International Research Journal of Applied and Basic Sciences
© 2018 Available online at www.irjabs.com
ISSN 2251-838X / Vol, 12 (1): 22-27
Science Explorer Publications

Review of some nondestructive methods for concrete structures and proposed PSD method for nondestructively evaluating damages in concrete slabs

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ABSTRACT: The weak point in the structural elements reduces the durability of structures and irreparable damage received from natural disasters like earthquake or other kind of degradation factors such as temporal attacts, constructing errors. In economical point of view reconstructing grand structurs needs strong budjets whereas, rehabilitating needs lower ons. Therfore, rehabilitation is prefered in civil engineering. The most important factor, which is concerned rehabilitation, is identification of possible failures and strength of structural elements. Particularly, concrete structures suffer more than other materials because of the dichotomy medium and uncertainties caused by internal reactions. Furthermore, reducing uncertainties could not be implemented easily. Multi-channel analysis of surface wave method has gained popularity in engineering practice for determining homogeneity in depth profiles of soil and concrete structures. This paper sifts through common nondestructive test (NDT) technics in charge of seismic methods F-K method furthermore, proposed Power Spectral Density (PSD) method and Attenuation Analysis of Rayleigh Wave (AARW) method which are particularly used for soil structures, which has the ability to use in this field of engineering, for detecting voids and zone degradation in concrete structures. the PSD method was appreciated in this paper since high accuracy and ease of usage. Although hand peaking of the location of the inhomogeneities is avoidable for important structures, in field of NDT proccedure of application consists of several methods to locate the anomaly and the final check was assigned by the most sensetive method. The time saving and defect resolution of the method are important reasons to consider this method as a high level of sensetive category.
Keywords*:* MASW, PSD, AARW, concrete structures, NDT.

INTRODUCTION

The majority of concrete structures degradation is referring to the shallow materials, since this zone faces the physical attack consisting climate change, environmental effect and so on. In most of the time deep degradation up to construction errors. The errors overcome by replacing new pavement. The point is how to detect the damage areas. Therefore, there should be provided tools for evaluating errors in important structures in charge of supervision manner and characterizing for rehabilitating repairable structures.

In recent years, identification of possible failures in structural concrete elements is one of the great challenges of rehabilitation investigations. Actually variety of technics were used to determine degradations, apart from destructive tests, which are employing different types of waves in order to achieve the goals. The main point is to proceed evaluation in appropriate time and high exactness, also the simple procedure with programmable algorithm is another promising factor that consider to choose a method for actual works.

There are lots of nondestructive approaches were existed to characterize concrete structures such as finite element updating (Teughels,2005,123-164), ground penetrating radar GPR (Kong,1994,1-10) and variety of waves. In this paper, seismic waves were employed to compare methods especially Rayleigh wave was considered.

Lamb waves are dispersive, and their propagation in the plate is governed by an infinite number of modes (fundamental-modes and higher order modes) classified into two groups, symmetric and antisymmetric, which propagate independently (Al-Wardany,2007,268-275). The phase velocity of a Lamb wave depends on the thickness, the Poisson's ratio of the plate and the frequency (Al-Wardany,2007,268-275).

Rayleigh waves are dispersive; the different wavelengths (frequencies) travel the layered system at different modal velocities related to the elastic properties (Poisson’s ratio, shear modulus) and the mass density of the traveled layers (Al-Wardany,2007,268-275). In solid plates, Rayleigh waves are formed by the

superposition of Lamb wave fundamental-modes for all waves having a wavelength less than approximately half the thickness of the slab (Viktorov,1967).

Moreover, several approaches were used to characterized soil structures. Popular one, which is common for concrete structure, is MASW method. In this method several sensors, named trace, locate at a linear array with regular or irregular distance also an appropriate source was choosing and locating with specified distance from the first sensor in direction of the array and a data logger to collect data Figure 1.

