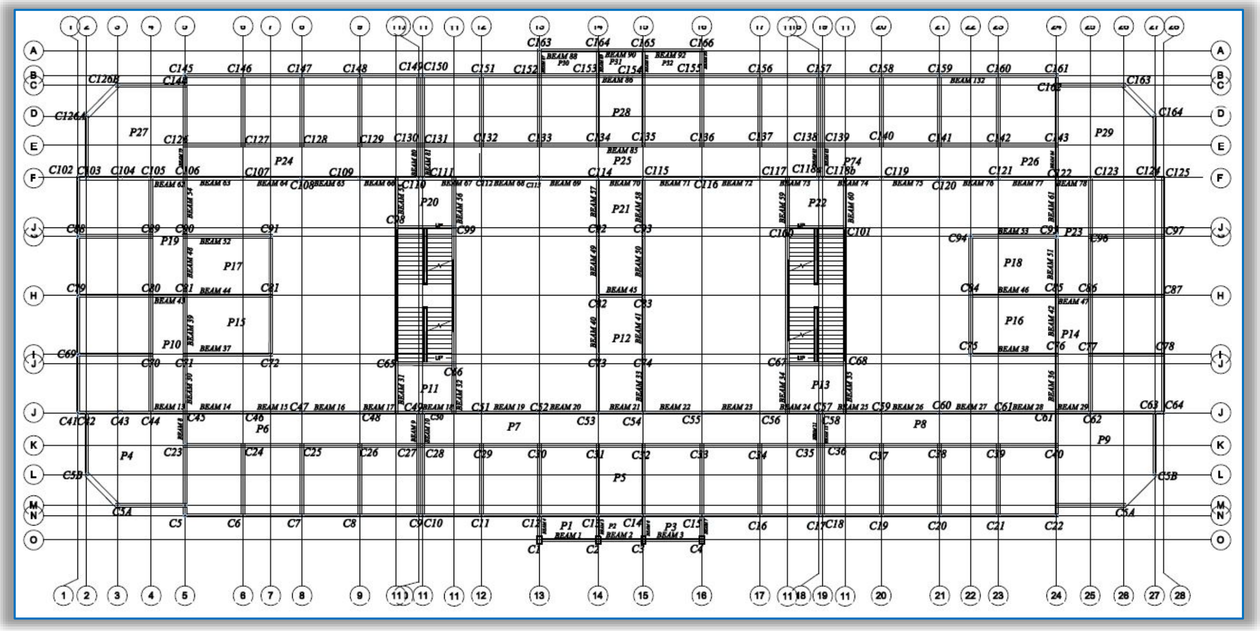


Figure 6: The structural layout of the building Hostel B

6. RESULTS AND DISCUSSION

The various laboratory and field measurements on concrete cubes and the structural elements of the existing buildings, respectively, are presented and discussed.

— Results of Calibration of the Profoscope

Table 1 shows the results of the detected cover for the reinforced concrete blocks. The data in the table show that Profoscope can effectively be used to measure diameter of rebars and their corresponding cover depths. These results follow the equipment's specification of measuring range (for standard, it is 100 mm while for large range, it is 185 mm).

Table 1: Details of different reinforced concrete block specimens and their detected clear cover and rebar diameter.

Concrete Block Specimen	$\emptyset$ (mm)	$\emptyset^1$(mm)	H (mm)	h (mm)	h^1 (mm)	E (%)
B1	16	16	50	43	42	2.33
B2	20	20	50	43	40	6.98
B3	25	25	50	43	37.5	12.79
B4	16	?	100	78	92	-17.95
B5	20	?	100	79	90	-13.92
B6	25	?	100	80	87.5	-9.38

Note: $\emptyset$ is the actual diameter of bar, $\emptyset^1$ is the diameter of rebar detected by the meter, H is the actual location of bar centre from top surface, h is the detected clear cover and $\boldsymbol{h^1}$ is the clear cover.

