Acoustic Surface Wave Condition Monitoring of Subsea Concrete Structure

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Abstract - Recent advances in hardware and software have generated a remarkable enhancement in the image quality and have broadened the obtainable information spectrum. Acoustic Surface Wave (ASW) is a naturally occurring phenomenon in surface of materials under load (force, temperature, etc). Spectral Analysis of Surface Wave (SASW) condition monitoring is related to the identification of certain vibration parameters due to surface waves and their measurement with a view to diagnose underwater part of concrete structures. Condition monitoring of subsea concrete structure of Shahid Rajaee Harbor using SASW is discussed in this paper. The paper also pays some attention to methods for underwater nondestructive testing of concrete and detecting of faults. Proposed method refers to the determination of the propagation times between the transducer sample and imactor by determining the frequency dependent on the material.

Keywords: Acoustic Analysis, Subsea Concrete Structure

I. INTRODUCTION

The repair of concrete structures under water presents many complex problems. The harsh environmental conditions and specific problems associated with working underwater or in the splash zone area cause many differences. Proper evaluation of the present condition of the structure is the essential first step for designing long-term repairs. To be most effective, evaluation of the existing structure requires historical information on the structure and its environment, including any changes made to the structure over time, and the records of periodic on-site inspections or repairs.

Reduction of the human experts’ involvement in the diagnosis process has gradually taken place upon the recent developments in the modern Artificial Intelligence (AI) tools. Artificial Neural Networks (ANNs), fuzzy and adaptive fuzzy systems, and expert systems are good candidates for the automation of the diagnostic procedures and e-maintenance application [6], [9]. The present work surveys the principles and a criterion of the diagnosis signal processing and introduces these achievements to an expert system technique. In this paper a new sensor design is discussed and experimental results are presented for an expert system application, based on the concept of spectrum and cepstrum analysis detected signals and method of measuring defected part of subsea concrete without disturbing their structures for suspected part harbor. A transducer using the principle of a vibration sensors has been tried and considered to be suitable for measuring any probable damage due to irregular phenomenal such as voids, mix separations and cracks on the suspected superficial portion of the subsea concrete structures. Such transducers are proposed to be the basis for condition monitoring of armored steel structure in the subsea concrete by means analyzing the change of vibration sensed by related transducer of the testing probe (Fig. 1).

It is a common observation that, when there were voids, mix separation or crack the reflected waves detected by the receiving sensor were weaker than those from the perfect areas. The results showed that the analysis of surface wave testing has the ability to detect changes in the constructed structures. The vibration signals which appear on the perfect part of structure, give a characteristic vibration signature. This signature provides a base line against which future measurements can be compared.

It is important to note that similar concrete structure in good condition will have similar vibration signature differing only in respect of their constructional and structural conditions tolerances. Vibration condition monitoring makes use of vibration analysis for the following purposes:

1) Periodic routine vibration measurement of harbor concrete structures to check their structural condition.
2) Trouble shooting for suspected constructional problems.
3) Check to ascertain that the concrete structure has returned to good operating condition after implementing the reconstruction or repair.
4) Check to enable planning of repair of the harbor concrete structures prior to harbor service shut-down.

Different defects cause the vibration signatures to change in different ways. A changed vibration signature provides a means to determine the source of problem as well as prior warning of the problem itself. This research
work is limited to implementing the acoustic signal processing and condition monitoring of concrete structures in the splash zone and underwater portions of structures located in lakes, rivers, oceans, and ground water. Most of the activity in this connection is related to the Shahid Rajaee Harbor that offers a tough environment for condition monitoring of concrete.

II. DECIDING WHAT ACTION TO TAKE

Deciding on the appropriate action to take after a defect has been discovered depends on the potential hazard of the defect, the risk of continued structural deterioration, the technology available to repair the defect, the cost associated with the needed repair, and the intended remaining life of the structure. Following are the possible methods of concrete harbor inspection:

1) Visual inspection
2) Tactile inspection (Inspection by touch)
3) Underwater non-destructive testing of concrete (signal processing)

III. DIVING TECHNOLOGY

Underwater work can be generally classified into one of three broad categories for accessing the work site: manned diving:

1) one-atmosphere armored suit
2) manned submarine
3) Remotely Operated Vehicle (ROV)

The development of remotely operated vehicle (ROV) based tool to assess the nature of acoustic vibration of under construction concrete structure part of Shahid Rajaee Harbor facilitates at the nondestructive testing where the divers activities are not easily feasible, standard and acceptable.

The industry standards currently allow a diver using compressed air to work at 30 ft (10 m) for an unlimited period of time. If work is being performed at 60 ft (20 m), however, the diver can only work for approximately 60 minutes over a 24-hour period without special precautions to prevent decompression sickness. The industry standard upper limit is 30 minutes of work time at 90 ft (30 m) in seawater. If these limits are exceeded, precautions must be taken to decompress the diver.