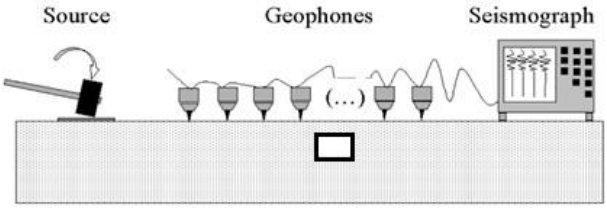


Figure 1: schematic image of the MASW test setup

The procedure for implementation of this method is as following:

Acquisition

The acquisition is usually performed generating seismic waves with an active source and recording the full waveform. The equipment can be very different: impulsive or vibrating sources, or even noise, in passive methods, can be used to generate surface seismic waves in which historical load was replaced to the active or passive methods; vertical and horizontal geophones or accelerometers to detect the vibrations that here vertical geophones assign to the model for collecting the data; digital recorders such as seismographs or signal analyzers can be used for the recording or the analysis of the seismic waves.

The number of receivers, the sampling parameters, the layout geometry, and all the acquisition parameters are important. Therefore, there is way to design mentioned parameters.

Processing

The investigation of concrete properties by the dispersion analysis of elastic waves propagating at the surface of concrete slabs requires a complete solving of the vibration modes of the slab. The main step of evaluation is related to the signal processing technic which is widely discussed in following (Parsa et al., 2016). In general, most of technics was applied for soil structures and poorly was used for concrete structures. In present article beneficial of soil usage technics in concrete structures was applied.

Data analysis of the collected seismogram consists of applying a Fast Fourier Transformation (FFT) along the time-axis to transfer data from the time domain to the frequency domain. This allows spatial distribution of energy for all frequencies propagating along the whole length of the F-K test (Al-Wardany,2007,268-275). When it is applied evenly on the transformed data along the space-axis (distance), the FFT provides information on the wavenumber content of the seismogram, which is directly related to the propagating wavelengths (Komijani et al., 2016). The result is a two dimensional representation of the energy of elastic waves captured at the concrete surface; it illustrates the seismogram content in terms of frequency and wavenumber. Knowing the relation between the phase velocity, the frequency f and the wavenumber k,

$$V_{ph} = \frac{2\pi f}{k} \qquad (1)$$

Where V_{ph} is phase velocity, f is frequency and k is wavenumber.The seismogram energy is redistributed in the frequency-phase velocity domain by a simple axis transformation. The obtained image is called an FK image, and it illustrates the different modes of propagation of Lamb and Rayleigh waves. The resolution of the F-K image can be improved by extending the seismogram signals with zeros in the time and/or the space direction before applying the FFTs (zero padding). The dispersion curves are finally determined for the different modes by selecting the peaks of energy on the F-K image (Al-Wardany,2007,268-275).

Related works

In general, there was a few works, which used MASW technic to characterize structural elements, was investigate concrete properties in concrete structures. Al Wardany et al. (Al-Wardany,2007,268-275) have recently applied F-K method to characterize the concrete block in 2D image. The novelty of this work was associating of typical seismic method, evaluating dispersion curve then applying inversion to determine profile of shear wave velocity in varied depth; however, property of the sample was easily calculated by having shear wave velocity of the media (Whitehurst,1951,433-444). Phillips et al. (Phillips,2002) was proposed PSD method

to detect voids which were located a distance from the ground surface. Thereafter, in this study spectral analysis of surface wave (SASW) method was studied. Nasserimoghadam et al. (Nasseri-Moghaddam,2005,51-64) extended PSD method to MASW approach for detection of underground caves, and indicated the accuracy of PSD method for cavity detection by numerically and experimentally studying this problem. Moreover, a new approach was proposed by nasserimoghadam (Nasseri-Moghaddam,2006), which used energy attenuation for magnifying the amplitude in location of cavity boundaries, named AARW method. In following the summary of selected methods is discussed.

Favorite methods

PSD method

As the propagation of seismic waves in media where consists of cavities or cracks, gained waves was refracted from the gap. The Rayleigh waves characterized by shear waves, thus these waves need a medium which sustained shear strength. Actually, air and water cannot act as a roll of propagated medium (Phillips,2002).

The energy analyzing was implemented by power spectral density (PSD) in which this preparation was occurred respect to the frequency and offset in order to estimate the location of air occupied particle buried in ground or concrete structural or non-structural elements (Phillips,2002). Regarding to this goal, a simulated model from MASW test was implemented to describe the location of cavity. Fig 1 shows the presents of a cavity (0.15m width and 0.2m height) which is located about 1.05 meter from source generation of a concrete slab. Table 1 indicates the material characteristic of the concrete slab.

