Quality Assessment Of Reinforced Concrete Structural Elements Of Some Selected University Buildings Using Ultrasonic Pulse Velocity Test

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Abstract —The rate at which buildings collapse in the world is increasing at an alarming rate and most often the aftermath effects are highly devastating to both humans and properties. As a result of this, there is a need for preventive measures on the existing buildings to prevent failure. Structural health monitoring through non-destructive techniques is a good approach to this. In this research, two institutional hostels (A and B) were chosen, and an ultrasonic pulse velocity tester was used to test the accessible structural components (slabs, beams, and columns) for their concrete quality. It was discovered that the hardness of concrete of columns of Hostel B has high pulse velocities than Hostel A, but Beams A have high quality of concrete more than B and that of slab B is more than slab A. Similarly, floor beam 10 possesses greater hardness than other structural elements while some of the beams (beams 9, 13, and 14) also possess so low a concrete quality as 3.0 km/s in Hostel A. The maximum pulse velocity for the slab is 5.30 km/s, 5.40 km/s for beams, and 4.30 km/s for columns in Hostel A. For Hostel B, the maximum pulse velocity is 6.20 km/s, while that of the slab is 5.60 km/s and 5.30 km/s for first floor beams. The variation in the nature of the hardness of the tested concrete as well as low quality performance obtained in some structural elements signifies that periodic structural health monitoring is advised in order to prevent failure.

Keywords—Reinforced concrete; non-destructive techniques; ultrasonic pulse velocity

I. INTRODUCTION

From the time immemorial, man has found several means to protect himself from the weather such as rain fall, snow fall, sunlight, heat waves, etc. Due to this, he used a lot of materials for construction of shelters so as to achieve this cogent objective. Such materials that have been used from creation include wood, leaves, animal skin, clay (mud), stone, brick, metals, plastics, concrete, etc. All these materials have their own pros and cons because of their variation in both physical and chemical properties. For instance, wood can be locally sourced and possesses both heat and electrical resistance but its light weight property does not make it good to support heavy loads and also not strong enough to withstand long span. As well, steel has very good fatigue strength and can be used for high rise buildings but it is generally very expensive. However, the most commonly used building materials on earth is concrete [1]. This is because concrete has good compressive strength, durable and can be used to form any desired shape. When used in conjunction with steel, it forms reinforced concrete, which is better than ordinary mass concrete [2]. The addition of reinforcement increases its tensile strength. As a result of these laudable properties, concrete proves to be a versatile material used for construction of buildings. However, overtime, the concrete tends to get deteriorated during service life. The deterioration may be in form of scaling, delamination, efflorescence, disintegration, erosion, corrosion of reinforcement, spalling, alkali-aggregate reactions and cracking. The defect may occur for building under construction or in use. The consequences of not paying attention to these defects on time may be calamitous to human, properties and economy. The five-story building collapse at India in August 2020 which left twelve people dead [3]; the fear for collapse of Central PP building, Cambodia (70 years old having more than one thousand rooms and 65 families) in September 2020 when parts of the building crumbled and particles fell off into the nearby road after rainfall

[4]; and the high rise building (under construction) which belonged to Houston-based Marathon Oil's new headquarter collapsed in October 5, 2020 leaving at least three people dead [5] are typical examples. In order to avert collapse, most especially for building in service, structural health monitoring of the structural components through non-destructive approach may be employed. The data obtained from it will reveal the status of the building whether it is fit or unfit to use.

II. LITERATURE REVIEW

The integrity of structural elements can be assessed by either destructive testing or non-destructive testing. Destructive testing (DT) is a good approach but the elements being tested will be destroyed in the course of the test and it is used during construction to ascertain the quality/strength of the concrete during production. Non-destructive testing (NDT), as the name implies, is the assessment of structural integrity of a structure (whether at serviceability state or at construction stage) without tampering with the structural behaviour of the structural elements (with little or no-damage) [6]. With this, less expensive testing equipment is involved, the quantity of labour required for the testing is reduced and where cores cannot be drilled, it is easier to assess the concrete strength [7], [8]. Other advantages of NDT are that they can be used to assess concrete uniformity, homogeneity and in-situ compressive strength; measure elastic modulus of concrete, detect cracks, voids and other faults; checking any changes in the structure with respect to time, knowing reinforcement's position and condition, etc. [9], [10]. [11] highlighted the basic principal test methods of investigating the condition of structures (Table I).

