APPLICATION OF THE NON-DESTRUCTIVE TEST FOR FKASA BUILDING EVALUATION

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ABSTRAK

Penilaian kualiti konkrit adalah penting untuk mengenal pasti di mana konkrit perlu diselenggara. Ujian tanpa musnah (NDT) telah digunakan dengan lebih kerap untuk menilai keadaan bangunan. Penilaian ini merangkumi pelbagai aktiviti, termasuk pemeriksaan visual. Pada fasa penyelenggaraan, bangunan lebih kerap dipantau. Usaha khas telah dilakukan pada aplikasi pelengkap pelbagai teknik NDT ke dalam sistem pemantauan kesihatan berstruktur (SHM) bersepadu. Objektif utama kajian adalah untuk menilai keadaan struktur konkrit tetulang di Universiti Malaysia Pahang Kampus Paya Besar, Gambang. Kajian ini menggunakan alat ujian tanpa musnah (NDT) untuk menentukan keadaan bangunan FKASA. Dua jenis utama struktur bangunan, iaitu, rasuk dan tiang telah dipilih untuk menilai kualiti bangunan. Dua ujian NDT yang digunakan ialah tukul pantulan (RH) dan halaju nadi ultrasonik (UPV). Akhir sekali, keputusan dan analisis menunjukkan bahawa keadaan rasuk dan tiang di bangunan FKASA adalah memuaskan dan lemah. Manakala untuk kekuatan rasuk dan tiang, keputusan mendapati kedua-dua struktur tersebut mempunyai kekuatan lapisan keras yang sangat baik dan ~~adil~~ memuaskan.

ABSTRACT

The evaluation of concrete quality is important to identify where the concrete needs to do maintained. Non-destructive testing (NDT) has been used more frequently to evaluate the condition of buildings. This evaluation includes a wide range of activities, including a simple visual inspection. During the maintenance stage, buildings are monitored more often. Special efforts have been placed on the complementary application of various NDT techniques into an integrated structural health monitoring (SHM) system. The main objective of the study is to evaluate the condition of the reinforced concrete structure at Universiti Malaysia Pahang Kampus Paya Besar, Gambang. The present study used the non-destructive test (NDT) tools to determine the condition of the FKASA building. Two major types of building structures, namely, beams and columns were selected to assess the building's quality. Two NDT tests used are rebound hammer (RH) and ultrasonic pulse velocity (UPV). Finally, the results and analysis show that the condition of the beams and columns at the FKASA building is satisfactory and poor. For the strength beams and columns, it was found that the condition for both structure elements was a very good hard layer and fair, respectively.

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LIST OF SYMBOLS

%	Percentage
°C	Temperature in celsius
mm	Milimeter
mm^2	Milimeter square
km/s	Kilometer per second
MPa	Megapascal

LIST OF ABBREVIATIONS

B1	Beam 1
B2	Beam 2
BS	British Standard
C1	Column 1
C2	Column 2
FKASA	Faculty of Civil Engineering and Earth Resources
NDT	Non-Destructive Test
RH	Rebound Hammer
RC	Reinforced Concrete
SHM	Structural Health Monitoring
SDG	Sustainable Development Goals
UPV	Ultrasonic Pulse Velocity

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Non-destructive test (NDT) is used to evaluate the quality of components and the condition of components before or during use. NDT of concrete was found to be gaining increasing acceptance as a means of evaluating the strength, uniformity, durability, and other properties of existing concrete structures (Helal et al., 2015). NDT will be performed to estimate the strength and possible restoration of the reinforced concrete (RC) structures. Despite this, NDT is performed without causing any harm to the tested equipment.

In this case study, a non-destructive test (NDT) was used to make testing on concrete structures for both beams and columns. Therefore, the accurate quality of the in-situ strength assessment is a fundamental point. The type of test NDT that is used in this case study are rebound hammer (RH) and ultrasonic pulse velocity (UPV). The NDT techniques such as RH and UPV are widely used separately or in combination to estimate the in-situ strength (Ali-Benyahia et al., 2023). A series of non-destructive tests were carried out on an important historic building in Reggio Calabria: the National Museum of "Magna Grecia" (Pucinotti, 2015).

Existing concrete structures may be evaluated for their compressive strength by NDT. It is necessary to first assess the building's performance and condition to determine how and when maintenance may be performed. Because it will be more expensive to maintain and repair. A series of on-site data (205 data triplets) of non-destructive testing (RH and UPV) and coring have been carried out on structural elements (columns and beams) in an existing building to assess the in-situ concrete strength according to the new standard version procedures (EN 13791-2019) with a comparison to its old version 2007 (Ali-Benyahia et al., 2023).

1.2 Problem Statement

Concrete structure will change their performance and condition from time to time same as to FKASA building in their structure. With that, suitable tests are required to check the condition of a concrete structure without destroying the original concrete structure. Obtaining robust information regarding in-situ compressive strength is necessary as part of a reliable structural analysis and strengthening intervention, especially in the case of structural seismic capacity of existing buildings which are designed in most cases only for gravity loads or according to old seismic codes with low seismic safety factors (Ali-Benyahia et al., 2023). Destructive tests can be supplemented by non-destructive tests with the objective of improving information and containing quality control costs (Pucinotti, 2015).

The strength and other qualities of concrete are evaluated using NDT techniques. Both new and old buildings can learn from this sort of examination, since it helps determine their overall quality. Therefore, it makes it easier to know where needed to restore the concrete because the cost of maintenance is very expensive nowadays. NDT methods are mainly used to test strength and investigate its changes over time. Usually, samples taken from the structure, and sometimes whole members or structures, are tested in this way. Also load tests, which rather rarely applied to buildings (Schabowicz, 2019). Because the natural factors cause the RC structures to deteriorate over time and require care, it is important to keep the building functional and excellent in all weather conditions.

The existing RC structure that has been used for several years should be known for its condition and strength so that the structure building is harmless. NDT techniques make available or provide a cost-effective means of testing a sample for individual investigation and examination or may be applied to the whole material for checking in a production quality control system (Dwivedi et al., 2018). The accidents may be avoided if conduct these tests because will be able to predict if a structure will collapse, cutting costs as preparations can be taken to demolish the structure before it collapses at a random time, potentially causing injury or death of someone. NDT is extremely appealing since practically all NDT procedures are safe for humans.

1.3 Objectives of Study

In this study, there is two main objectives are conducted as follows:

i) To evaluate the condition of the beams and columns of FKASA building by using ultrasonic pulse velocity (UPV).
ii) To estimate the strength of the beams and columns of FKASA building by using a rebound hammer (RH).

1.4 Scope of Study

The study is focused on the non-destructive test (NDT) which is the priority of our case study. The study is limited to only two non-destructive tests which are the rebound hammer test and ultrasonic pulse velocity (UPV). This two of type NDT were applied to beams and columns. The case study area is located in the FKASA building at Universiti Malaysia Pahang Kampus Paya Besar, Gambang. To estimate the compressive strength of the RC structures (rebound hammer test). The rebound hammer was conducted using a horizontal position. The preparation for the rebound hammer test by providing a dimension grid of 50 mm with a size area of 300 mm² for each tested location. To predict the quality of the RC structure (UPV). For UPV the test, it was conducted using indirect transmission and direct transmission. For indirect transmission, the path length was various. The results of tests are analysed based on British Standards.

The tests conducted have two columns and two beams. One column looks in good condition in the middle ground floor FKASA building while one more column that looks not a good condition at the corners FKASA building and the beams that chose to be tested are the main beam which looks in good condition and secondary beam which look not good condition. The opportunity to choose whether a component structure seems to be in excellent condition or not, due to the ability to compare data results after being tested.

For rebound hammer, beam and column had three-part rebound numbers in the datasheet but to make good accurate data result, one part had 36 readings. The columns had three parts that were tested where one part at the bottom column, one part at the middle column and one more part at the top column. The beams had three parts that were tested where one part at the left-side beam, one part at the middle beam and one more part at the right-side beam. For the UPV test, got the seven-reading data for each beam and column. Figure 1.1 shows the location of the testing for NDT on the column and beam structure.

