Role of Non-destructive Testing and Evaluation (NDTE) in Water Resource Engineering

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Abstract: The quality of infrastructure and materials used in water resource engineering are vital importance in any civil work designed to last long. Survey of non-destructive testing and evaluation (NDTE) techniques in the field of civil engineering and their applicability to water resource engineering structures like water storage tanks, reservoirs, piping irrigation structures etc. NDTE methods could be employs are discussed. We found NDTE methods are very helpful in ensuring material integrity leading to safe operation and maintenance. We highlight real life advantages, scope and limitations of different NDTE methods from stand point of civil engineering works with reference to water resource engineering structures.

We reviewed the applicability of different NDTE methods based on ultrasound testing (UT), electro-magnetic testing (ET and MT) X - ray (RT) and radar flaw detection technologies, Ultrasonic Localized Guided Wave (ULGW), Ground penetrating radar; Rebound Hammer, Surface Electrical Resistivity test methods etc. & found Half-Cell Corrosion Mapping, Ultrasonic Tasting and Ultrasonic Localized Guided Wave techniques and acoustic emission testing quite interesting.

Among many factors adversely affecting water resource and irrigation structures, extreme variations in climatic conditions and those in water quality parameters, reduce the durability of the structures. We found that effective testing, analysis, monitoring and maintaining of water resource engineered structures can effectively be achieved through development of NDTE techniques. One of the most challenging tasks was to plan, procure and use different kinds of nondestructive testing machines and optimize methodologies by solving real time technical problems and ensure ease of usage.

Keywords: Civil Engineering NDT, Climate, Durability, Ground Penetrating Radar, Half-cell corrosion testing, Non-destructive Testing and Evaluation (NDTE), rebound hammer ULGW technique, Water resource structures.

1 Introduction

Water is one of a vital element of the nature, Water resources engineering (WRE) is the field which includes the study of water , land and recourses, management, equipment, water structures, facilities and techniques etc.. It addresses the best ways to control and ensure its availability for water-related activities – such as irrigation, waste disposal and canal development, ensure safe drinking water for humans, plants and animal usage. WRE is responsible to ensure that the planning and management of

available water supply are adequately leveraged and remain safe to use for as long as possible. They may also be involved in water treatment, so that the quality of water is improved upon for various end users, whether that's recreationally, commercially or industrially.

There are only few renewable sources – such as wind, solar, hydro and biomass. While water may be renewable in terms of the many different ways it can be used and reused, it's not as abundant as it once was, which many earth scientists and climatologists point to as a function of climate change.

The Bureau of Reclamation provides some perspective as to just how limited this resource is in terms of usability, despite its vastness. Surface water makes up about 71% of the planet, which is the equivalent of roughly 326 million cubic miles. At the same time, though, fresh, of this total, 2.5% of it is out of reach, contained in the soil, polar ice caps, the atmosphere and glaciers or too polluted to use safely, so only 0.5% is available for safe usage.

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Water resource engineers may be charged with developing new systems or processes for private or government entities that can preserve freshwater sources and find new ones. This may require the assistance of civil engineers involved as well, design of water purification methods through desalination or creating new equipment for contaminant transport when water is used for irrigation purposes. Understanding what works and what doesn't when it comes to water resource management is often a combined effort and may involve a number of different analyses, including hydrologic, which is the study of the water cycle and directions in which it flows, which may be influenced by weather and other environmental forces. the WRE deals with water resource structures like reservoirs, lakes waterways, breakwaters, sewage conduits etc., takes major role in conservation and management of the water.

In order to use civil engineering structures for full duration of designed safe life, the quality and quantity of materials used, their composition and their ratios, are in general as per SODP (Standard Design Procedure). In the field of Civil Engineering, Water resource engineering structures are critical, so as to conserve the huge amount of water along with its different quality factors, they should be strong enough to take the water load but also entire surface of the structure has to be resistant to climatic variations and composition of material in contact for the designed life.

Especially in water resource engineering, hydraulic action and composition of water can also lead to strength to deterioration the strength of the structure. Hence the hydraulic water resource structure should have the strength to avoid downstream effects and also to counter unexpected negative impacts caused by failure of these structures. Non- Destructive Tasting helps to assess the strength of such structures to give residual life estimation.

Non Destructive testing also helps to avoid the sudden failure of structures by providing the information about in service strength of the material used for construction. Nondestructive testing is carried out by some of the state of the art machines along with established testing techniques.

While Nondestructive testing evaluation gives result by considering key constraint points like, type of material used and its ratios, geometric properties of the structure or structure component and the result also can talk about the age of structure along with existed structure's strength.