ROVs look much like an unmanned version of a submarine (Fig. 2). They are compact devices that are controlled by a remote crew. The operating crew and the vehicle communicate through an umbilical cord attached to the ROV. The crew operates the ROV with information provided by transponders attached to the frame of the ROV. ROVs may be launched directly from the surface or from a submarine mother ship. Most ROVs are equipped with video and still photography devices. The vehicle is positioned by ballast tanks and thrusters mounted on the frame. Some ROVs are also equipped with robotic arms that are used to perform tasks that do not need a high degree of dexterity. ROVs have been used at depths up to approximately 8000 ft (2400 m). Structural investigations of underwater facilities are usually conducted as part of a routine preventive maintenance program, an initial construction inspection, a special examination prompted by an accident or catastrophic event, or a method for determining needed repairs. The purpose of the investigation usually influences the inspection procedures and testing equipment used. Underwater inspections are usually hampered by adverse conditions such as poor visibility, strong currents, cold water, marine growth, and debris buildup. Horizontal and vertical control for accurately locating the observation is difficult. A diving inspector must wear cumbersome life-support systems.
and equipment, which also hampers the inspection mission.

Underwater inspections usually take much longer to accomplish than inspections of similar structures located above the water surface. This necessitates more planning by the inspecting team to optimize their efforts. Inspection criteria and definitions are usually established before the actual inspection, and the inspection team is briefed. The primary goal is to inspect the structural elements to detect any obvious damage. If a defect is observed, the inspector identifies the type and extent of the defect to determine how serious the problem may be. The inspector also determines the location of the defect so repair crews can return later to make the repair, or another inspection team can reinvestigate if necessary. Many divers who perform structural inspections do not have specific structural engineering training for this task. In this case, another person with the appropriate engineering background is normally employed to interpret the results of the inspection and make the appropriate evaluations.

IV. UNDERWATER NONDESTRUCTIVE TESTING OF CONCRETE

Studies of nondestructive testing (NDT) of concrete have shown that the following techniques and instruments are applicable to underwater work.

A. Soundings

Soundings are taken by striking the concrete surface to locate areas of internal voids or delamination of the concrete cover as might be caused by the effects of freezing and thawing or corrosion of reinforcement. Although the results are only qualitative in nature, the method is rapid and economical and enables an expeditious determination of the overall condition. The inspector’s ability to hear sound in water is reduced by waves, currents, and background noise. Soundings are the most elementary of NDT methods.

Figure 2. The proposed ROV and diagnostic arm

B. Ultrasonic pulse velocity

Ultrasonic pulse velocity is determined by measuring the time of transmission of a pulse of energy through a known distance of concrete. Many factors affect the results, including aggregate content and reinforcing steel location. The results obtained are quantitative, but they are only relative in nature.

A special form of this technique is the pulse-echo method. The pulse-echo method has been used for the in-place determination of the length and condition of concrete piles.

C. Magnetic reinforcing bar locator

A commercially available magnetic reinforcing bar locator (or pachometer) has been successfully modified for underwater use. The pachometer can be used to determine the location of reinforcing bars in concrete, and either measure the depth of concrete cover or determine the size of the reinforcing bar if one or the other is known.

Techniques are available for approximating each variable if neither is known. Laboratory and field tests of the instrument demonstrated that the modification for underwater use had no effect on the output data.

V. IMPACT HAMMER

A standard impact hammer (ASTM C 805), modified for underwater use, can be used for rapid surveys of concrete surface hardness. The underwater readings, however, are generally higher than comparable data obtained in dry conditions. These higher readings could be eliminated by further redesigning of the Schmidt hammer for underwater use. Data also can be normalized to eliminate the effect of higher underwater readings.

VI. ECHO SOUNDERS

Another ultrasonic device, the echo sounders (specialty fathometers), can be useful for underwater rehabilitation work using tremie concrete, both to delineate the void to be filled and to confirm the level of the tremie concrete placed. They are also effective in checking scour depth in a stream bed. They consist of a transducer that is suspended in the water, a sending/receiving device, and a recording chart or screen output that displays the water depth. High-frequency sound waves emitted from the transducer travel through the water until they strike the bottom and are reflected back to the transducer. The echo sounder measures the transit time of these waves and converts it to water depth shown on the display. When an echo sounder is used very close to the structure, however, erroneous returns may occur from the underwater structural elements.