The error in detection of the cover depth increases as the rebar diameter increases for both 50 mm and 100 mm locations. It can therefore be affirmed that the equipment can measure cover depth up to 80 mm but could not measure the rebar at this depth. The rebar can only be measured at 43 mm depth when the actual location of bar centre from top surface is 50 mm. This implies that though the equipment can locate rebars, measure rebar diameter and cover depth, it has its limitations. The thicker the cover depth, the lesser the efficiency of the equipment in locating rebar, which corroborates the work of Sivasubramanian, *et al.*, (2013). The slope of the plot of the Profoscope reading against the actual cover (Figure 7) is 0.714 with its constant as 14.649 mm. This shows that the equipment needs to be calibrated to be able to know its efficiency and limitation before usage.

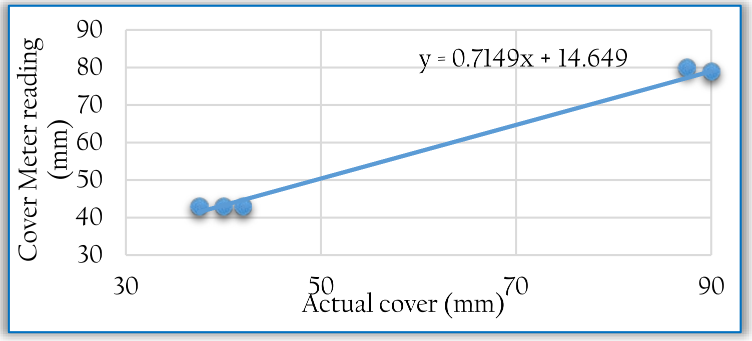


Figure 7: Cover Meter reading against actual cover

— **Cover Depth on the investigated Buildings**

Figures 8 and 9 show the plots of the measured and designed cover depths of the columns for Hostel A and Hostel B respectively:

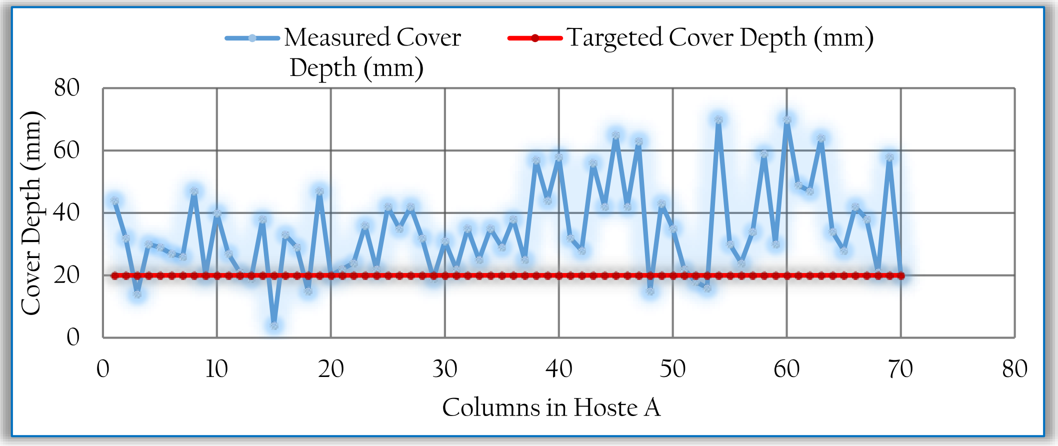


Figure 8: Cover depth for Hostel A columns

From these Figures, the average cover depth and standard deviation of the columns are 34.71 mm and 14.52 mm for Hostel A, and 33.32 mm and 8.94 mm for Hostel B respectively. Similarly, it was observed that the columns labelled C3, C13, C15, C18, C29, C48, C52 and C53 for Hostel A and C8, C12, C19, C26, C45, C57, C65, C66, C83, C106, C118, C125, C129, C152 and C159 for Hostel B did not meet the targeted cover depth of 20 mm as specified in the Table 3.4 of BS 8110-1:1997 under any condition of exposure. To effectively keep the bond between the concrete and reinforcement and to avoid corrosion of the embedded rebars, urgent attention for repairs is needed.