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2 Most Commonly used NDE Techniques in Water Resource Engineering

In the field of water resource engineering some of NDE techniques are commonly used because of ease operating procedures, ease of availability of equipment and they offer reasonably accurate results, These NDE techniques like ultrasound testing and evaluation, electro-magnetic testing and evaluation, X - ray and radar flaw detection technologies, Ultrasonic Localized Guided Wave (ULGW), Ground penetrating radar; Rebound Hammer, Ultrasonic Pulse-Echo (UPE), Surface Electrical Resistivity test method, Half-Cell Corrosion Mapping, and acoustic emission testing etc. are found to be most commonly used and found to be special in the WRE.

Brief discussions of each techniques and their applicability are discussed below along with their particular area of usage.

2.1 Ultrasound Testing and Evaluation

Ultrasound testing and evaluation is one of the uncomplicated methods of finding the quality of mortar material. This method involves recording and analysis of ultrasound waves penetrated through the mortar under curing, while hardening process is on, the transmitted ultrasound waves get affected by hydration process. Ultrasound evaluation method gives clear idea about how concrete structures formed by hardening the mortar to get enough strength to structure. In this method factors like, velocity, variation frequency, amplitude etc. are rely on the life span of the material and these can be detected in the course of hardening action (IWB et al. 2000).

It is a quality control method in civil engineering either it may with respect to mortar or concrete. In the field of civil engineering the quality control methods are not dealt in only one factor, the quality control factors in life of the civil engineering are water/cement ratio, humidity, temperature, aggregate to cement ratio etc. are decide the consistency of concrete and the workability. The terms like frequency, velocity amplitude are depends upon age of the material composite. Recording the transmitted or reflected waves to be recorded can be possible only by one term and most probably used term is velocity.

Ultrasound evaluation gives age of the structure component and it will be depend upon different types of materials used for the concrete. In water resource engineering, in case of structures those connect with water directly can possible to give more water content in the concrete compound, so the probability of recording the ultrasound waves in such case gives inaccurate reading. Rather than this, this method is very easy and less error method to find age of compound by analysis of this we can conclude the strength of the concrete.

2.2 Electro-Magnetic Testing and Evaluation

In Electro-magnetic testing and evaluation, the magnetic fields are generated by either permanent magnets or solenoid coils, or yokes. Such magnetic field easily penetrates magnetic materials like Steel. A defect in such material will affect the leakage magnetic fields which can be detected by NDT techniques like magnetic particles. The strength of magnetic field in the material to be tested will increase with increase in solenoid current or when the permanent magnet is close to test object

Similarly an alternating current carrying coil when brought near a conducting material, an eddy current is induced in the test object This induced eddy current is also related to defects in material hence we can detect hidden conductive materials (Paul J. et al. 2006).

This method is very helpful in finding the location of reinforcement or it is helpful in fixing the siltation of reinforcement. In case of large scale construction in water resource engineering structure like bridge and dam construction, the structure contacts directly with water, because of dynamic climate the durability of material reduces in the presence of water results corrosion, finally it decreases the magnetic property of material. As so as magnetic property reduces, finding the quality of reinforcement results cannot be accurate always for structure monitoring cases.

2.3 Radar flow detection technologies

The radar flow detection technology is very important in field of waste water supply or in sewer and in water supply area. In this technique, the water or sewage flow rate is determined by Doppler Effect. Flow determination can be done by using the special kind of sensors and this allow for measurements without contact. It works on the principal that, the sensor is to be fixed outside or at some elevation height of the medium, the signals emitted out from sensor are hits the surface of water. Once reflected signals from the water surface are detected, the change in frequency is created due to velocity in incident and reflected signals the difference in frequencies is termed Doppler shift and this frequency is detected by the sensor to be assess the flow characteristics by the principle of Doppler Effect. (NIVUS, Article ID=15080, 2018).

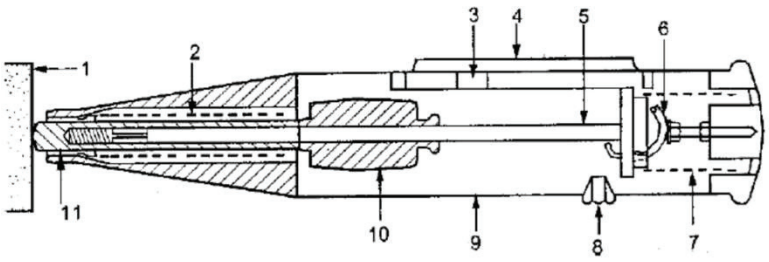
This technology is relies on velocity measurement, it helps to analyze the effect of water quantity as well as quality inside the conduit by knowing the continuous variations in velocity.in case of open channel it is very important to get the velocity variation, because sedimentation problem is a big issue in case of open channel, so as to know sedimentation in the channel, the velocity measurements helps to find solution for this. Sedimentation can cause major impact on inner wall of channel and increasing sedimentation increases discharge capacity of channel.