TABLE I. PRINCIPAL METHODS OF INVESTIGATING THE CONDITIONS OF STRUCTURES

S/N	Property under investigation	Test
1	Concrete strength	Cores, Near-surface tests, Rebound hammer.
2	Concrete quality	Visual examination of cores and lump samples, ultrasonic pulse velocity, petrographic examination, expansion of cores, chemical analysis.
3	Corrosion of reinforcement	Carbonation depth, cover depth, chloride content, half-cell potential and potential mapping, corrosion rate, resistivity.
4	Integrity	Reinforcement location, concrete porosity, initial surface absorption, water permeability, gas permeability, radar, thermography, gamma radiography, impact echo, acoustic emission.

Table 1 implies that non-destructive tests can be used to access in-situ concrete strength, concrete quality, level of corrosion of embedded steel and concrete integrity among others. However, among these equipment for testing in-situ concrete strength and quality, rebound hammer and ultrasonic pulse velocity tests are the most common [12], [13], [14], [15], [16], [17], [18] and [19]. For this research, ultrasonic pulse velocity was used.

A. Ultrasonic Pulse Velocity Tester

Ultrasonic pulse velocity tester is used to determine the modulus of elasticity and dynamic Poisson's ratio of the concrete; examine the uniformity of concrete; measure changes that occur with time in the properties of concrete and correlate pulse velocity and strength as a measure of concrete quality. Ultrasonic Pulse Velocity tester (Fig. 1), as the name implies, is based on a pulse of longitudinal vibrations produced by an electro-acoustical transducer when in contact with the concrete or member. When the pulse generated is transmitted into the concrete from the transducer using a liquid coupling material such as grease or cellulose paste, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves develops, which include both longitudinal and shear waves, and propagates through the concrete. The first waves to reach the receiving transducer are the longitudinal waves, which are converted into an electrical signal by a second transducer. Electronic timing circuits enable the transit time T of the pulse to be measured.
The longitudinal pulse velocity (km/s) is given as shown in (1)

$$V = \frac{L}{T} \quad (1)$$

where V is the longitudinal pulse velocity, L is the path length and T is the time taken by the pulse to traverse that length. [20] highlights the method of finding the pulse velocity of concrete.

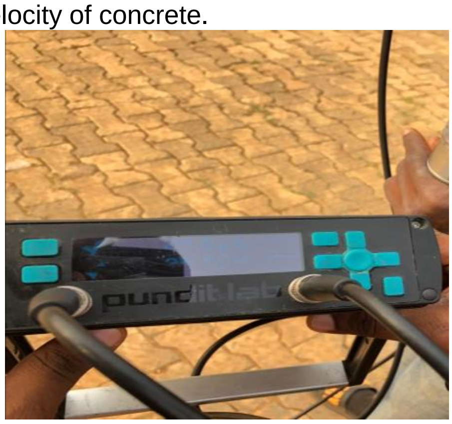

Fig. 1. Pundit Lab Equipment

The three basic ways of arranging the transducers are: (i) Direct transmission, (ii) Semi-direct transmission, and (iii) Indirect transmission. Since the maximum pulse energy is transmitted at right angles to the face of the transmitter, the direct method is the most reliable from the point of view of transit time measurement as shown in Fig. 2. Also, the path is clearly defined and can be measured accurately, and this approach should be used wherever possible for assessing concrete quality. The semi-direct method can sometimes be used satisfactorily if the angle between the transducers is not too great, and if the path length is not too large. The sensitivity will be smaller, and if these requirements are not met, it is possible that no clear signal will be received because of attenuation of the transmitted pulse. The path length is also less clearly defined due to the finite transducer size, but it is generally regarded as adequate to take this from centre to centre of transducer faces.