FKASA building

Figure 1.1 Location of the tested building for the present study

1.5 Significant of Study

By doing research on the topic of NDT, one may identify it and understand more about the applications and advantages of NDT in human works. The state of the present RC structure of the FKASA building must be identified to examine the present state of the building's construction. To estimate the level of strength of the FKASA building structure, it is also necessary to determine the structure's strength. Because NDT is simpler to use, doesn't cause injury to the user, and tests component structure, it may be used to assess condition and estimate strength. By implementing NDT and doing research on NDT, it is possible to determine the interior conditions of a building structure, hence facilitating human labour. To be able to evaluate the application of NDT, be knowledgeable about the NDT process, and be able to interpret NDT results using British standards. NDT helps to evaluate concrete properties. NDT helps to understand how the effectiveness of NDT in evaluating concrete properties.

Based on view of SDG Goal 11 criteria, the application of NDT in structural health monitoring (SHM) is essential because it can monitor the structural action to identify deterioration at an early stage. Among the SHM approaches, ultrasonic pulse velocity (UPV) and rebound hammer have lately gained popularity for assessing structural health and safety in actual time.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The objective of engineering investigation is to identify the present conditions and quality of the structure and evaluate them. Therefore, this chapter will continue to discuss case studies that are related to the study. Information here that has a connection with the study on non-destructive test assessment. Non-destructive test (NDT) terms of the characteristics and types of NDT explain in this chapter. Besides that, this chapter also focused on the applications of NDT. Moreover, factors that affect the results of NDT will touch on in this chapter.

2.2 Structural Health Monitoring

Structural health monitoring (SHM) is defined as "the process of acquiring and analysing data from on-board sensors to evaluate the health of a structure" (Güemes et al., 2020). The objective of this procedure for long-term SHM is information that is regularly updated on the structure's capacity to execute its intended function considering the inevitable age and degradation caused by operating settings. By imitating the self-sensing and self-diagnosis abilities of humans, SHM deals with the real-time sensing, identification, and assessment of the safety and performance evolution of structures (Bao et al., 2019).

SHM is the observation and analysis of a system utilising regularly sampled response measurements to monitor changes to the material and geometric aspects of engineering structures such as bridges and buildings. SHM systems include a network of sensors, permanently attached to the structure. This aspect establishes the main difference from conventional non-destructive testing (NDT) procedures and is essential for performing automated inspections (Güemes et al., 2020). The benefits of tracking, identifying, and measuring features of interest from structure responses have endless applications for saving cost, time and improving safety (Gharehbaghi et al., 2021).

Any change to material properties, geometrical assets or boundary conditions occurring during the operative life of a mechanical system, out of the designer meanings, may be considered as damage. The causes of structural damage may be several: sudden intense events like explosions, the impact of foreign objects, earthquakes or slower -and more predictable- phenomena such as microcracks evolution, gradual loss of efficiency of fasteners/constraints, fatigue, deterioration, and ageing effects (Porcu et al., 2019). NDT can be used for this purpose and a very extensive variety of NDT were developed in the last decades (Porcu et al., 2019). A wide variety of highly effective local non-destructive evaluation tools are available for such monitoring (Farrar & Worden, 2006). This theme issue was necessitated by the rising interest in SHM and its potential for substantial life-safety and economic advantages.

2.3 Non-Destructive Test

Non-destructive testing (NDT) are methods to evaluate material integrity for surface or internal flaws or metallurgical conditions without interfering in any way with the destruction of the material or its suitability for service (Dwivedi et al., 2018). NDT is part of a method of analysing the quality of the structure. NDT refers to the assessment or evaluation and inspection process of materials or components for characterization or finding defects and flaws in comparison with some standards without altering the original attributes or harming the object being tested (Dwivedi et al., 2018). The most commonly used non-destructive method to verify the quality of concrete and determine its compressive strength is the rebound hardness test method (Lehner & Hrabová, 2022).

Non-destructive methods are mainly used to test strength and investigate its changes over time. Usually, samples taken from the structure, and sometimes whole members or structures, are tested in this way. Also load tests, which rather rarely applied to buildings (Schabowicz, 2019). Standard testing for compressive, flexural, and tensile strengths is used to evaluate the quality of concrete used in buildings or constructions. Concluded that the combined use of both the UPV method and rebound hammer method offers higher accuracy where test errors were found to be below 10% (Tsioulou et al., 2017).

2.4 Advantages of Non-Destructive Test

The general advantages of non-destructive testing of structures are well known, but the most important are speed and economy. Trykoz et al. (2018) presented evidence of the importance of non-destructive testing (NDT) measurements in practice in the evaluation of existing concrete structures (Lehner & Hrabová, 2022). The NDT on testing of existing structures is often associated with an evaluation of structural integrity or sufficiency. Non-destructive tests are a suitable choice for structures diagnostics because they are fast, accurate, and can be repeated (Lehner & Hrabová, 2022). Consequently, NDT has several benefits over destructive testing. Frequently, the testing equipment is portable, and many tests may be done on a single component. The component's outside and inside may be extensively inspected for quality and strength.

2.5 Type of Non-Destructive Test (NDT)

The type of NDT used for this case study was ultrasonic pulse velocity (UPV) and rebound hammer (RH). The main purpose for UPV was to evaluate the condition of the beams and columns on the existing structure building while RH was used to estimate the strength of the beams and columns on the existing structure building. The compressive strength of concrete is one of the most important variables in assessing the quality of a structure and should be viewed as a variable parameter (Lehner & Hrabová, 2022). Associated with non-destructive testing (NDT) for evaluating strength, improving information, and providing a higher level of knowledge such as strength variability in structure with lower cost. For this purpose, RH and UPV tests are widely used in practice and are often combined to obtain a better assessment of concrete strength (Ali-Benyahia et al., 2023).

2.5.1 Ultrasonic Pulse Velocity (UPV)

Non-destructive ultrasonic pulse velocity testing has been widely used to examine the mechanical properties and integrity of concrete structures. It can be easily used at construction sites and provides results promptly. For homogeneous materials such as concrete, mechanical properties and relationships can be derived based on elastic theory, but they need to be corrected using data derived from various conditions because they can be affected by factors such as cement, aggregate, admixture, and water content (Lee & Lee, 2020).

The ultrasonic pulse velocity (UPV) test is a non-destructive, in-situ method for evaluating the quality of concrete and natural rocks. This test is performed by transmitting an ultrasonic pulse through the tested concrete and measuring the time required for the pulse to go through the structure. Higher velocities show the material's high quality and consistency; however, slower velocities may indicate concrete with many fractures or voids. Ultrasonic pulse velocity (UPV) test is a non-destructive popular test used to examine the homogeneity, quality, cracks, cavities, and defects in concrete (Kaliyavaradhan & Ling, 2019).

UPV test means to assist the transit time of ultrasonic pulses with 50–58 kHz, created by an electro-acoustical transducer and passing from one surface of the element to the other. The transit time of ultrasonic pulses depends on the density and elastic properties of the material tested (Faraj et al., 2022). It is also possible to use the ultrasonic evaluation method, which works according to the principle of transmitting ultrasonic waves to the surface of the structure by an exciter and then monitoring the speed of the transmitted pulses (Lehner & Hrabová, 2022). Figure 2.1 shows the UPV tester instruments:

Figure 2.1: 58-E4800 UPV tester
Source: Ndagi et al. (2019)

In the ultrasonic pulse velocity method, a short and strong electrical signal is transmitted to the transducer to make it vibrate according to the resonance frequency. The vibration of the transducer is transferred to the concrete by the contact medium and detected by the receiving transducer on the opposite side. As the time between the generation and arrival of the wave is recorded by the electrical equipment, the wave velocity can be obtained if the distance travelled by the wave is known (Hong et al., 2020). With a rise in the pulse velocity, it can be ascertained that the internal structure of a material is good and well-compacted. In the case of cement-based composites, it helps in assessing its uniformity. It is also known as health monitoring techniques used for concrete or mortars (Singh et al., 2022).

