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Non-Destructive Testing (NDT) in Teaching and Learning as Exposure to Forensic to Civil Engineering Student

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Abstract

Non-Destructive Testing (NDT) method is a method that has a lot of advantages in finding the defects, checking the integrity of the structure or monitoring the structure's health by maintaining the element in nondestructive mode, can be carried out on site, and can applied to a fully occupied building or historical building that to be protected for heritage wise reason. In order to develop the culture of maintaining the building to achieve sustainability and carrying out forensic engineering when needed, new generation of engineers should be train throughout their engineering program years of study. Thus, it is important for the student to have the exposure of NDT as it will create the interest and awareness of this technique that can be beneficial in the forensic engineering field of work, which is still low in practice and high dependent on the foreign expertise in Malaysia scenario. By looking at the number of advantages, various methods available and numbers of devices to choose from hence various parameters that can be solved with NDT it will give the edge for the future engineers of the country to further explore the forensic engineering discipline using NDT method in the future.

Keywords: Non-Destructive Test, Forensic Engineering, Building Health Monitoring

Introduction

Malaysia is a growing nation that is expanding quickly both economically and socially. Due to its thriving economy, Malaysia has been constructing first class infrastructure and buildings that enhance the country's reputation. Unfortunately, Malaysia's culture of building maintenance has not been well-executed over the years. For instance, insufficient funding for maintenance tasks and improper financial management frequently occur. For some parties, building maintenance is a time-consuming and expensive to be practiced. In fact, if the maintenance is done properly, it could save money in addition to perhaps extending the life of the structure. Education is one of the methods that may be utilized to improve the culture of exact maintenance by instill the awareness to the graduates so that they can bring the better change to the country.

Proper maintenance culture is a something to be applied in Malaysia in order to sustain the first-class facilities in the country. Furthermore, maintenance is a necessary activity for structural health monitoring (SHM) to make sure that the building and infrastructure are secure enough to be used and occupied. An essential component of evaluating diverse structures and infrastructure is structural health monitoring (SHM), which entails inspection, monitoring, and maintenance. Buildings, bridges, and tunnels are examples of structures and infrastructure systems that need to be properly inspected, monitored, and maintained to ensure their usage for the duration of their useful lives (Kot et al., 2021).

The traditional method of structural health monitoring (SHM) relies on visual inspection by humans, which is unable to detect any concealed damages (Feng et al., 2018). Structural health monitoring (SHM) through visual inspection is difficult to be applied by novice because it acquires vast of experiences and extensive training. Better inspection methods are therefore needed to track the deterioration of infrastructure, as determining a structure's condition is essential for its dependability and safety. One of the alternatives is non-destructive testing (NDT) whereby it able to offer techniques for locating concealed damage, which provides important information that can be used to increase the lifespan of monitored structures.

By definition, non-destructive testing is the assessment, evaluation, and inspection procedure of materials or components for characterization or detecting flaws in comparison to some criteria without changing the original characteristics or damaging the object being tested (Dwivedi et al., 2018). Nondestructive testing can be used to assess a material's integrity for surface or internal faults without negatively affecting the material's destruction or fitness for use. The field of Non-Destructive Testing (NDT) involves the process of identifying and characterizing flaws or defects on a material's exterior and interior to give a better data that can be interpret and analyzed for the assessment of the buildings and structures.

For instance, non-destructive testing is used in construction to evaluate building materials such wood, masonry units, concrete, fiber-cement, and steel. Non-destructive testing is put to the test on a variety of occasions and for a variety of reasons, such as during construction and service life. To measure strength and look into how it varies over time, non-destructive techniques are typically used. This type of testing often uses samples extracted from the structure, though it can also involve testing entire members or structures. Also included in this category are load tests, which are more frequently used on highways and bridges than on buildings (Schabowicz et al.,2019). In order to test a sample for individual research and examination or to verify the entire material for any civil engineering construction, NDT techniques offer a practical, fast, and affordable method (Gholizade, 2016).

Over the past 60 years, modern concrete building has advanced significantly, but one feature has largely remained unchanged which is the usage of molded cylinders and cubes tested in compression to assess the strength of concrete in a structure (Atoyebi et al., 2018; Atoyebi et al., 2019). Nowadays, in developed nations the practice of evaluating concrete in-situ has grown. There are several different sorts of methods which are resistance, pulse velocity, penetration, rebound, surface hardness, screed test, penetration resistance test, internal fracture test, break-off test, pull-out test, ultrasonic pulse velocity, acoustic emission, radiograph, radiometric thermography, half-cell potential, surface permeability, carbonation depth, resonance frequency, etc. (Hoła et al., 2010).