The indirect method is definitely the least satisfactory, since the received signal amplitude may be less than 3% of that for a comparable direct transmission. The received signal is dependent upon scattering of the pulse by discontinuities and is thus highly subject to errors. The pulse velocity will be predominantly influenced by the surface zone concrete, which may not be representative of the body, and the exact path length is uncertain [21]

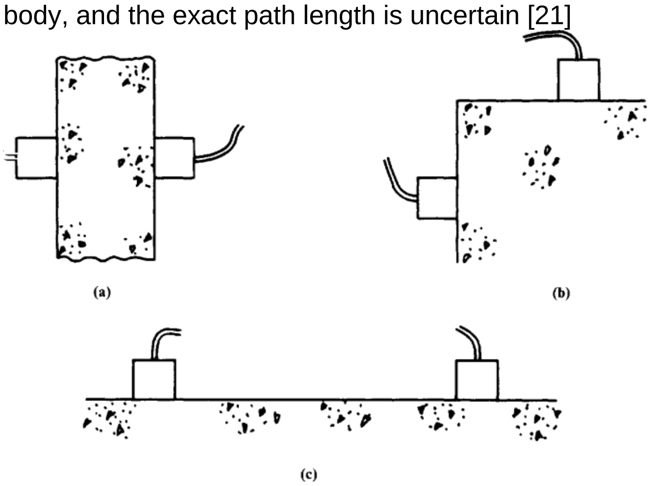

Fig. 2. Types of reading (a) Direct; (b) semi-direct; (c) indirect.

Table II shows the quality of concrete viz a viz the longitudinal pulse velocity. Concrete having the pulse velocity greater than 4.5 is classified as being very good or excellent while the one having its pulse velocity lesser than 2.5 is classified as being very poor.

TABLE II. CONCRETE QUALITY WITH CORRESPONDING PULSE VELOCITY [22]

Average Ultrasonic Pulse Velocity (km/s)	Quality of concrete
>4.5	Very Good
3.5 - 4.5	Good
3.0 – 3.5	Fair
2.5 – 3.0	Doubtful
<2.5	Very Poor

The magnitude of the pulse velocity which determines the quality of concrete as highlighted in Table 2 are affected by so many factors. Some of the factors are: the moisture content of the concrete, the path length, the temperature of the concrete, the effect of reinforcing bars and the shape and size of specimen.

III. METHODOLGY

The equipment used is the ultrasonic pulse velocity type called Pundit Lab instrument as shown in Fig. 3 and it is calibrated before use for efficiency. This is done by using the equipment calibration rod together with its transducers. Couplant is applied to the transducers and both the transducers and the calibration rod are held firmly together. Fig. 4 shows the field measurement of the accessible structural elements.

Fig. 3. Calibration of Pundit Lab instrument

Fig. 4. Field investigation

The two buildings considered for investigations were the institutional Hostel Buildings A and B as shown in Figs. 5 and 6. The structural components considered are spelled out in Table III

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TABLE III: NUMBER OF STRUCTURAL COMPONENTS OF THE BUILDINGS

S/N	Component	Hostel A (Number)	Hostel B (Number)