The ultrasonic pulse velocity (UPV) has three transmissions which are direct, semi-direct and indirect transmission. For direct, when an ultrasonic pulse travelling through concrete encounters a concrete-air interface, there is a negligible transmission of energy across this interface and hence, any air-filled crack or void lying directly between the transducers will obstruct the direct beam of ultrasound if the void's projected area is larger than the area of the transducer faces. For indirect, access to two surfaces is required for UPV testing, unless indirect (surface transmission) testing is to be performed

(N.Mohamed Sutan & M.Meganathan, 2003). Figure 2.2 shows the transmission of the ultrasonic pulse for the direct method for the UPV test while Figure 2.3 shows the transmission of the ultrasonic pulse for the indirect method for the UPV test. Table 2.1 shows the good average range result data for UPV.

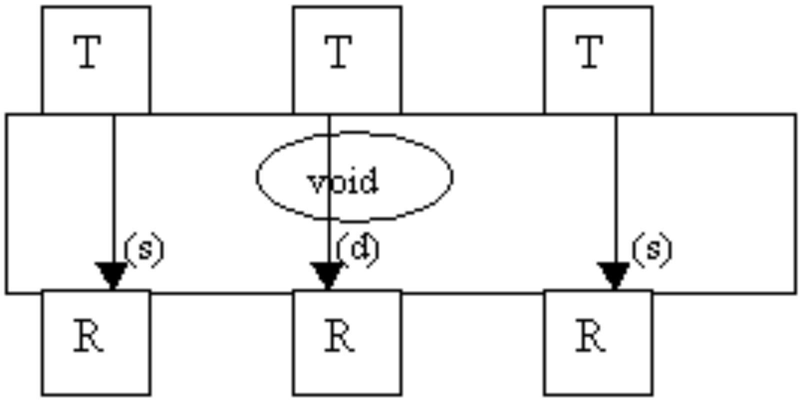


Figure 2.2 Transmission of ultrasonic pulse for direct method
Source: N.Mohamed Sutan & M.Meganathan (2003)

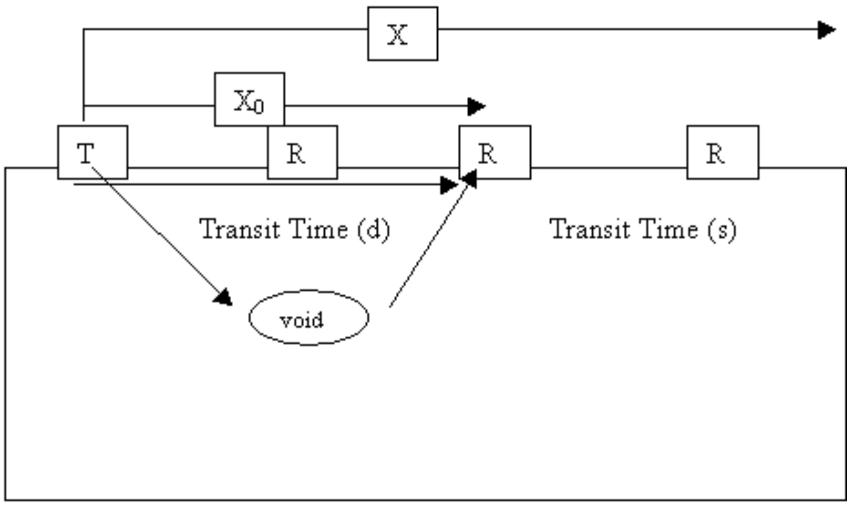


Figure 2.3 Transmission of ultrasonic pulse for indirect method
Source: N.Mohamed Sutan & M.Meganathan (2003)

Table 2.1 Classification of concrete quality ratings

Concrete Quality (Grading)	Pulse Velocity (km/s)
Excellent	Above 4.5
Good	3.5 to 4.5
Medium	3.0 to 3.5
Doubtful	Below 3.0

Source: BS 1881: Part 203 (1986)

2.5.2 Rebound Hammer (RH)

A Schmidt hammer, also known as a Swiss hammer, rebound hammer, or concrete hammer test, is an instrument used to determine the elastic characteristics or strength of concrete or rock, specifically surface hardness, and penetration resistance. Ernst Heinrich Wilhelm Schmidt, a Swiss engineer, created it. The rebound hammer test is useful in determining the hardness of concrete. When structural concrete is exposed to heat load, it affects concrete hardness and its micro-structural behaviour as well. The main driver of this relationship is the independent variable i.e., the rebound index obtained from the Schmidt rebound hammer, used for evaluating the hardness properties of the specimens (Hemraj et al., 2021).

The estimation of concrete quality is needed both for quality controls of new buildings and for the assessment of existing structures, mainly when being retrofitted to the standards of modern seismic codes. Among the NDT procedures, the rebound (Schmidt hammer) test is largely used in common engineering practice because of its simplicity and the low price of the equipment (Brencich et al., 2020). Rebound hammers, also known as Schmidt hammers, consist of a mass controlled by a spring that moves on a plunger inside a tube casing. The rebound hammer test is a cost-effective non-destructive testing method widely used to assess concrete quality (El-Mir et al., 2023). The advantages of using a rebound hammer are the equipment is simple to use, and the equipment is affordable.

By creating an appropriate relationship between the rebound index and the compressive strength of concrete, the rebound hammer technique offers a practical and quick estimate of the compressive strength of concrete. Frequently, on-site testing of hardened concrete is required to establish whether a building is suitable for its intended use. The structural integrity of existing structures must be evaluated after years of exposure to severe climatic conditions and other forces. The aim of rebound hammer tests of concrete is usually to find a relationship between surface hardness and compressive strength within an acceptable error (Kristine & Nathaniel, 2015). Figure 2.4 shows the standard graph to estimate the compressive strength using rebound hammer.

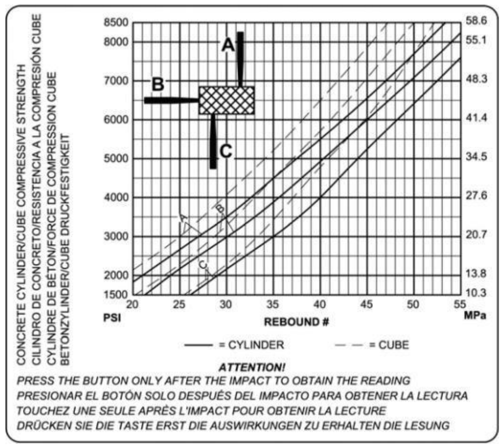


Figure 2.4 Graph compressive strength for rebound hammer test
Source: epc (2020)

2.6 Factors that Affect the Result NDT

The pulse velocity is not affected in any way by the geometry or shape of the concrete material being tested. It is however affected by factors such as cement type, aggregate type and size, water cement ratio, the distance between transducers, admixtures, positioning of the transducers and concrete age (Ndagi et al., 2019). Moreover, steel in concrete was also found to affect the test result of UPV to cause pulse velocity reduction by 1.2 to 1.9 times less the propagation speed in the presence of steel reinforcement (Ndagi et al., 2019). Sturrup et. al. (1984) after using pulse velocity to measure the compressive strength of concrete, deducted from his test that unless temperatures exceed 20°C , pulse velocities are not significantly affected by temperature effects but as temperatures exceed 40°C, correlations to pulse velocities can be seen to range between 2 to 5% in air cured concrete and between 1.7 to 4% in water-saturated concrete (Ndagi et al., 2019). It may not be feasible to examine the strength development by the fracture test within the required period due to the influence of environmental factors, such as materials used, temperature, humidity, and solar radiation, and site construction factors such as pumping, compaction, curing, and construction environment (Lee & Lee, 2020).