2.4 Rebound Hammer (Schmidt Hammer)

Principle: The method is based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which mass strikes. When the plunger of rebound hammer is pressed against the surface of the concrete, the spring controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete.

The surface hardness and therefore the rebound are taken to be related to the compressive strength of the concrete. The rebound value is read off along a graduated scale and is designated as the rebound number or rebound index. The compressive strength can be read directly from the graph provided on the body of the hammer. Depending upon the impact energy, the hammers are classified into four types i.e. N, L, M & P. Type N hammer having impact energy of 2.2 N-m and is suitable for grades of concrete from M-15 to M-45. Type L hammer is suitable for lightweight concrete or small and impact sensitive part of the structure. Type M hammer is generally recommended for heavy structures and mass concrete. Type P is suitable for concrete below M15 grade.

The Rebound Hammer is a simple, handy tool, which can be used to provide a convenient and rapid indication of the compressive strength of concrete. It consists of a spring controlled mass that slides on a plunger within a tubular housing. The schematic diagram showing various parts of a rebound hammer is given in figure below.



1. Concrete surface	5. Hammer guide	9. Housing
2. Impact spring	6. Release catch	10. Hammer mass
3. Rider on guide rod	7. Compressive spring	11. Plunger
4. Window and scale	8. Locking button	

The rebound hammer method could be used for –

(a) Assessing the likely compressive strength of concrete with the help of suitable co-**relations between** rebound index and compressive strength.(b) Assessing the uniformity of concrete (c) Assessing the quality of concrete in relation to standard requirements.(d) Assessing the quality of one element of concrete in relation to another.

This method can differentiate between the questionable and acceptable parts of a structure or for relative comparison between two different structures. This is a hardness test method and is based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. The energy absorbed by the concrete is related to its strength. Despite its apparent simplicity, the rebound hammer test involves complex problems of impact and the associated stress-wave propagation. There is no unique relation between hardness and strength of concrete but experimental data relationships can be obtained from a given concrete. However, this relationship is dependent upon factors affecting the concrete surface such as degree of saturation, carbonation, temperature, surface preparation and location, and type of surface finish. The results also affected by type of aggregate, mix proportions, hammer type, and hammer inclination. Areas exhibiting honeycombing, scaling, rough texture, or high porosity must be avoided. Concrete must be approximately of the same age, moisture conditions and same degree of carbonation (note that carbonated surfaces yield higher rebound values). It is clear then that the rebound number reflects only the surface of concrete.

2.5 Ultrasonic Localized Guided Wave (ULGW)

In case of pipe inspection, it is very difficult to find problems inside the pipe, as go as pipe length increases the difficulty of finding problems also increases. ULGW method is pipe inspection method. It is a very good method as compare to other conventional method because old methods are used to test for only limited area and process was also slow. ULGW covers maximum length of area and gives fast result but in old methods test was restricted to small area, to get result for system the whole system has to be tested (SaeedIzadpanah et al. 2008). Almost all pipe, either it may be oil pipe or it may water or sewer pipe are cover with some insulating material in order avoid weathering action causes damage to pipe, insulated pipe testing in order to find the internal damage is very difficult, to find the problem is such cases requires removal of insulators over pipe but it results expensive testing, so as to overcome this problem ULGW method found to be very interested, because in this method waves travels through insulation that is too for long distance helps to find the internal damage or pipe problems without removing the insulating cover over pipe.

This method is mainly used only for oil pipes because as compare to water oil is the expensive liquid, so in order avoid oil loss by leakage, ULGW method is to be carried out. But irrespective of water cost the leakage of water results rapid corrosion and reduces the durability of pipe and pipe network.so to avoid such losses this method should also follow for water lines.

2.6 Half-Cell Corrosion Mapping

Half-cell corrosion method is use for finding the corrosion of reinforcement in concrete elements. Potential difference is called voltage with reference electrode is called half-cell is used to measure the corrosion potential Ecorr, and obtained value of the potential difference between concrete having steel inside, along with standard electrode will depend on the standard electrode used and also depends upon condition of steel inside the concrete (B. Elsener et al. 2003). In inclusion, half-cell potentials of steel metal in concrete cannot be quantify as straight at coherence of concrete/Rebar because of cover of the concrete, thus the potentials are controlled by iR drop in the cover, by using macro-cell current and likely by potentials of junction (B. Elsener et al. 2003).

Corrosion of reinforcement happen mainly due to weather actions, it include climatic variations. Especially in case of water resource structures, the structure durability reduces as age increases because of pollutants of water and its interface with structure may cause chemical action and it reduces the quality of structural material results the average reduction in strength of the structure. Structures contact with water regularly support for corrosion of steel in presence of air from environment. So as to find such defects in structure, finding the corrosion is very important to avoid the failure of structures and structures requires periodical monitoring with respect to corrosion mapping.