1	Ground floor columns	72	161
2	First floor beams	46	89
3	Slab	18	32

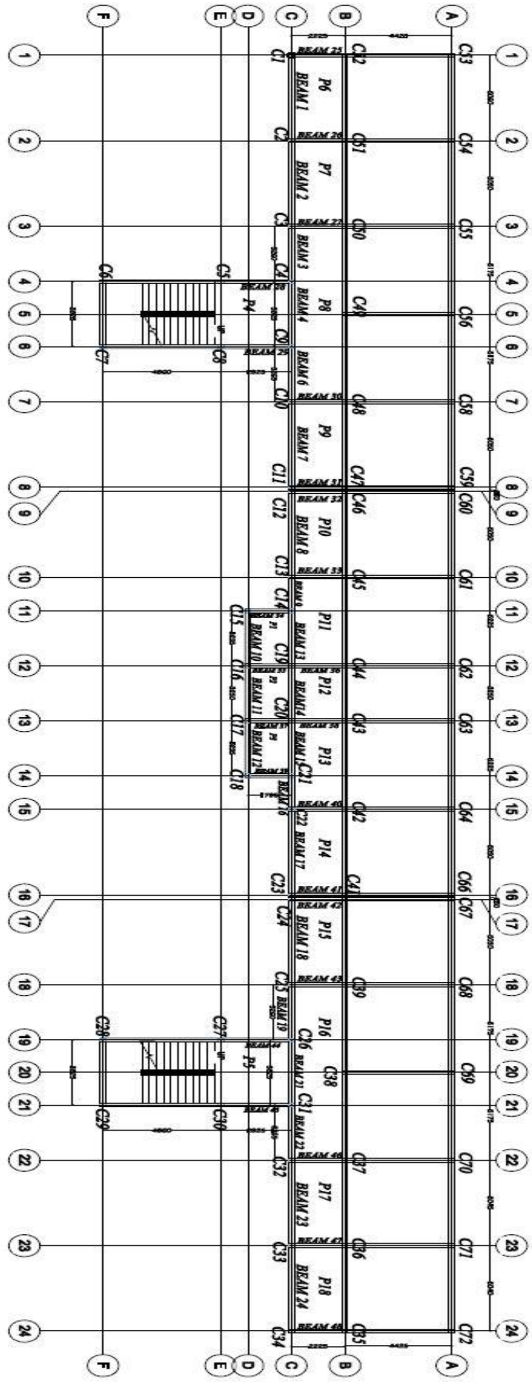

Fig. 5. The structural layout of the building Hostel A

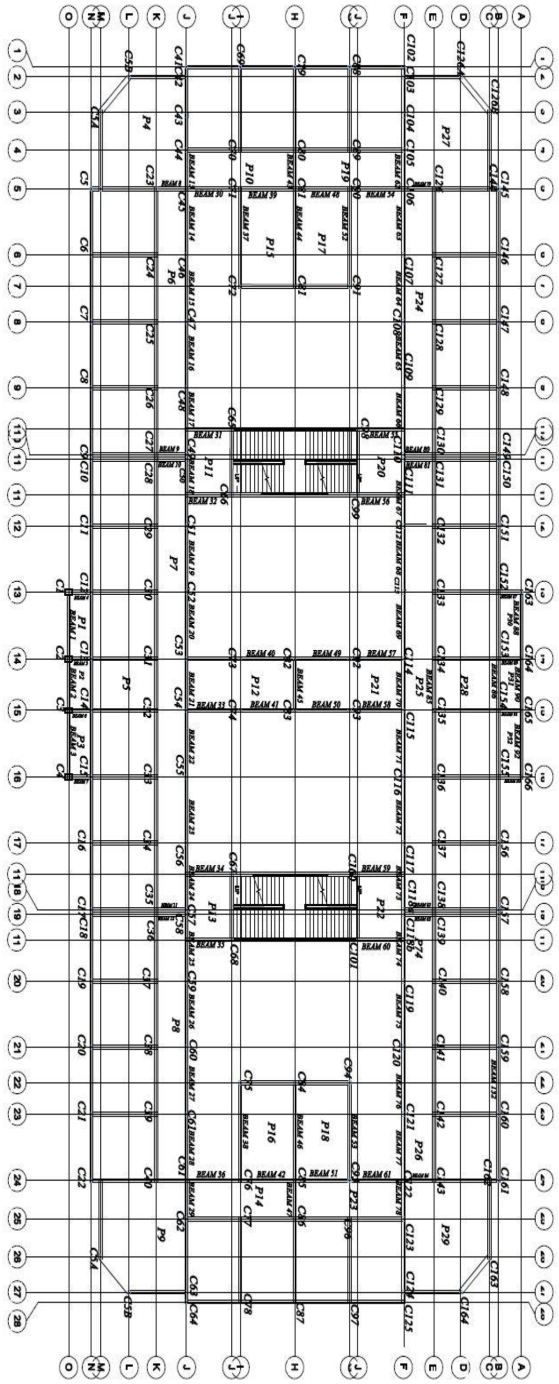

Fig. 6. The structural layout of the building Hostel B

IV. RESULTS AND DISCUSSION

Fig. 7 is the plot of pulse velocity against the ground floor columns for Hostel A. From the plot, the average pulse velocity is 3.79 km/s and their standard deviation is 0.25. With [22] classification, 85% of the columns are of good concrete quality while 15% are fair. This shows that the quality of the concrete in the columns is averagely okay. For the quality of the concrete of the slab in respect to Fig. 8, the average pulse velocity is 4.1 km/s while their standard deviation is 0.6. The minimum and maximum pulse velocities are 3.30 km/s and 5.30 km/s respectively. It is observed that only 11% of the slabs can be said to be of fair hard concrete, 61% are of good concrete layer, while 28% are of very good hard [22]. This implies that the slabs are very good in concrete quality.