Next, for RH the studies have shown that rebound readings are sensitive to near-surface properties, thereby casting doubts on the accuracy of the test in estimating compressive strength. Factors that were found to influence the surface hardness include surface smoothness, age of concrete, moisture content, carbonation, presence of aggregates, presence of air voids and steel reinforcement, temperature, and calibration of the rebound hammer (Kristine & Nathaniel, 2015). Schmidt hammer provides the relationship in the form of equations and graphs between measured values of rebound index and compressive strength of concrete specimens. A comprehensive interpretation should cover all factors of concrete structure including grade variation, cement type, compaction, carbonation, cured condition, exposed temperature, and moisture content (Hemraj et al., 2021).

2.7 Applications of Non-Destructive Test (NDT)

Non-destructive testing (NDT) is appropriate for a wide range of applications. It is used in construction for non-destructive testing of concrete. The remaining service life and stability of the old building material are analysed. Concrete is extensively used in various structures. Defects in concrete structures can lead to severe damage and loss of life. Deterioration of concrete structures often goes unnoticed, and in many cases, initial damage is not visible until there is huge damage which is beyond repair. Thus, structural failure can be prevented by using non-destructive tests to check for defects during the initial stages only (Gupta et al., 2021).

NDT can act as a powerful tool providing valuable information about the current condition of a structure. Using NDT during the initial stages of building construction can help in identifying errors beforehand allowing easy repair. This helps in averting grave situations like loss of life and prevents them from happening in future (Gupta et al., 2021). Ultrasonic methods of NDT can be used in quality control of the ground improvement for setting up crude oil storage tanks. Ground transportation vehicles can also be monitored using structural health monitoring. The wheelset of these vehicles produces sound signals which can be detected by using the acoustic emission monitoring technique of NDT. If there is any damage in the wheel treads such as pitting (formation of cavities or holes), sound signals produced change, and these changes can be detected by integrating the AE monitoring system in the wheelset hollow shaft (Gupta et al., 2021).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter outlines the research methods, items used, and procedures utilised to conduct the test. The testing was on the FKASA building at Universiti Malaysia Pahang Kampus Paya Besar located at Gambang, Pahang. The purpose of this methodology is to achieve the objectives in Chapter 1 that to evaluate the condition of the beams and columns on the existing RC structure by using ultrasonic pulse velocity (UPV) and to estimate the strength of the beams and columns on the existing RC structure by using a rebound hammer.

3.2 Methodology of Study

Figure 3.1 shows the flow chart in the research methodology. The case study begins with deciding the case study area, and the FKASA building becomes the location site study case area. After selecting the area for the case study, a visual inspection is carried out to identify the columns and beams that are to be evaluated since they are the major structural components, ideally one in excellent condition and one with flaws such as cracks or degradation. Then, on a sheet of 50 mm by 50 mm paper, a grid is created. The grids had served as test sites for the rebound hammer test. After the grid papers are made, put to testing on the beam and column. Non-destructive tests were performed, which included the rebound hammer and the ultrasonic pulse velocity (UPV). To begin, the UPV test was performed in three distinct positions: direct, semi-direct, and indirect. Next, the rebound hammer was conducted in both horizontal and vertical positions. After the tests are done, the data acquired from the tests are analysed and the strength of the concrete was determined, and its structure is safe. Lastly, the case study was finalized. Figure 3.1 shows the flow chart of the methodology for NDT assessment on the FKASA building.

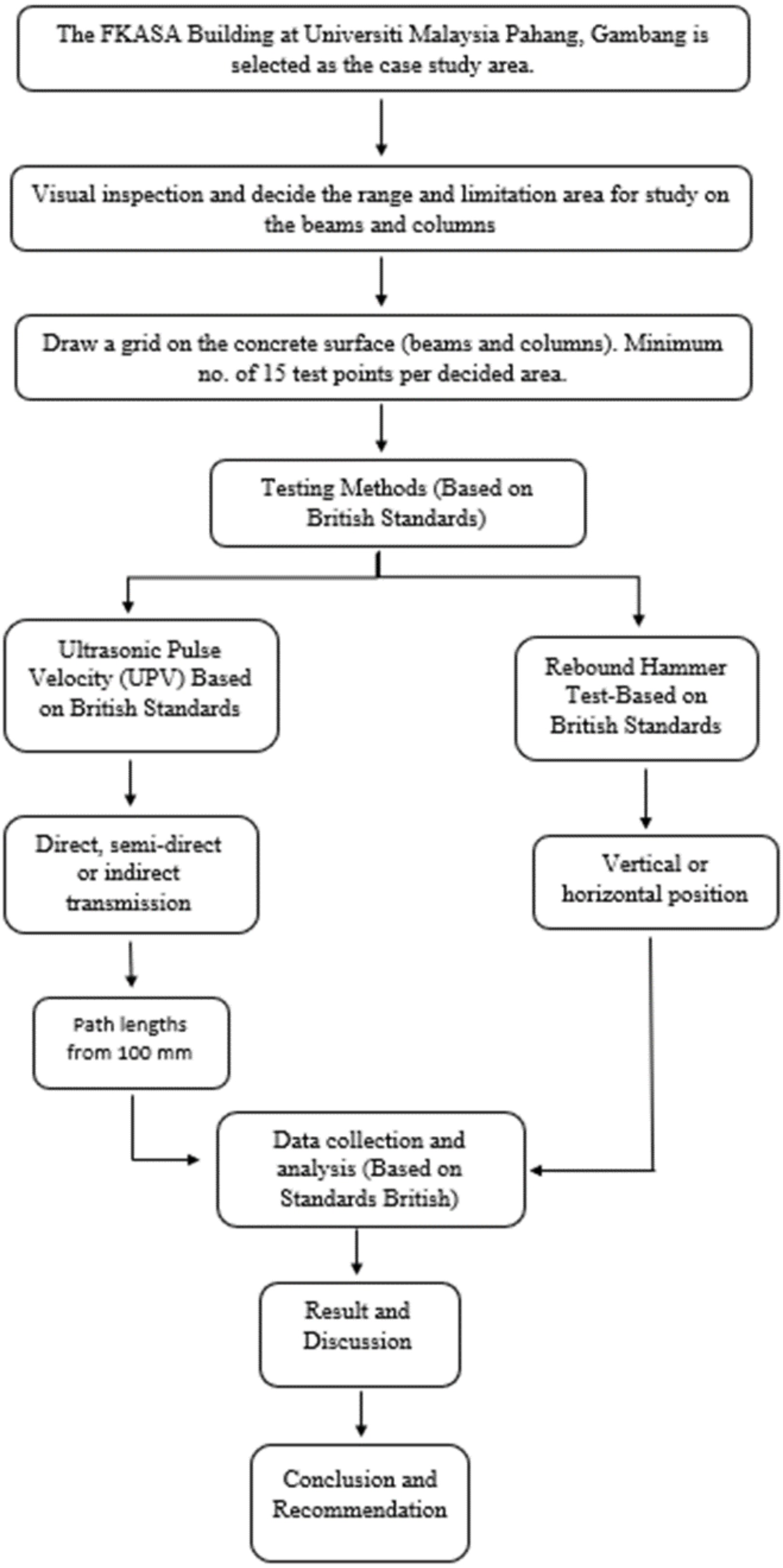


Figure 3.1 Flow chart of the methodology

3.3 Case Study Area

The selection of a case study area is the first step in the methodology. Figure 3.2 shows the FKASA building in Universiti Malaysia Pahang Kampus Paya Besar, Gambang as the case study area as the building is in use by students, lecturers, and lab technicians.