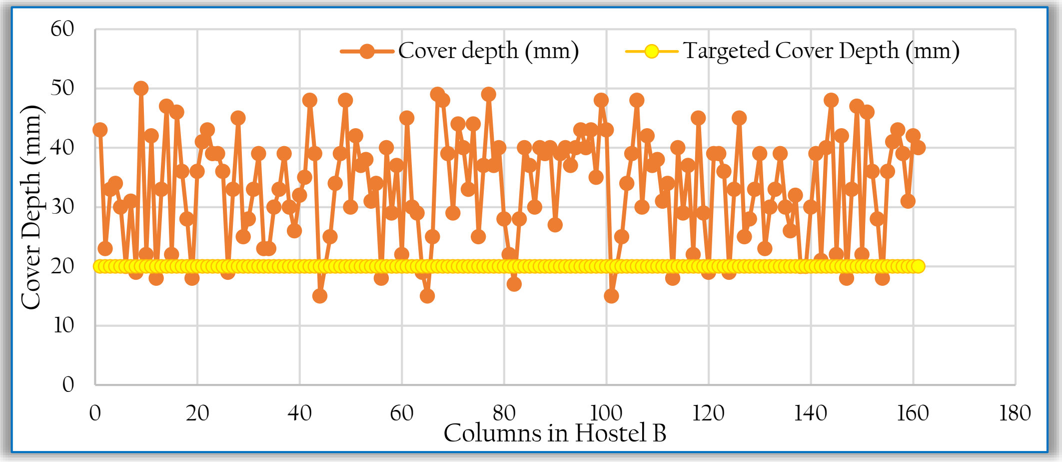


Figure 9: Cover depth for Hostel B columns

The frequency plots for cover depth of columns in Hostel A and Hostel B (Figures 10 and 11) show that 93% of columns in Hostel A and 98% columns in Hostel B meet the minimum requirements.

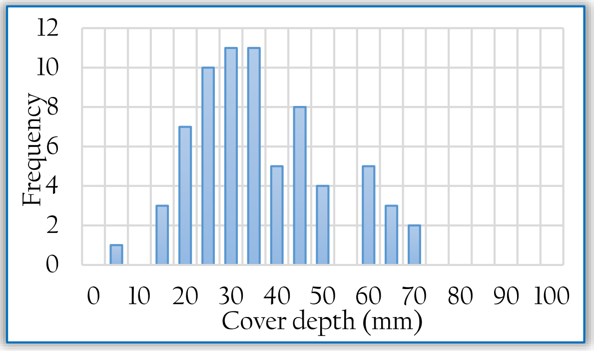


Figure 10: Frequency plot of cover depth of Hostel A columns

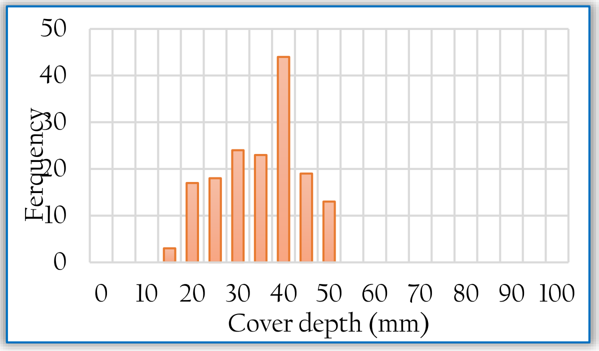


Figure 11: Frequency plot of cover depth of Hostel B columns

For the beams, the mean value and the standard deviation of the cover depth are 37 mm and 11.41 mm for Hostel A, and 39 mm and 11.02 mm for Hostel B respectively. The beams labelled B10, B14, B36, and B41 in Hostel A and beams labelled B23, B42, B45, B46, B47 and B52 in Hostel B (Figures 12 and 13) failed the minimum requirements of cover to reinforcement. Although more than 95% of the beams meet up to standard of cover depth in Hostel A while more than 93% in Hostel B passed, there is still need for proper maintenance before noticeable deterioration.