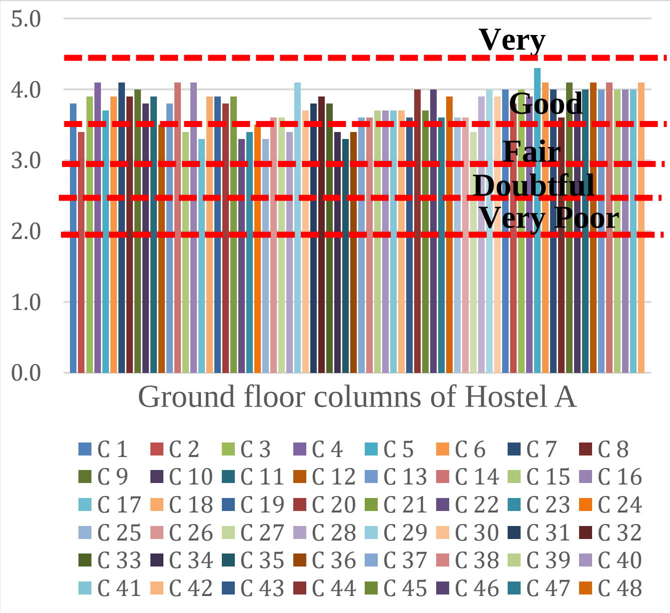

Fig. 7. Pulse Velocity results for ground floor columns of Hostel A

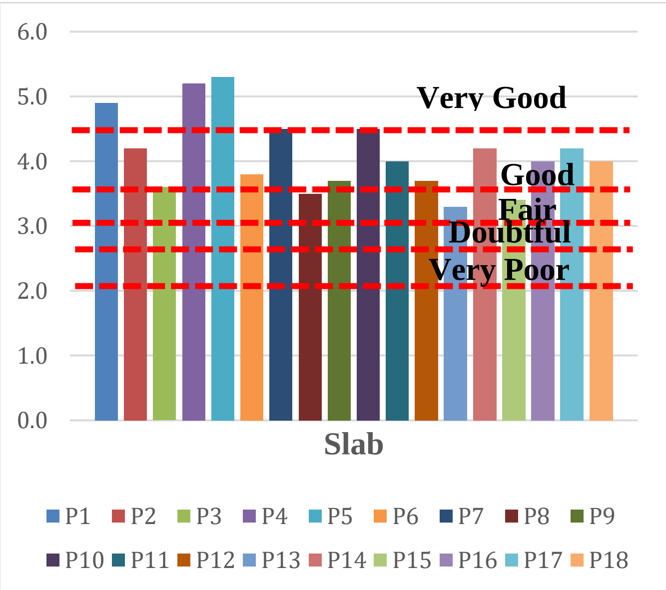

Fig. 8. Pulse Velocity results for Slab

Similarly, regarding the concrete qualities of the ground floor beams in Fig. 9, the average pulse velocity is 3.8 km/s and their standard deviation is 0.51. The minimum and maximum pulse velocities are 3.00 km/s and 5.40 km/s respectively. 11% of the beams are of very good concrete layer, 67% are of good concrete quality while 22% are of fair concrete quality. Making a comparison with the qualities of concrete of these structural elements of this building (Fig. 10), the floor beam 10 possesses greater hardness than other structural elements while some of the beams (beams 9, 13 and 14) also possess so low a pulse velocity as 3.0 km/s, which signifies a doubtful quality of concrete