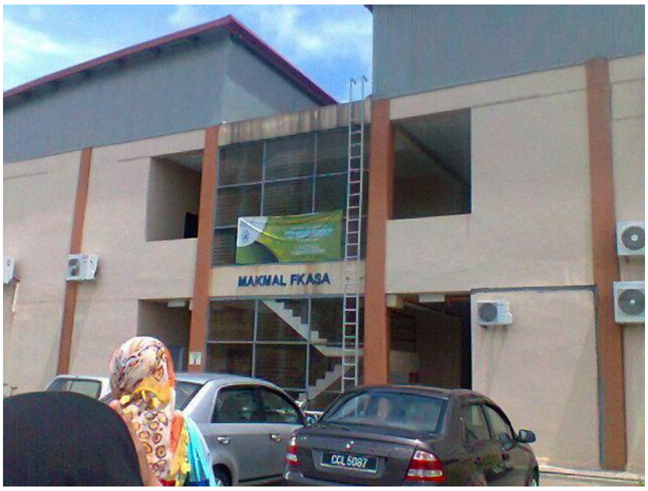
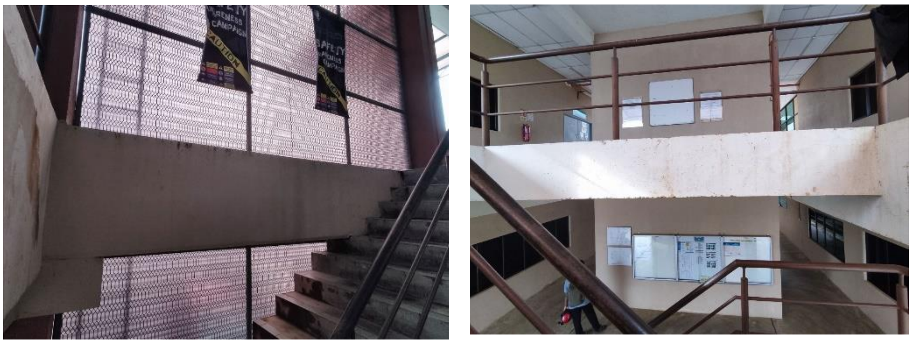


Figure 3.2 FKASA building

3.4 Visual Inspection

Visual inspection is the next step in the procedure. This inspection is carried out to assess the structural reliability of the structure's main components. The primary beams, secondary beams, and columns that all be seen while visiting the site. Two beams and two columns are chosen for test once all the structural parts have been identified. This allows for a comparison of the data to observe how the results vary depending on the state of the structural element. Figure 3.3 shows the component structure that was selected for testing at the FKASA building.

Column1 and Column 2



Beam 1 and Beam 2

Figure 3.3 Component Structure Tested

3.5 Grid on the Surface Concrete

The grid must be drawn using a size that is appropriate for the task at issue and is related to the case study. Testing for UPV differs from testing for a rebound hammer because UPV only needs to know how far the transmitting transducer is to the receiving transducer, so a rebound hammer uses a grid size of 50 mm, which means testing the previous rebound to one next place. The area of the grid for the rebound hammer is 300 mm². Figure 3.4 shows the grid used for the rebound hammer test on the beams and columns.

Figure 3.4 Grid for rebound hammer test

3.6 Non-Destructive Test Methods and Guidelines

Based on British Standards and guidelines, ultrasonic pulse velocity (UPV) and rebound hammer tests were performed. It is because, in Malaysia, the use of British Standards is more prominent. The information about this test can be found in the literature review. British Standards (BS) also provide the testing procedures.

3.7 Procedure Testing

This part is procedure testing for UPV and rebound hammer. This is a process for UPV and rebound hammer that is performed in accordance with British Standards. The step by step of procedures makes it good when testing.

3.7.1 UPV Test Procedures (BS1881: Part 203:1986)

1. The columns and beams are ready for testing by making sure of the smoothness of the surface prior to testing.

2. The measurement points have been marked on the beam and column. The points should be marked according to the method of reading, whether direct that use the thickness of the beam or column as the path length, indirect, with a minimum spacing of 200 mm. Each column or beam should be marked with a total of 14 points, with 2 points for each reading, for a total of 7 readings of UPV for each component.
3. On the surface of the testing point, a little bit of grease is applied. This will increase reading accuracy since there will be less movement of transducers while taking readings, which will generate noise and cause inaccuracies in the reading.
4. When taking the reading, both transducers are positioned at each testing point, and the time that it takes for the pulse from the transmitting transducer to reach the receiving transducer is recorded. Figure 3.5 shows both transducers are positioned on each testing point on beams to take reading UPV.

Figure 3.5 Testing UPV on beams at the FKASA building

5. Steps 3 and 4 are repeated for the tested structural component six times more.
6. Analyse data results from element structure tested that is beam and column about concrete quality based on British Standard as shown in Table 3.1.

Table 3.1 Classification of concrete quality ratings based on UPV test

Concrete Quality (Grading)	Pulse Velocity (km/s)
Excellent	Above 4.5
Good	3.5 to 4.5
Medium	3.0 to 3.5
Doubtful	Below 3.0

Source: BS 1881: Part 203 (1983)

3.7.2 Rebound Hammer Test Procedures (BS1881: Part 202:1986)

1. The surface of the column or beam is checked before testing to ensure that it is smooth and appropriate for rebound hammer testing.
2. After preparing the surface for testing, a grid paper with 50 mm by 50 mm grids is used as a test point to obtain rebound readings from rebound hammer test.
3. The rebound hammer is then pressed at a right angle on the surface of the beam or column until the hammer impacts. Figure 3.6 shows the rebound hammer being tested on the beam at the FKASA building.

Figure 3.6 Tested rebound hammer on beams at FKASA building

4. The rebound number obtained without releasing is recorded in the datasheet.
5. Steps 3 and 4 are repeated 11 times more, with three sets for each of the three components of a column or beam.
6. Analyse data results from the element structure tested that is beam and column about compressive strength based on British Standard as shown in figure 3.7 and refer to this graph to estimate strength.

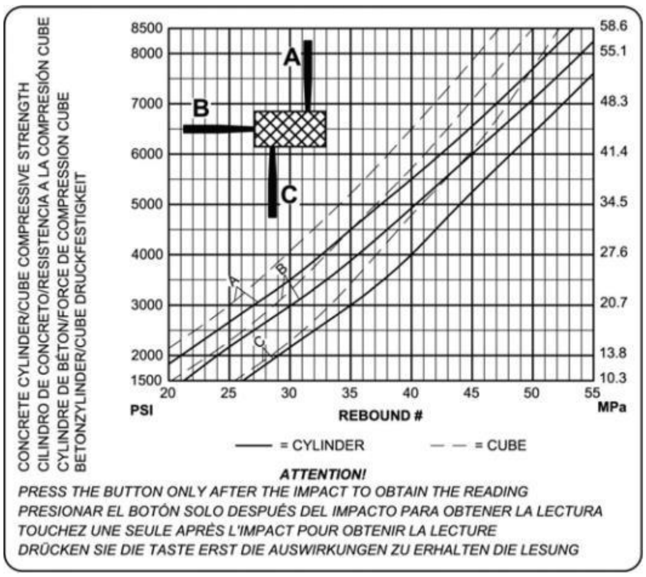


Figure 3.7 Graph compressive strength for rebound hammer test
Source: epc (2020)

3.8 Data Collection and Analysis

After the completion of the test, data analysis is also followed. This is a critical step in the whole case study since it will demonstrate whether the objective was met or not. Data analysis also reveals the strength and quality of the concrete structure of the FKASA building. In addition, the data may be applied to compare how the results change based on the condition of each structural component. Finally, data analysis allows us to see how different tests correlate among themselves and if there are changes in findings for different NDT testing.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter, the results of a non-destructive test (NDT) used to estimate concrete strength and quality for the FKASA building structure are discussed. Beams and columns were the two (2) structural components evaluated on the FKASA building structures. Two different tests, the rebound hammer test, and the ultra-pulse velocity test, were performed for each type of structural element. A rebound hammer test was performed to capture the rebound index in order to estimate concrete strength. Following that, the strength of the concrete was evaluated using the standard graph (BS1881: Part 202:1986) described previously in Chapter 3. Meanwhile, the UPV was used to assess the quality of the concrete, and the pulse wave was recorded before being analysed. The concrete quality was also assessed using g the table of classification of concrete quality rating specified in BS 1881: Part 203: 1986.