Techniques for non-destructive testing (NDT) have gained a lot of attention recently for the structural health assessment (SHA) of reinforced concrete structures. Various NDT

methods have been developed to keep track of and update the structure's health as necessary throughout its service life. For forecasting the compressive strength of concrete structures, some researchers have employed impact rebound hammer (IRH) and ultrasonic pulse velocity (UPV) (Aseem et al., 2019; Hobbs et al., 2007). The structural health and integrity of reinforced concrete cannot be predicted using a single NDT approach in a trustworthy or sufficient manner. A mix of non-destructive methods must be used to examine the health of concrete (Balayssac et al., 2017). Shih et al (2015) also have combined the use of the rebound hammer method and ultrasonic pulse velocity to determine the strength of concrete.

Non-destructive testing is a very useful method to assess the integrity of the structures throughout the entire life of the building. Due to service, fatigue loads, weather conditions, and other extreme events, concrete structures can deform, crack, honeycomb, and have voids. These defects can further deteriorate the integrity of concrete structures due to the concrete's own damage and steel reinforcement's corrosion. NDT methodology in this way can also be executed to identify the structural health, integrity, and serviceability of concrete structures that have experienced fire, earthquake, extreme events, and other natural disasters (Cioni et al., 2001). The application of engineering principles to the analysis of damages or various structural performance issues is known as forensic engineering. Finding the failure mechanisms using the procedural causes and contributing factors is the main goal of a forensic engineering inquiry into a building failure (Etemadi et al., 2020). The forensic engineer's involvement in the dispute resolution procedures has been defined as included in the ongoing investigation to find out what happened, why it happened, and most crucially, how to avoid similar catastrophes in the future (Calvi et al., 2019).

With the growing rate of deterioration in the nation's infrastructure, it is now more important than ever to integrate field instrumentation and non-destructive testing (NDT) into engineering curriculum. Students' interest in and learning from the course were greatly boosted by the implementation of the curriculum for improving the concrete laboratory with NDT and instrumentation modules (Mirmiran, 2001). Tertiary education such as diploma aims to acquire, generate, and develop post needed for the knowledge, ability and quality (Hu et al., 2009). The curriculum must always be in line with the demands of the job at hand and the specifications of the position.

The non-destructive testing field is very practical, and professional training heavily relies on practical instruction. To build a systematic, comprehensive, effective, and applicable standard of personnel training in tertiary education, it is crucial to lay a strong foundation for the training of skilled individuals. It also serves as a crucial teaching link to increase students' post-competence (Chen et al., 2019). Non-destructive testing adopted in education is aim is to develop technical application abilities, or those who put engineering concepts into practice and then translate them into tangible forms like engineering and products (Cheng and Li 2002). It is important to stress the practical teaching method to encourage the development of students' technological application, analytical, and problem-solving skills.

Structural Health Monitoring

All damage before visible deficiencies become evident. This allows inspectors and engineers to implement repair recommendations before minor deficiencies become safety hazards. Ultrasonic techniques have been used for the measurement of the various properties of concrete. Also, many international committees' specifications and standards adopted the ultrasonic pulse velocity.

Objective

1. Assessment of existing structure for rehabilitation planning
2. Detection of cracks, voids and other imperfections in the material
3. Monitoring changes in the concrete with the passage of time.

Non-destructive Testing

- Is a form of testing to be carried out on various construction members and materials without causing any permanent damage to them
- Does not permanently alter the article being tested.

Methodology

Typical situations where NDT may be useful are as follows:

1. Quality control of pre-cast or construction in situ removing uncertainties about the acceptability of the material supplied owing to apparent non-compliance which specification confirming or negating doubt concerning the workmanship involved in batching, mixing, and placing.
2. Comparing or curing concrete
3. Monitoring of strength development in relation to formwork removal, cessation of curing, pre-stressing, load application or similar purpose.
4. Location and determination of the extent of cracks, void, honeycombing, and similar defects which a concrete structure.
5. Determining the concrete uniformity, possible preliminary to core cutting, load testing or other more expensive or disruptive tests.
6. Determining the position, quantity or condition of reinforcement.
7. Increasing the confidence level of a similar number of destructive tests. Many of NDT methods used for concrete testing have their origin in the testing of more homogeneous, metallic systems.