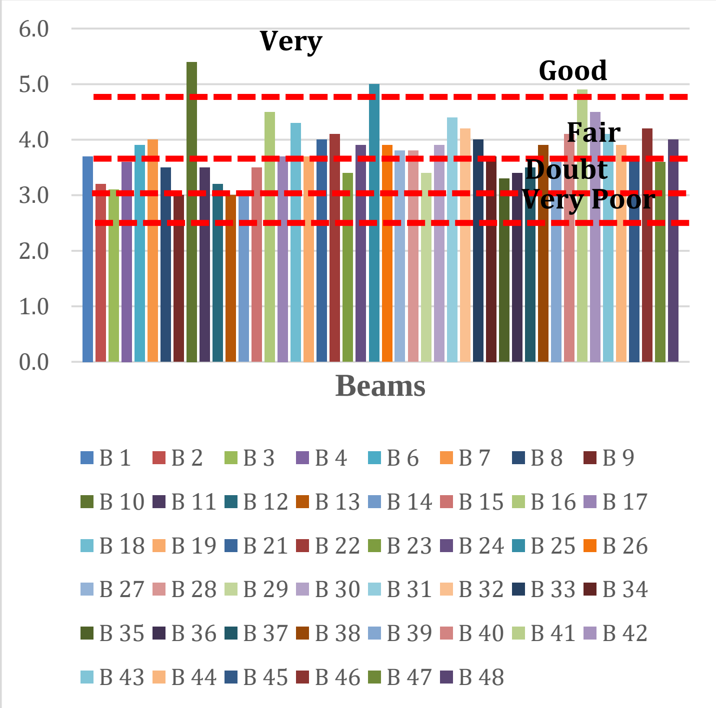

Fig. 9. Pulse Velocity results for first floor beams of Hostel A

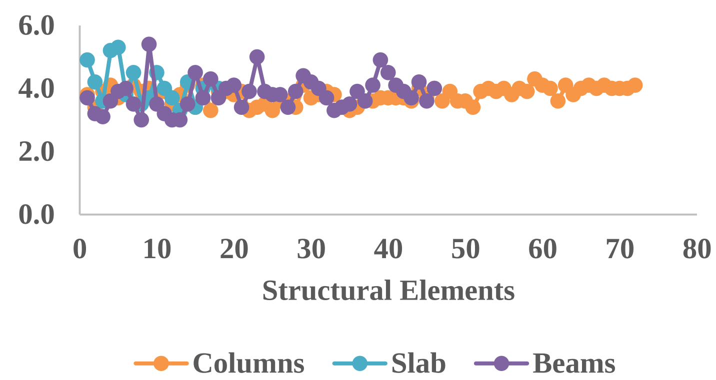

Fig. 10. Comparison of Pulse Velocity results for Columns, Slab and Beams

However, for Hostel B, Fig. 11 is the plot of the pulse velocities against the columns. The average pulse velocity is 3.8 km/s for the ground floor columns while their standard deviation is 0.6 km/s. The minimum and the maximum pulse velocities are 3.10 km/s and 6.20 km/s. According to the Indian Standard, [22], 26% of the ground columns are of fair hard concrete, 63% are of good concrete layer and 11% are of very good concrete.

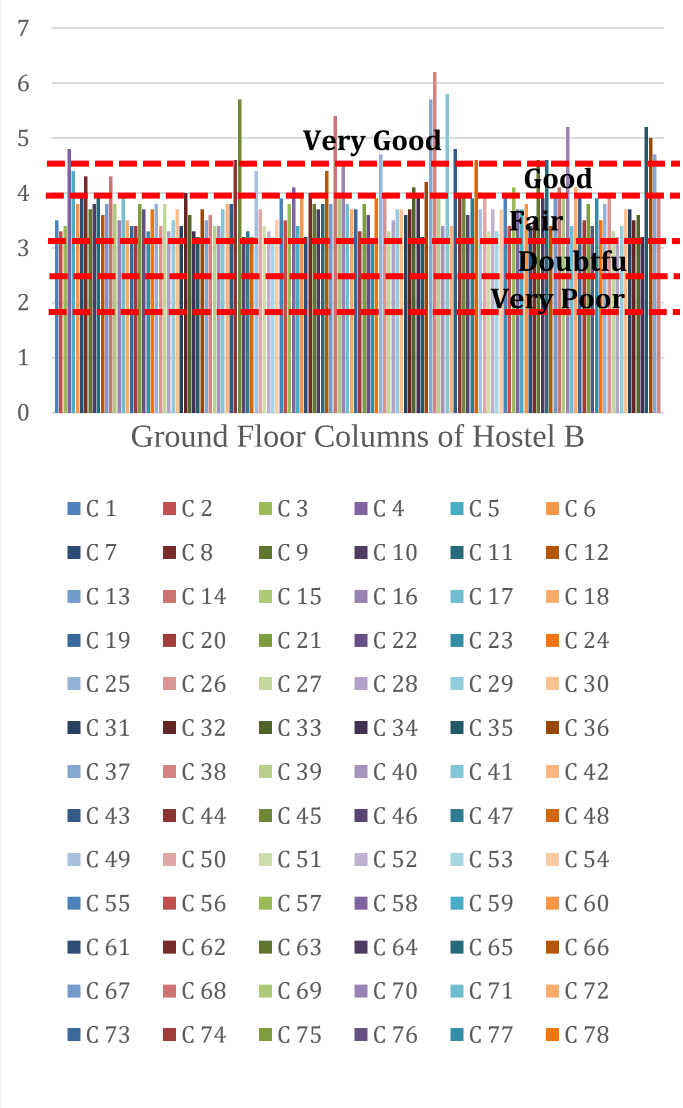

Fig. 11. Pulse Velocity results for Ground floor columns of Hostel B

However, the average pulse velocity for the slab is 4.4 km/s while their standard deviation is 0.55 km/s (Fig. 12). The minimum and maximum pulse velocities are 3.60 km/s and 5.60 km/s respectively. Using IS 13311-1:1992 classification, it is observed that 63% are of good concrete layer, while 38% are of very good hard concrete. This means that the entire slabs can still function well,