4.2 Prediction of the Concrete Strength using Rebound Hammer

Figure 4.1 represents the average rebound number (index) for the beam on the FKASA building. A1, A2, and A3 are the three different places (areas) that were tested. The result in the figure displays the quality of concrete quality for the FKASA building's surface. The rebound number for beam 1 (B1) located at A1, A2 and A3 was found to be 43.78, 28.64 and 47.75, respectively. For beam 2 (B2), the rebound number attained for A1 was 43.06, A2 is 42.83 and A3 is 42.50. According to Hitesh et al. (2015), The concrete quality for B2 is defined as a very good hard layer with a rebound number greater than 40. However, rebound number for B1 only A1 and A3 can identified as a very good hard layer while for A2 is fair where rebound number obtained is between 20 to 30. The figure also showed that the rebound number with the highest value was indicated on B1 (A3), followed by B2 (A1).

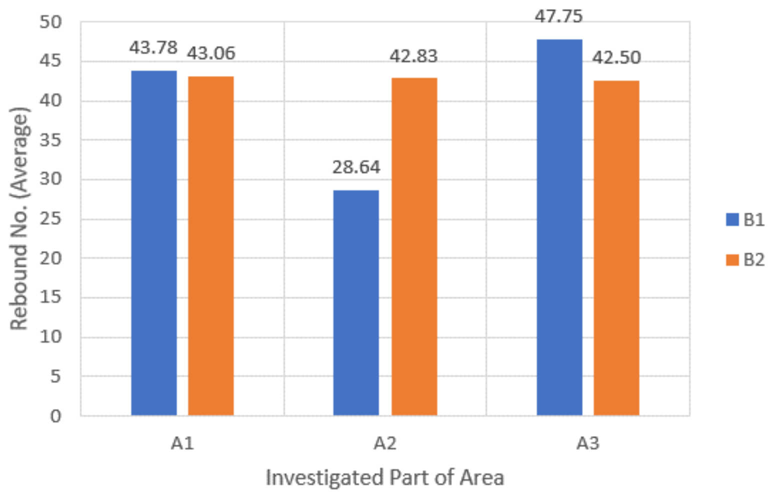


Figure 4.1 Rebound number for beams

Figure 4.2 shows the predicted concrete strength for the FKASA building. According to the graph, the compressive strength of B1 and B2 was 41.00 MPa and 45.00 MPa, respectively. The target means strength for concrete work should be more than 30 MPa, according to MS EN 1992-1-1:2010. As a consequence, the results achieved significantly above the minimal need. It also showed that the predicted compressive strength for beam, B1 is 8.89% higher when compared to B2.

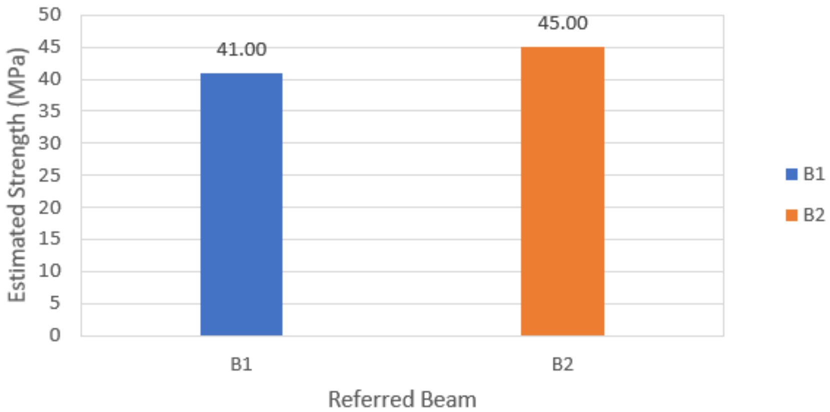


Figure 4.2 Prediction of concrete strength for beams

Figure 4.3 represents the average rebound number (index) for the beam on the FKASA building. A1, A2, and A3 are the three different places (areas) that were tested. The result in the figure displays the quality of concrete quality for the FKASA building's surface. The rebound number for column 1 (C1) located at A1, A2 and A3 was found to be 28.08, 24.94 and 26.86, respectively. For column 2 (C2), the rebound number attained for A1 was 28.81, A2 is 30.00 and A3 is 30.61. According to Hitesh et al. (2015), The concrete quality for C1 is defined as a Fair with a rebound number between 30 to 40. However, rebound number for C2 only A2 and A3 can identified as a good layer while for A2 is fair where rebound number obtained is between 20-30. The figure also showed that the rebound number with the highest value was indicated on C2 (A3), followed by C2 (A2).

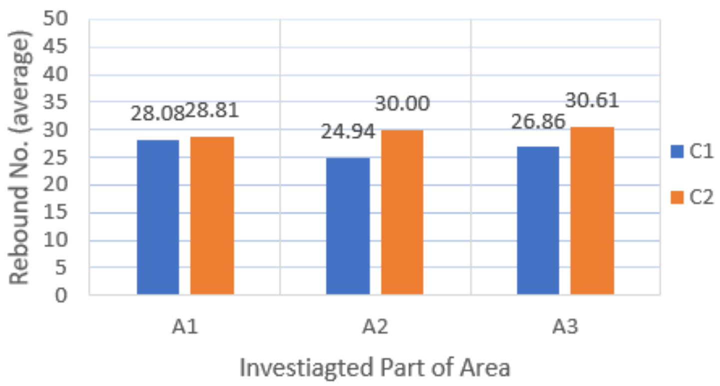


Figure 4.3 Rebound number for columns

Figure 4.4 shows the predicted concrete strength for FKASA building. According to the graph, the compressive strength of C1 and C2 was 21.00 MPa and 23 MPa, respectively. The target means strength for concrete work should be more than 30 MPa, according to MS EN 1992-1-1:2010. As an outcome, the results were not significantly above the minimum need. This, in my perspective, is due to poor concrete quality during construction.

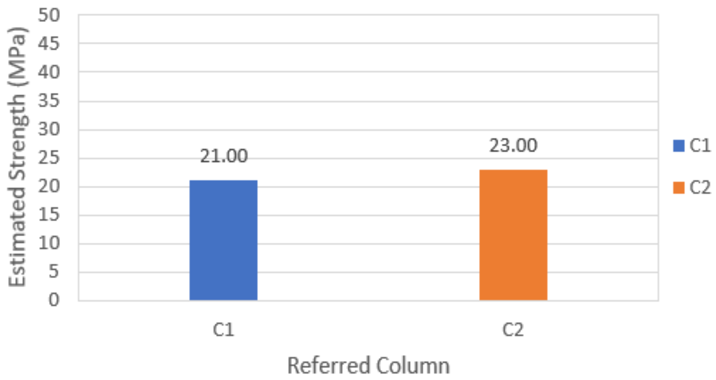


Figure 4.4 Prediction of concrete strength for columns

4.3 Estimation of the Quality of Concrete using UPV

Figure 4.5 illustrates the results of UPV readings for two (2) different types of beams on the FKASA building. The various path lengths between the UPV transducers are discovered to affect the UPV readings. When the path length was increased, the UPV readings improved massively. When the transducers were set far apart, higher UPV measurements were obtained. This is due to the fact that the direct path length between the two transducers may influence the UPV readings. The least UPV value was attained when the path length for both B1 and B2 beams was 200 mm. The UPV readings for B1 and B2 were determined to be 2.81 km/s and 3.03 km/s, respectively. However, the maximum UPV value was obtained from the readings taken in B1, which was 3.65 km/s. Figure indicates that the quality of beams B1 is good when the UPV values at a path length of 300 mm are more than 3.50 km/s while for B2 is satisfactory because the UPV values at a path length of 300 mm was between 3.00 to 3.50 km/s as specified in BS 1881: Part 203 (1986).