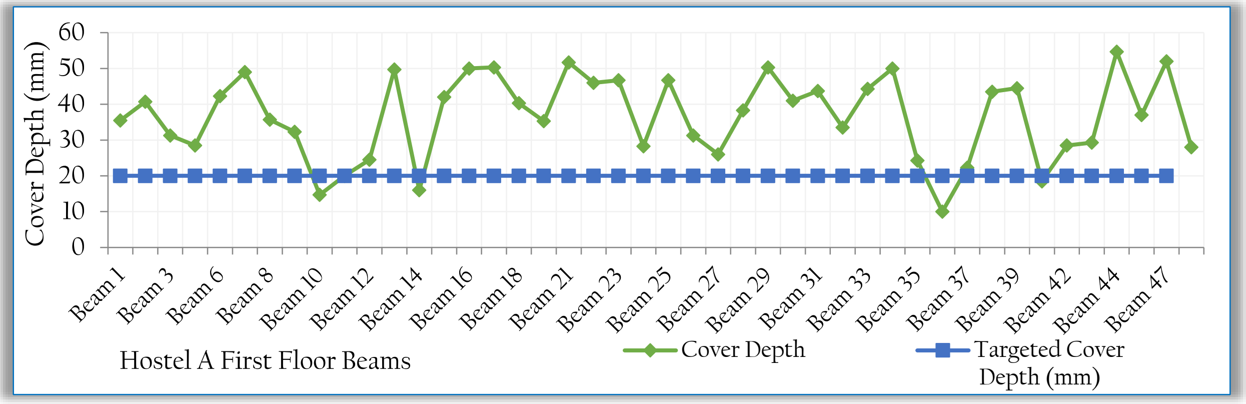


Figure 12: Cover depth for Hostel A beams

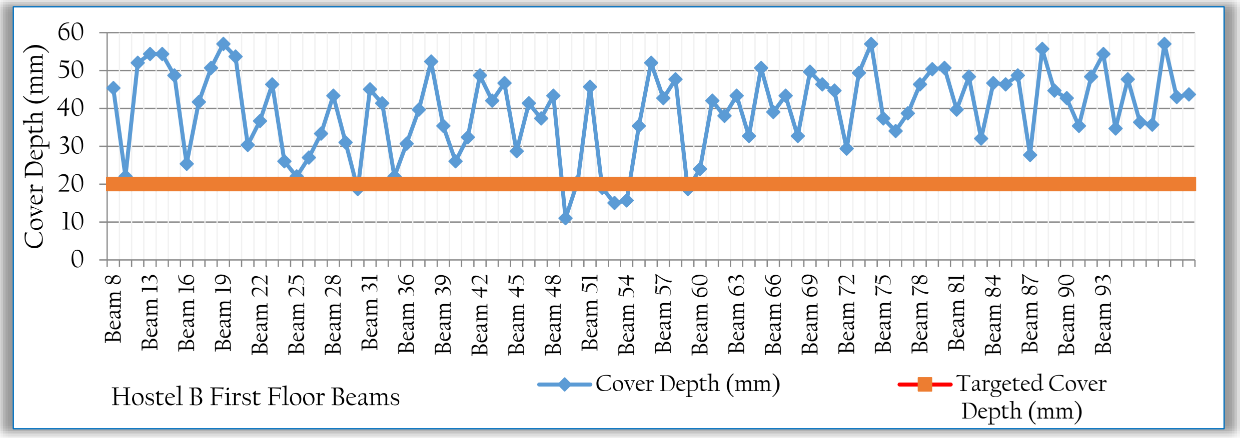


Figure 13: Cover depth for Hostel B beams

7. CONCLUSIONS

As part of the measure to ensure continuous use of structures, integrity of structures should be taken very seriously. This paper has reported the use of Profoscope to evaluate adequacy of the concrete cover depth to reinforcements in columns and beams of two selected reinforced concrete buildings. The field investigation has established that Profoscope is a very good equipment that can be used to locate rebar and evaluate the cover depth in reinforced concrete. Although the equipment has its limitations, it is easy to use, durable, compact, very light, robust and can measure concrete cover up to a depth of 80 mm. This investigation is for quality assurance, and it is noted that about 7% of the columns and 5% of the beams in Hostel A, and 2% of the columns and 7% of the beams in Hostel B fail to meet the minimum requirements. The total number of structural members that fail to meet the minimum requirement is seemingly insignificant, the consequence of abnormal loading or exposure of the affected members may be consequential depending on their locations in the main structural system. The need for proper and prompt maintenance strategy on the examined buildings is advised.

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