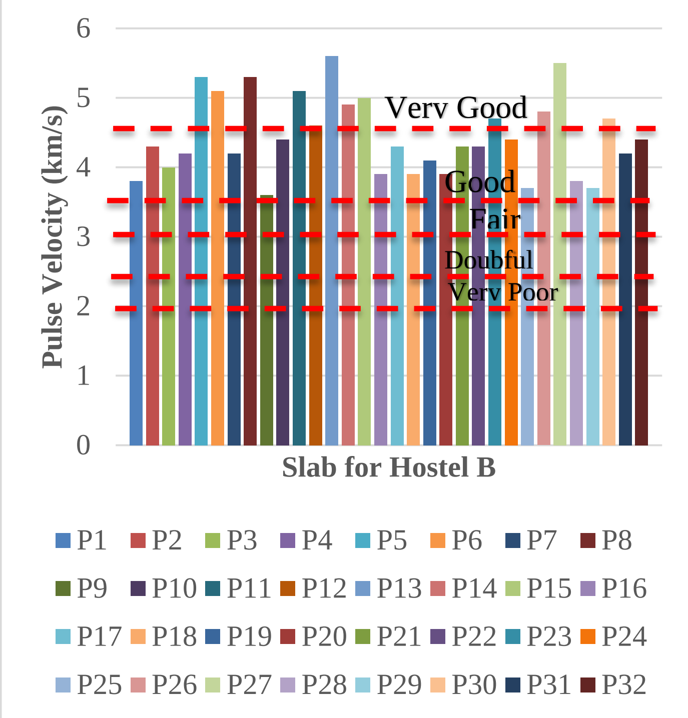

Fig. 12: Pulse Velocity results for Slab of Hostel B

From Fig. 13, the average pulse velocity for the first floor beams is 3.7 km/s while their standard deviation is 0.49 km/s. The minimum and maximum pulse velocities are 3.00 km/s and 5.30 km/s respectively. It was observed that only 39% of the beams are of fair hard concrete, 54% are of good concrete layer, while 8% are of very good hard concrete. This implies that almost all the beams can still function well.
Referring to Fig.14 (plot of pulse velocity against structural elements in Hostel B), it is noted that columns have greater pulse velocities more than the slabs and the beams and with Fig. 15 which gives the comparison of the pulse velocities of the structural elements in Hostel A and B, the pulse velocities of columns of Hostel B are higher than the other structural elements in both Hostels and Beams B gave the lowest. This implies that the quality of concrete in Hostel B is high and may remain in this state throughout its service life ***ceteris paribus.***