2.7 Acoustic emission testing

This technique detects the elastic wave's signals originating from within the specimen which is under some stress. When the material with defects is under stress the defects start growing and creates new surface of defects (expansion of Cracks) releasing energy in elastic waves form These growing defects arise from some physical and thermal deformation of structure yield signals, so that the defect can be detectable only during the growth of defects (Ajay Kapadia et al.).

Acoustic emission Monitoring is the detection of acoustic emission from the test object are the signals emitted by the result of failure and hence AET it is nothing but to listen to the failure.

This technic is mainly used in precast material structure component. The sound may be arising because of crack expansion, the friction and rusting of reinforcement (DaliusMisiunas et al. 2005). For the best maintenance of any large scale sewer lines or water lines, this method needs to be carried out periodically very strictly, so it can give some clues of failure before the cause. We can know when the structure will fail and Acoustic Emission Monitoring is a major NDT tool to inspect concrete and metal bridges.

3. Conclusions

In this paper we have introduced water resource engineering structures as engineering objects which also need Non-destructive Testing and evaluation upon detailed study we find a number of NDTE techniques are being pursued at many a places. As the concrete structures are usually macroscopic and reasonable large objects, Ultrasonic, electromagnetic are more useful and X ray radiography is not feasible, Acoustic emission testing is useful to learn about growing defects, These growing limits when exceed the limits failure occurs This will prevent the disasters from happening. We have also discussed the applicability of Rebound hammer as a hardness testing tool

By studying different types of non-destructive testing and its evaluation says that methods like ultrasound evaluation, electro-magnetic testing and evaluation, X - ray and radar flaw detection technologies, Ultrasonic Localized Guided Wave (ULGW), Ground penetrating radar; Rebound Hammer and Half-Cell Corrosion Mapping, and acoustic emission testing etc. are very much useful in the field of Civil Engineering.

- Among many types of NDE technics, some methods like X - ray and radar flaw detection technologies, Ultrasonic Localized Guided Wave (ULGW), Half-Cell Corrosion Mapping, and acoustic emission testing methods are found to be very interesting and very useful in case of water resource Engineering.
- In case of radar flow detection, it gives the results by contactless measurement of the velocity inside the conduit in the sense of sensors is a very innovative method to analyze the defects by speed of water to the inner pipe surface And this method offers for both open channel and close channel flow. But only by velocity variation we cannot decide the results, in case of sewer lines velocity depends upon many factors like type of pollutants present, number of pollutants present, internal temperature, chemical action among pollutants and with water and overall density of water so cannot ensure the defect's reason exactly.

- Ultrasonic Localized Guided Wave (ULGW) technique is very useful for the pipe inspection in order to find the leakages or defects. It seems to be very costly for inspection of water line networks. Most of the time they use for water pipelines, because water cost is very cheaper than cost of oil. But when you consider leakages in case of water lines it allows the air to interact with more area of pipe with air in presence of water results corrosion of steel content in the pipe and also leakage points in pipe allows foreign particles to enter into the pipe results the clogging of the pipe. Area where joints, pipe fittings are present in pipe cannot give results because of non-uniformity in pipe dimensions or sudden enlargement and sudden contraction of pipe. So these kinds of drawbacks bring some challenges to find economic and accurate method can apply for water lines in order to find internal defects.
- Half-Cell Corrosion mapping technic is useful to find the corrosion in the concrete, this method takes important role because in water resource structures are always in a contact with water, main factor which allow for corrosion is salt water, chemicals and one more is air. Large scale Structures like Reservoirs bund, water runway, bridges, overhead tank requires corrosion finding evaluation without disturbing to structure in sense of reduction of failure risk. But this technique requires technical person should know about corrosion spots and technic of finding.
- Acoustic emission testing takes it role where structures failures give noise waves. It is useful during failures of structural components gives sound waves by recording of waves can recognize as failure. Nondestructive evaluation is better to takes its role before failure of structures or during monitoring of structures. But this method can be taken as final safety technic in case of precast material structures like bridges.

As we have discussed almost all important techniques, each field requires multi nondestructive testing's and evaluation methods for accurate monitoring of structural health, many NDE techniques in single area of interest gives expensive management. Some of cases mandatorily require many tests but priorities of following of different tests in single area of interest are to be challenging by considering operating cost. Assessment of different test follows as period wise is to be scheduling accordingly the types of structures. Overall in field of water related structures requires multi testing facility in a single method, for example finding corrosion, surface hardness and chemical action rate and speed of interaction between water and structural material is required in the field of water resource Engineering in low cost and ease operation.it is very essential to select an appropriate NDE method and technique to get accurate results, it also helps to understand the behavior of the structure at an early stage of the failure. With NDE Methods it will be easy to take precautionary measures, save or increase the life of the structures by making some modifications and alteration if it is necessary. These methods are more cost effective in nature.

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