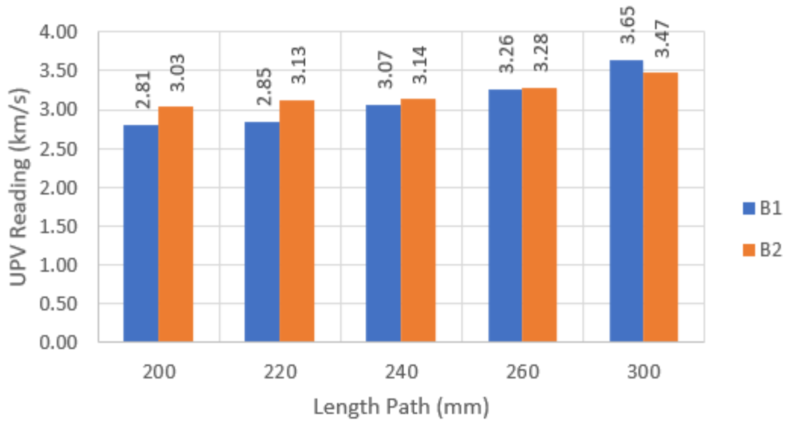


Figure 4.5 Effect of path length on UPV readings for the beams

Figure 4.6 demonstrates the average UPV readings for beams situated on the FKASA building. The UPV value for B1 was 3.13 km/s while that for B2 was 3.21 km/s. Both beams were discovered to be in satisfactory condition, according to BS 1881: Part 203 (1986). UPV readings for B1 and B2 are in the range of 3.0 – 3.5 km/s which illustrates the quality of the concrete is in satisfactory condition, but loss of integrity is suspected in the concrete beam.

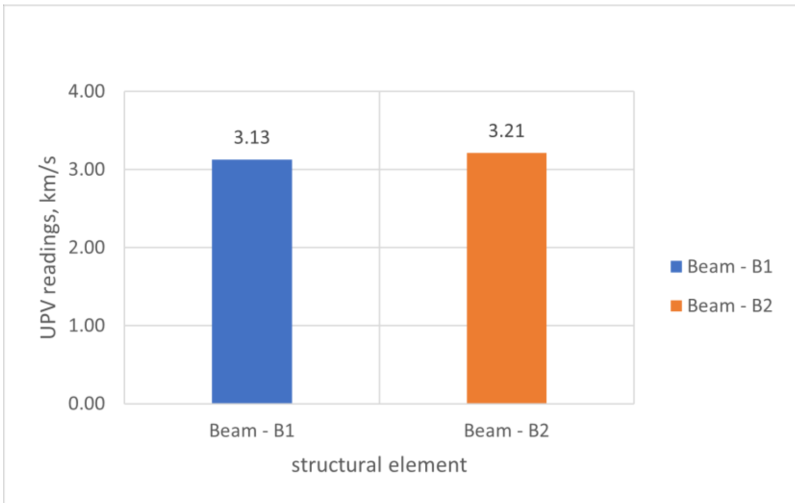


Figure 4.6 Average UPV reading for beams

Figure 4.7 illustrates the results of UPV readings for two (2) different types of columns on the FKASA building. The various path lengths between the UPV transducers are discovered to affect the UPV readings. When the path length was increased, the UPV readings improved massively. When the transducers were set far apart, higher UPV measurements were obtained. This is due to the fact that the direct path length between the two transducers may influence the UPV readings. The least UPV value was attained when the path length for both C1 and C2 beams was 200 mm. The UPV readings for C1 and C2 were determined to be 1.71 km/s and 2.55 km/s, respectively. However, the maximum UPV value was obtained from the readings taken in B1, which was 3.33 km/s. Figure indicates that the quality of beams C2 is satisfactory when the UPV values at a path length of 300 mm are between 3.00 to 3.50 km/s while for C1 is poor because the UPV values at a path length of 300 mm was below 3.00 km/s as specified in BS 1881: Part 203 (1986).

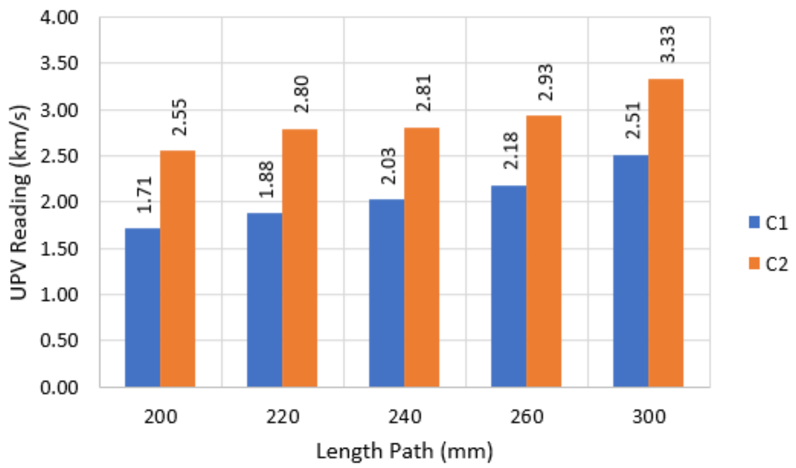


Figure 4.7 Effect of path length on UPV readings for the columns

Figure 4.8 demonstrates the average UPV readings for beams situated on the FKASA building. The UPV value for C1 was 2.06 km/s while that for C2 was 2.88 km/s. Both columns were discovered to be in poor condition, according to BS 1881: Part 203 (1986). UPV readings for B1 and B2 are in the below 3.00 km/s which illustrates the quality of the concrete is in poor condition, but loss of integrity may exist in the concrete beam. I think this is the cause for the inaccurate UPV readings. Apply another non-destructive test (NDT) for the column structure is an option for this issue.

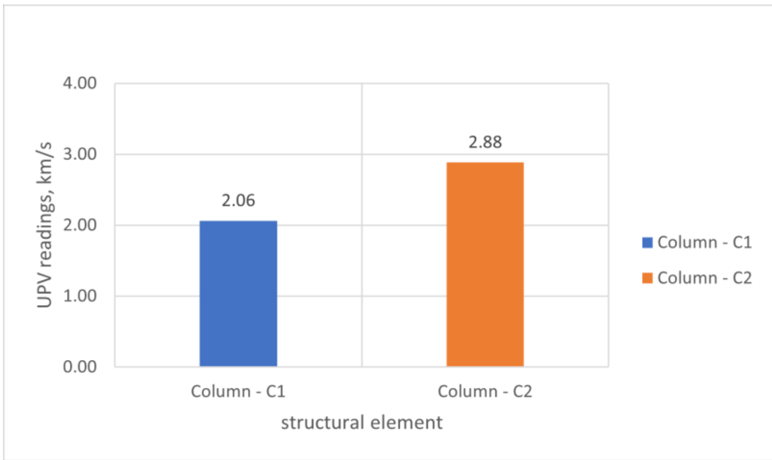


Figure 4.8 Average UPV reading for columns

CHAPTER 5

CONCLUSION

5.1 Introduction

The result of non-destructive testing (NDT) on the FKASA building at Universiti Malaysia Pahang Kampus Paya Besar, Gambang, were presented in this research. The compressive strength and quality of the concrete on the FKASA building were predicted using NDT, namely the rebound hammer test and the ultra-pulse velocity (UPV) test. The conclusion was described in the parts that followed.

5.2 Conclusion

Based on the outcomes of the current study, the following conclusions are drawn:

1. It was found that the quality of the concrete surface obtained from rebound numbers for B1 and B2 was a very good hard layer while C1 and C2 was a fair.
2. The predicted compressive strength for the beams and columns obtained from the rebound hammer was sufficient strength in accordance with BS1881: Part 202:1986. The predicted compressive strength attained for B1, B2, C1 and C2 was found to be 41.00 MPa, 45.00 MPa, 21.00 MPa and 23.00 MPa, respectively.
3. The UPV readings obtained classified the B1 and B2 represented that quality of concrete was a satisfactory while the C1 and C2 defined a poor quality for the FKASA building.