VII. SIDE-SCAN SONAR

A side-scan sonar system is similar to the standard bottom-looking echo sounder, except that the signal from
the transducer is directed laterally, producing two side looking beams. The system consists of a pair of transducers mounted in an underwater housing, or “fish,” and a dual-channel recorder connected to the fish by a conductive cable. In the past several years, the side-scan technique has been used to map surfaces other than the ocean bottom. Successful trials have been conducted on the slopes of ice islands and breakwaters, and on vertical pier structures. Although the side-scan sonar technique permits a broad-scale view of the underwater structure, the broad beam and lack of resolution make it unsuitable for obtaining the kind of data required from inspections of concrete structures.

VIII. RADAR

Certain types of radar have been used to evaluate the condition of concrete up to 30 in. (800 mm) thick. Radar can detect delaminations, deteriorations, cracks, and voids. It can also detect and locate changes in material. Radar has been used successfully as an underwater inspection tool, and is being developed for possible future use. Radar with the antenna contained in a custom waterproof housing was used in 1994 in conjunction with pulse velocity testing to investigate the structural integrity in a concrete plug submerged 150 ft (46 m) in a water supply tunnel.

IX. UNDERWATER ACOUSTIC PROFILERS

Because of known prior developmental work on an experimental acoustic system, acoustic profiling has been considered for mapping underwater structures. Erosion and down faulting of submerged structures have always been difficult to accurately map using standard acoustic (sonic) surveys because of limitations of the various systems. Sonic surveys, side-scan sonar, and other underwater mapping tools are designed primarily to see targets rising above the plane of the sea floor. Sampling and destructive testing also can be used when other methods are not possible.

X. SPECTRUM & CEPSTRUM ANALYSIS

The vibration spectrum can be expressed on a linear frequency scale with constant bandwidth. This type of spectrum provides fine resolution at higher frequencies but a poor resolution at lower frequencies. Whereas a constant percentage bandwidth analyzer uses logarithmic frequency scale and cover three decades with equal resolution. It is for this reason that the best analysis method for the comparison of spectra and fault detection is the use of constant percentage bandwidth with a logarithmic frequency scale.

Cepstrum analysis is carried out to identify a series of harmonics or sidebands in the spectrum. Cepstrum may be considered to be the frequency analysis of frequency analysis. The power cepstrum is defined as:

\[ C_p(\tau) = F^{-1} \{ \log F_{xx}(f) \} \]  
(1)

Where \( F_x(t) \) is the time signal and its Fourier transform is \( F_{xx}(f) \).

Fig. 3 shows a spectrum from a concrete structure in its deteriorated condition. It contains several harmonics. It is not possible to detect from this spectrum that there are two series of harmonics indicating two different phenomena. Cepstrum of this spectrum is also give in the side. It may be seen that the cepstrum identifies these two families of harmonics (with a spacing of 48.5 Hz and 119.4 Hz respectively).

Fig. 4. Frequencies below that of half of the Impactor frequency are removed.
Fig. 4 shows the edited spectrum such that frequencies below that of half of the Impactor frequency are removed. The cepstrum of this spectrum is then calculated. The cepstrum does not show the 119.4 Hz component at all. It indicates that this component originates from the lower frequency range. The cepstrum does retain the 48.5 Hz component indicating its origin in the medium frequency range. It may thus be concluded that the gearwheel rotation at 49.8 Hz may have an incipient fault while the shaft rotating 119.4 Hz indicates unbalance or other low-frequency fault.

In this research the Acousto – Vibration (AV) technology utilized to detect defects, such as voids and mix separations in the constructed parts.

XI. CONCLUSION

The acoustic surface wave condition method was applied for underwater concrete structure condition monitoring. The focus here is the test for cracks, voids, and mix separation. An ROV based electro-dynamic impacter excite the undersea concrete structure at different positions.

A microphone (a laser vibrometer can be used as an option) picks up the sound. The computer calculates and compares the acoustic surface wave by a resolution of 1Hz and generates the decision for the test bench controller.

The results showed that acoustic vibration analysis testing has the ability to detect changes in the structure of concrete based products. However, further research is needed before it can be used as a routine testing tool.

It is apparent that in the proposed method the perfect undersea concrete structure should not produce vibration signal more than normal value. This is never the case, for it is impossible to eliminate all asymmetries in the materials and geometry of the concrete and steel armature in the Structure. It follows from the measurements having been carried out that several predominant frequencies arise in the specimens under test.

To extract knowledge from the expert the knowledge engineer must become familiar with problem of vibration and acoustic analysis. The rule base system is goal driven using back ward chaining strategy to test the collected structure vibration and acoustic properties information is true. The case specific data plus the above information with the help of explanation subsystem, allows the program to explain its reasoning to the user and will provide the expert system shell requirements. Significant difference can exist between the signals created by subsea concrete defects. The respective amplitudes of the mentioned signals may exceed each other in a different way in repeated measurements of the same specimen. This device serves as a base for development of expert system monitoring module. The change of reference signal with proposed expert system implies that something within the subsea concrete structure has altered and diagnosis is made.

REFERENCES