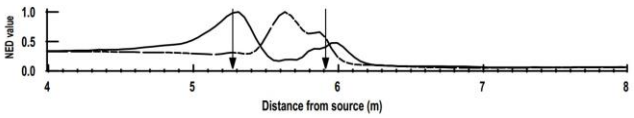


Table 1: Material characteristic of the concrete slab.

Slab	Mass density kg/m^3	Young's modulus Gpa	Poisson's ratio
Layered (top)	2380	27.3	0.21
Layered (middle)	2327	29.6	0.15
Layered (bottom)	2365	35.4	0.19

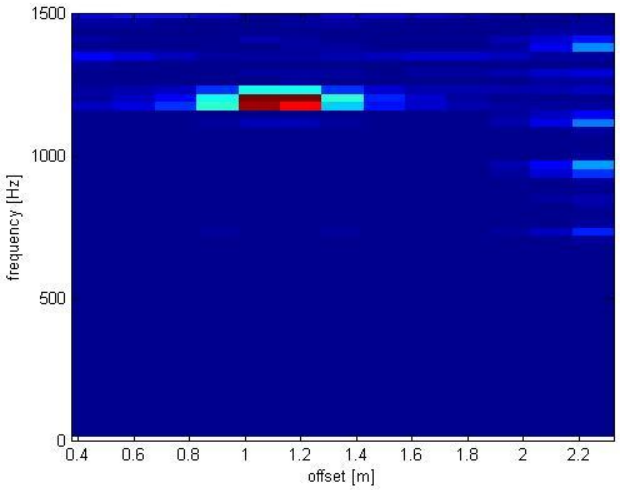


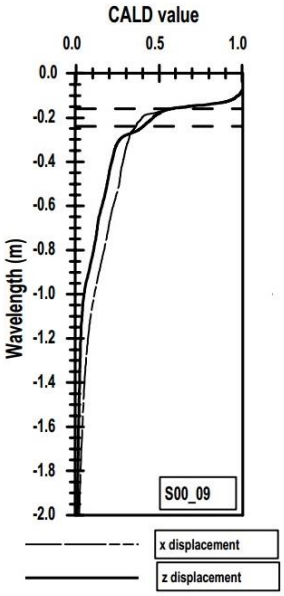
Figure 2: Power spectral density function of a buried cavity.

AARW method

When the cavity was exposed to Rayleigh waves, it began to vibrate. because of that, the appeared energy was dissipated in reflected waves, body waves and void trapped waves, and the remained energy was transmitted. Consequently, the energy was effectively attenuate proportional of the initial event. Moreover, the technic, which is based on calculating the attenuation of Rayleigh waves, was developed to systematically determine the underground cavities which can be employed to the concrete structures. To achieve this goal,

calculation of two plots are important. First one is the normalized energy distance parameter (NED) and second is the normalized cumulative logarithmic decrement values (CALD), which totally introduced in reference. Figure 3 indicates the evaluated spectrums for the case study of the nasserimoghadam work (Nasseri-Moghaddam,2006).

(a)

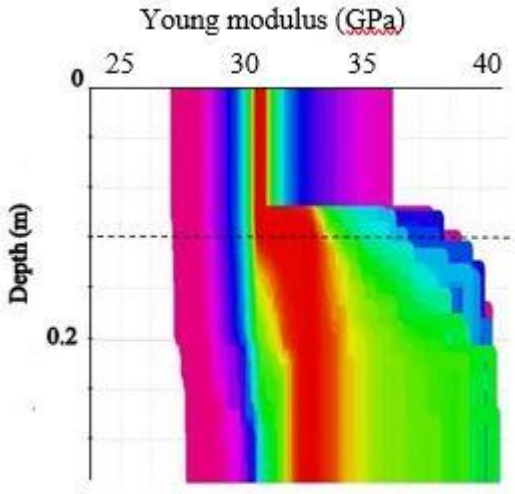


(b)

Figure 3: a) NED parameter plot. b) CALD values plot (Nasseri-Moghaddam,2006).