These methods have a sound scientific basis, but the heterogeneity of concrete makes interpretation of results somewhat difficult. These could be many parameters such as materials, mix, workmanship, and environment, which influence the result of measurements. Moreover, the test measures some other properties of concrete like hardness yet the results are interpreted to assess the different properties of the strength of the concrete. Thus, interpretation of the result is very important and a difficult job where generalization is not possible. Even though operators can carry out the test but the interpretation of results must be left to experts having experience and knowledge of the application of such NDT. A variety of NDT methods have been developed and are available for investigation and evaluation of different parameters related to strength, durability, and overall quality of concrete. Each method has some strengths and some weaknesses. Therefore, researcher's approach would be to use more than one method in combination so that the strength of one compensates for the weakness of the other. The various NDT methods for testing the integrity of concrete members are listed below:

Table 1
Various NDT methods for testing

NDT method	**Parameter measured**	**Advantages**	**Principle**
Visual inspection (VI)	Evaluating concrete quality, cracks, defects, and voids	Rapid, economical	Based on visual defects on the surface
Image pro plus (IPP)		Simple, rapid and cheaper	Comparing colors of different objects
Acoustic emission (AE)		The fast result, detect changes in materials	The sudden distribution of stress generates elastic waves
Impact echo		Able to detect the condition of concrete accessible for one side only, quick, accurate and reliable.	Transmission and reflection of electromagnetic wave
Infrared thermography		Easy interpretation, simple, safe, no radiation, rapid setup & portable	Surface temperature variation
One-sided single-wave transmission measurements		Used to detect pavements structure	Propagation velocity of signal waves
Radiography (x-ray)		Shows any changes in thickness, defects of internal and external of rebars	The velocity of X and gamma rays and their attenuation.
Petrographic testing		The reaction of alkali-silica and carbonation	Samples are examined through a petrological microscope using reflected or transmitted light
Rebound hammer	Compressive strength, surface hardness, adhesion	Simple, quick and inexpensive	Indicates the strength of concrete
Ultrasonic pulse velocity (UPV)		Large penetration path, quick, portable and inexpensive	Ultrasonic wave velocity and its attenuation
CAPO test		The correlation between pull-out force and compressive strength is reliable	The expended ring in the cored hole is pulled out
Probe penetration		Simple and low maintenance	Penetration of probe is measured and related to strength
Pull out test		Fast results, evaluate adhesion and tensile	Used to obtain pull-off strength

		strength which can be converted to compressive strength	
Quantab test	Chloride concentration	Fast and accurate	The reaction of silver dichromate with chloride ion produces a white column on the strip
Rapid chloride test		Portable, simple and quick	Will indicate chloride correlation
Potentiometric titration		Reliable	The final volume will indicate chloride content
Galvanostatic pulse method	Corrosion rate, percentage of corrosion, corrosion progress	Measure half-cell potential and electrical resistance simultaneously	Based on polarization or rebar by means of a small content count
Time domain reflectometry (TDR)		More robust, easy to locate corrosion and identifies the extent of damage	Physical defects of the reinforcement will change the electromagnetic properties of the line
Ultrasonic guided waves		Identifies location and magnitude of corrosion	Based on the propagation of ultrasonic waves
x-ray diffraction and atomic absorption		Simple and reliable	The intensity of -ray beams reduces while passing through a material
Phenolphthalein indicator test	Carbonation depth, pH of concrete	Simple, quick and inexpensive	Carbonation reduces pH of the concrete
Rainbow indicator		quick, descriptive and interpret	Carbonation the reduces pH of the concrete
Ground coupled penetrating radar (GPR)	Pavement inspection and subsurface condition	Inexpensive, portable and effective	Propagation of radiofrequency (0.5-2 GHZ)
Hammer sounding		Simple and easy to handle	Indicates the existence of delamination
Acoustic tomography		Useful result and moderate	Wave velocity depends on the material properties
Falling weight deflects meter (FWD)		Useful results	Loads are produced by dropping a large weight to detect concrete
Seismic refraction method	The entire depth of damage, percentage of	Reliable	Seismic waves travel outward from a source and reach the detector