5.3 Recommendation

Some improvements may be implemented in the future. The following are the recommendations:

1. To transmit ultrasonic, a surface must be permeable.
2. Consistent pressure is maintained for UPV by using a thin grease coating between the transducers and ensuring that the transducer makes excellent contact with the concrete surface.
3. The test should not be conducted on a rough surface caused by inadequate concrete compaction, grout loss, spoilt, or tooled surfaces for rebound hammer test.
4. Before testing, make sure the concrete surface is straight, clean, and dry.
5. For inaccurate test results, can use others test of NDT beside of UPV and RH test if the test results were inaccurate.

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APPENDICES

Appendix A: Raw data rebound number on rebound hammer test

Test Date:	*Estimated Strength:*		
Concrete Type:	*Hammer Orientation: Horizontal*		
Rebound numbers	**Reading**		
Reading	43	48	44
Reading	41	42	49
Reading	38	44	41
Reading	44	44	39
Reading	48	58	38
Reading	53	44	43
Reading	48	45	42
Reading	43	41	51
Reading	48	39	44
Reading	52	48	31
Reading	37	46	40
Reading	33	42	45
Average Rebound Reading	**44**		

Test	*Estimated Strength:*		
Concrete Type:	*Hammer Orientation: Horizontal*		
Rebound numbers	**Reading**		
Reading	24	32	30
Reading	16	28	31
Reading	25	25	28
Reading	30	29	32
Reading	29	31	28
Reading	28	29	28
Reading	28	31	32
Reading	30	31	25
Reading	28	31	29
Reading	30	30	28
Reading	32	30	26
Reading	30	28	29
Average Rebound Reading	**27.50**		

Test Date:	*Estimated Strength:*		
Concrete Type:	*Hammer Orientation: Horizontal*		
Rebound numbers	**Reading**		
Reading	59	47	51
Reading	38	54	46
Reading	47	56	45
Reading	54	37	38
Reading	56	44	53
Reading	47	44	57
Reading	44	48	47
Reading	42	53	53
Reading	47	47	42
Reading	52	46	63
Reading	54	52	33
Reading	46	37	40
Average Rebound Reading	**48.83**		

BEAM 1, B1 (primary beam)

Test Date:	Estimated Strength:		
Concrete Type:	Hammer Orientation: Horizontal		
Rebound numbers	**Reading**		
Reading	43	38	44
Reading	41	52	49
Reading	38	49	46
Reading	44	46	38
Reading	48	43	38
Reading	45	44	41
Reading	44	45	42
Reading	41	41	47
Reading	39	39	44
Reading	43	48	31
Reading	42	46	40
Reading	44	42	45
Average Rebound Reading	**42.67**		

Test	Estimated Strength:		
Concrete Type:	Hammer Orientation: Horizontal		
Rebound numbers	**Reading**		
Reading	48	42	42
Reading	39	45	41
Reading	44	40	44
Reading	46	44	45
Reading	40	46	39
Reading	45	38	40
Reading	40	46	39
Reading	42	31	46
Reading	49	46	41
Reading	44	38	42
Reading	41	43	48
Reading	46	45	47
Average Rebound Reading	**43.67**		

Test Date:	Estimated Strength:		
Concrete Type:	Hammer Orientation: Horizontal		
Rebound numbers	**Reading**		
Reading	46	44	32
Reading	38	50	36
Reading	45	48	46
Reading	46	40	42
Reading	46	40	36
Reading	44	40	36
Reading	45	44	45
Reading	44	42	36
Reading	46	44	36
Reading	36	56	45
Reading	44	46	44
Reading	38	46	38
Average Rebound Reading	**43.17**		

BEAM 2, B2 (secondary beam)

Test Date:	*Estimated Strength:*		
Concrete Type:	*Hammer Orientation: Horizontal*		
Rebound numbers	**Reading**		
Reading	30	30	32
Reading	22	26	30
Reading	22	27	28
Reading	24	30	30
Reading	28	30	30
Reading	28	27	33
Reading	22	28	30
Reading	22	27	34
Reading	23	32	32
Reading	22	27	32
Reading	22	27	32
Reading	26	28	38
Average Rebound Reading	**24.25**		

Test	*Estimated Strength:*		
Concrete Type:	*Hammer Orientation: Horizontal*		
Rebound numbers	**Reading**		
Reading	19	15	29
Reading	23	27	32
Reading	23	34	26
Reading	24	30	28
Reading	17	18	34
Reading	23	19	32
Reading	23	25	27
Reading	22	28	26
Reading	22	22	25
Reading	21	22	31
Reading	22	26	26
Reading	22	27	28
Average Rebound Reading	**21.75**		

Test Date:	*Estimated Strength:*		
Concrete Type:	*Hammer Orientation: Horizontal*		
Rebound numbers	**Reading**		
Reading	26	20	30
Reading	27	23	26
Reading	25	28	28
Reading	30	24	29
Reading	30	22	32
Reading	26	30	27
Reading	25	22	32
Reading	30	23	28
Reading	24	26	28
Reading	30	30	28
Reading	29	20	26
Reading	26	21	36
Average Rebound Reading	**27.33**		

Column 1, C1

Test Date:	*Estimated Strength:*		
Concrete Type:	*Hammer Orientation: Horizontal*		
Rebound numbers	**Reading**		
Reading	36	30	28
Reading	28	28	32
Reading	25	29	28
Reading	28	28	30
Reading	31	28	27
Reading	29	26	30
Reading	25	30	29
Reading	28	30	28
Reading	32	30	32
Reading	30	32	32
Reading	26	25	26
Reading	28	26	27
Average Rebound Reading	**28.83**		

Test	*Estimated Strength:*		
Concrete Type:	*Hammer Orientation: Horizontal*		
Rebound numbers	**Reading**		
Reading	29	32	31
Reading	32	32	30
Reading	34	30	28
Reading	32	24	32
Reading	28	30	28
Reading	28	30	25
Reading	27	32	34
Reading	25	27	32
Reading	30	30	30
Reading	29	30	30
Reading	30	31	33
Reading	31	30	34
Average Rebound Reading	**29.58**		

Test Date:	*Estimated Strength:*		
Concrete Type:	*Hammer Orientation: Horizontal*		
Rebound numbers	**Reading**		
Reading	30	28	30
Reading	33	28	30
Reading	30	30	30
Reading	31	29	30
Reading	34	30	31
Reading	32	32	27
Reading	34	35	32
Reading	28	32	30
Reading	32	32	32
Reading	34	32	30
Reading	30	29	30
Reading	29	26	30
Average Rebound Reading	**31.42**		

Column 2, C2

Appendix B: Result data UPV readings on UPV test

Reference (Beam)	Points	Distance (mm)	Transmit Time (ms)	UPV Reading	Average (km/s)	Condition
	1	200	71.3	2.81		
	2	220	77.2	2.85		
B1	3	240	78.3	3.07	**3.13**	Satisfactory
	4	260	79.7	3.26		
	5	300	82.3	3.65		

Reference (Beam)	Points	Distance (mm)	Transmit Time (ms)	UPV Reading	Average (km/s)	Condition
	1	200	66	3.03		
	2	220	70.3	3.13		
B2	3	240	76.5	3.14	**3.21**	Satisfactory
	4	260	79.2	3.28		
	5	300	86.5	3.47		

Reference (Column)	Points	Distance (mm)	Transmit Time (mμs)	UPV Reading	Average (km/s)	Condition
	1	200	116.7	1.71		
	2	220	117.3	1.88		
C1	3	240	118.2	2.03	**2.06**	Poor
	4	260	119.2	2.18		
	5	300	119.5	2.51		

Reference (Column)	Points	Distance (mm)	Transmit Time (ms)	UPV Reading	Average (km/s)	Condition
	1	200	78.3	2.55		
	2	220	78.7	2.80		
C2	3	240	85.5	2.81	**2.88**	Poor
	4	260	88.7	2.93		
	5	300	90	3.33		

Appendix C: Picture of testing RH on Column 1, Column 2, Beam 1 and Beam 2.

Appendix D: Picture of testing UPV on Beam 1