F-K method

In this approach signal processing was employed to present wave field energy in frequency – wave number domain for peaking modes of dispersion curves [hunaidi 1996use]. Adequate number of sensors were used to collect seismic data, thereafter 2D Fourier transform was applied to convert t-x data to the f-k domain. modal phase velocities were evaluated from the f-k spectrum as a function of frequency (Nabaei et al., 2016). Afterword, fundamental mode of Rayleigh wave was used to estimate the shear wave velocity profile using inversion process [use]. The young modulus of the specimen was then contributed as a function of shear wave

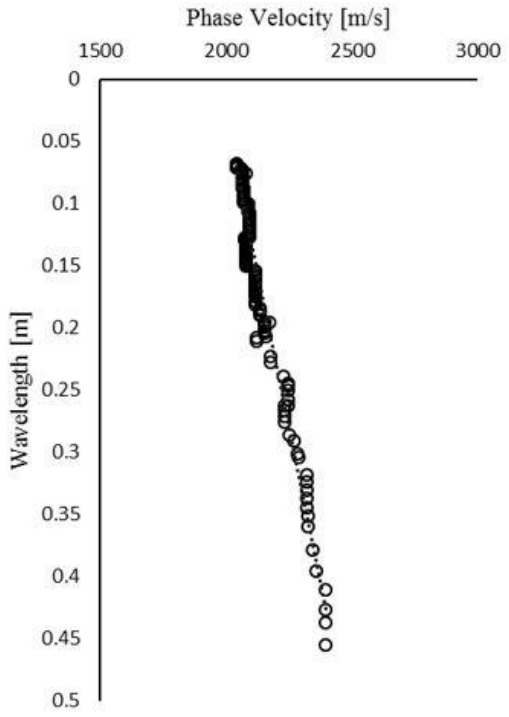


(c)

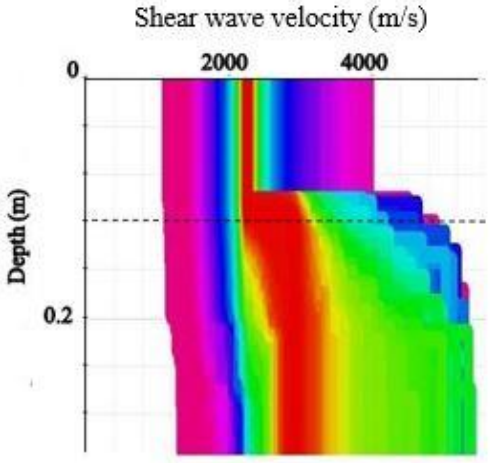
velocity, Poisson ratio and mass density with the following formula:

$$E = 2\rho(1+\nu)V_s \qquad (2)$$

Figure 4. shows the procedure of f-k method in order to characterize a concrete specimen.



(a)



(b)

Figure 4: Indicates a) The fundamental mode of Rayleigh wave. b) Shear wave velocity profile. c) Young modulus profile.

CONCLUSION

Three methods of non destructive test approaches in using seismic waves were discussed surrounding their applicability in damaged concrete structures. Some conclusion can be derived from the mentioned methods that classsify as following:

The PSD method, which has just been mentioned, performed as measuring of the Rayleigh waves energy used to find the consntrated range of frequency that indicates the location of probable voids or cracks. The ease of application and high performance of this method was powerful enough to use in field of NDT.

The AARW method, which has just reviewed, basically as the same as PSD method in involving measured energy to lacate voids or cracks in solid medium. However, in this approach locating the inhomogeneities was curvely placed.

The F-K method, which has just indicated, is more effective performance among others because of the evaluation of shear wave velocity profile as a function of depth, which provide main parameter, in order to estimate directly the young modulus.

In general, the PSD method was appreciated in this paper since high accuracy and ease of usage. Although hand peaking of the location of the in inhomogeneities is avoidable for important structures, in field of NDT proccedure of application consists of several methods to locate the anomaly and the final check was assigned by the most sensetive method. The time saving and defect resolution of the method are important reasons to consider this method as a high level of sensetive category.

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