Ultrasonic longitudinal wave (L-wave, P-wave)	damage, identification of deteriorating infrastructure	Inspect at large depths	Transmission and reflection of ultrasonic waves
Ultrasonic continuous spread spectrum signal		Improved sensitivity	Signals are received by detectors and signal speed depends on defect
Water permeability test	Permeability, water absorption	Preparation and skill required, time-consuming	Assess the ease with which water penetrates concrete
Initial surface absorption test (ISAT)		Consistent results	The rate at which water is absorbed in concrete is measured
Concrete absorption test (CAT)		Not influenced by local surface attacks	The rate of absorption of concrete is measured
Cover meter	Concrete cover, rebar diameter, location of reinforcement	Portable	Electromagnetic induction
Radioactive method		Simple	Generates images of the structure of RC and steel
Static truck and test	Load bearing capacity of the bridge	Reliable	Response of strain sensors under truck load indicates load bearing capacity
Multichannel analysis of surface waves (MASW)	Relative condition of brick masonry side walls	Reliable, fast and economical	Use multiple sensors to record wave field
Fiber optic Bragg grating sensors	Stress/strain sensor for monitoring composite beams	Suitable for a long-term test	Monitors the response of the structure subjected to full load

(Source: Verma et al., 2013)

Discussion

Widely used in Industry

NDT now is widely used in construction industries whereby this technique will minimize the deterioration of the structure that been tested. Therefore, NDT should be introduced to the students in engineering syllabus so that the graduates will be not left behind in this latest method that has been practiced by many developed countries.

Exposed student to preventive maintenance. Increase awareness to importance of preventive maintenance.

Currently most of buildings in Malaysia having problem with poor maintenance due to culture practiced by majority stakeholder for example government, properties' owner, and developers. This poor maintenance is happened due to lack of knowledge in conducting structural health monitoring activity. Thus by introducing NDT in Engineering at tertiary education such as diploma and degree level will prepare the future engineers the required

awareness of the importance of having preventive maintenance mentalities in their career objective.

Enhance forensic engineering activities among new generation/graduates

Previously NDT is less applied in construction industries due to unreliable results obtained from this technique to verify defects or checking structural integrity of the building because it will define whether the building is safe to be occupied or not. However, many researches have been done and advanced technique has been discovered using this NDT and has improve the reliability of the results obtained and hence improve the confident of the industries player. Therefore, forensic engineering activity will be flourish and actively been practiced widely in Malaysia.

Less Dependent to Foreign Expertise

Many Forensic engineering company established by foreign experts. Thus, to increase involvement of local expertise in NDT early exposure to the graduates is vital. Local experts in forensic engineering should be encouraged to take part in this technology and ready to compete with the more established parties. The government should think ways of growing the number local experts in forensic. However, the local experts need some exposure and well training program to make them ready to participate in the trade. That's why NDT is important in the syllabus of engineering program.

Reflect to image & standard of government and construction industry

The reputation of the government and construction industry in Malaysia might be tarnish by the lack and improper management of the building maintenance. Lack of expertise in the forensic engineering, poor maintenance planning and having no culture of sustainability minded among the problem that circulating industry. These problems will reflect to the image and standard of the government and construction industry players if not to be overcome. Thus, by introducing NDT to the civil engineering student will hopefully close the gap in the near future as this new generation of engineers would be ready to play their roles in this short back.

Conclusion

New generations of engineers should receive training during their early levels of engineering education to develop the culture of maintaining the building to achieve sustainability and performing forensic engineering as necessary. Therefore, it is crucial for students to be exposed to NDT since it will spark their interest in and raise their awareness of a method that can be applied in the field of forensic engineering, which is still lack of practice in Malaysia and heavily dependent on foreign expertise.

Psychomotor is one of important aspect for engineering education whereby the domain is used to assess the students' skill such as physical movement, coordination, and use of the motor-skill areas. Proper exposure to the NDT will allow students to have comprehensive quality for the psychomotor that will give value added to them in their career. The students can improve their theoretical and practical abilities and meet the requirements of their first job position. In term of cost, NDT will minimize the expenses for teaching and learning since it won't need to purchase samples frequently when the activity is conducted by the students. Students can use the apparatus limitless and all the student will have opportunity to operate the NDT devices Psychomotor.

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