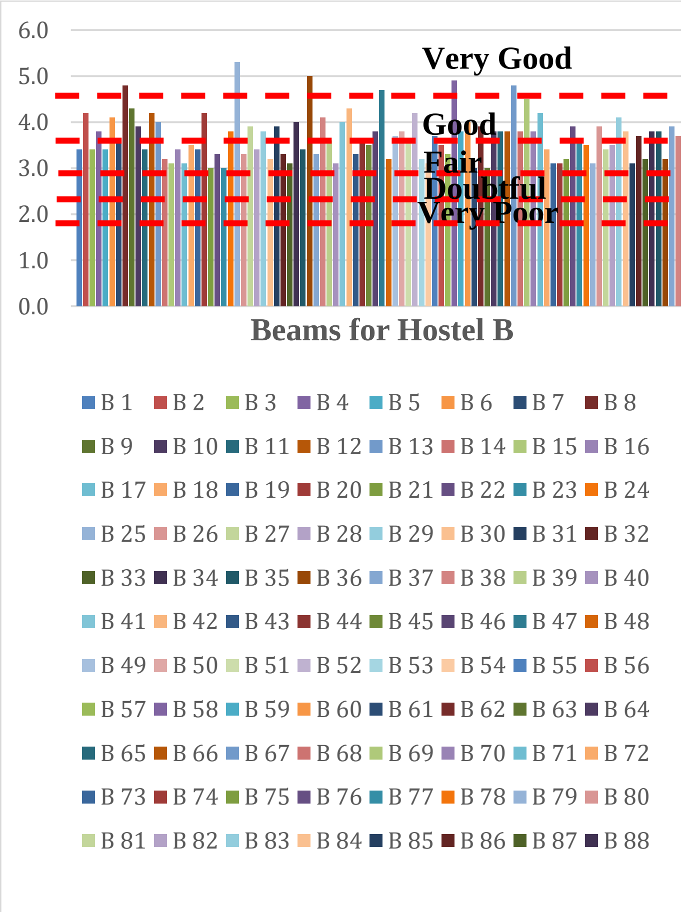

Fig. 13. Pulse Velocity results for Beams of Hostel B

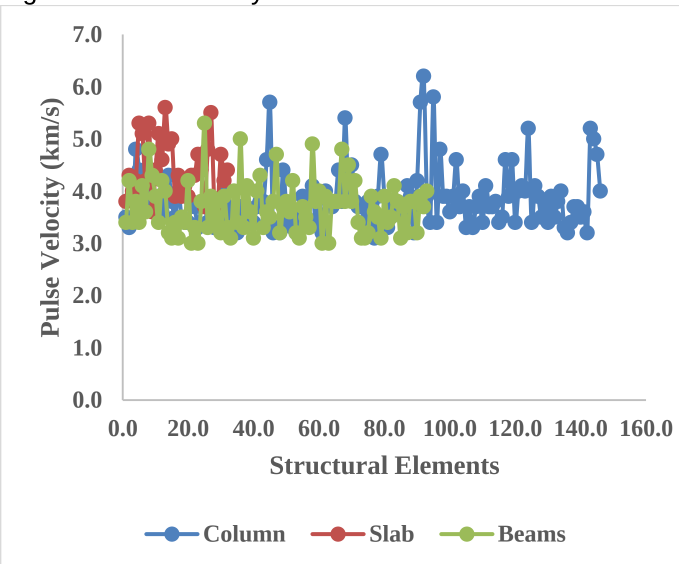

Fig. 14. Comparison of Pulse Velocity results for Columns, Slab and Beams for Hostel B

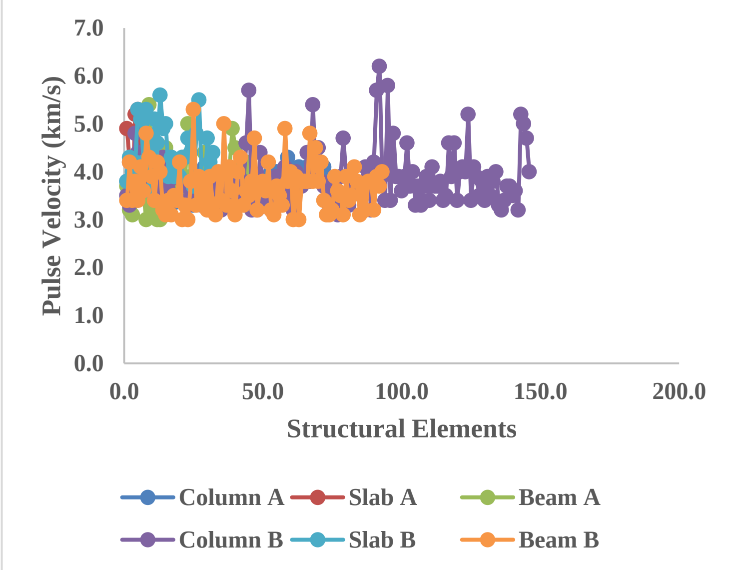

Fig. 15. Comparison of pulse velocities for Columns, Slabs and Beams for Hostel A and B Hostel B

V. CONCLUSIONS

In this investigation using ultrasonic pulse velocity tester to conduct the concrete qualities of two University Hostels, the following conclusions can be made:

1. Ultrasonic pulse velocity technique is a good technique for determining the hardness of concrete and it should be adopted to monitor any building under construction and in service;
2. Comparing the hardness of concrete of columns in the two buildings, it was discovered that the columns in Hostel B have high pulse velocities more than Hostel A, signifying that they are harder in concrete strength. Also, Beams A have high quality of concrete more than B and that of slab B is more than slab A; and
3. The quality of some floor beams in Hostel A is doubtful and therefore, those beams need to be strengthened to prevent future failure.

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