T.R.
VAN YUZUNCU YIL UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF CIVIL ENGINEERING

DETECTION OF DAMAGES IN CFST COLUMN USING ULTRASONIC WAVES

M.Sc.THESIS

PREPARED BY: Nashwan Ibrahim SALEH
SUPERVISOR: Assoc. Prof. Dr. Murat MUVAFIK
CO – SUPERVISOR: Prof Dr. Nadom Khalifa MUTLİB

VAN - 2021

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ACCEPTANCE and APPROVAL PAGE

This thesis entitled "Detection of Damages in CFST Coloum Using Ultrasonic Waves" presented by Nashwan Ibrahim Saleh under supervision of Assist. Prof. Dr. Murat MUVAFIK in the Department of Civil Engineering has been accepted as a M. Sc. thesis according to Legislations of Graduate Higher Education on 05/06/2021 with unanimity of votes members of jury.

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This thesis has been approved by the committee of The Institute of Natural and Applied Science on ..……../.........../…...….. with decision number ....

Signature

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Director of Institute

THESIS STATEMENT

All information presented in the thesis obtained in the frame of ethical behavior and academic rules. In addition, all kinds of information that does not belong to me have been cited appropriately in the thesis prepared by the thesis writing rules.

Signature

Nashwan Ibrahim SALEH

ABSTRACT

DETECTION OF DAMAGES IN CFST COLUMN USING ULTRASONIC WAVES

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M.Sc. Thesis, Civil Engineering Department
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The Concrete-Filled Steel Tube columns (CFST) are widely used in many buildings and other structures such as bridges due to the important properties of these elements, including resistance to stress, hardness, and many other characteristics. However, these elements are exposed to factors that weaken the interconnection between CFST components. Therefore, it is necessary to monitor those damages using ultrasonic waves. In this research, A numerical study conducted by Comsol software and verified experimentally is conducted to detect artificial damages. Cracks (2,4,5,6,8, 10 mm), Deboned damages [(1×5), (1×10), (1×15), (1×20), (1×25) and (1×30)cm] and several voids are investigated. Six levels were adopted through Wavelet analysis using Daubechies wavelet. For cracks results, damage index results have shown that level 3 has given a consistent and proportional relation contrary to the other levels. In debond damage, level 2 reflected the best results whereas in voids, levels 1&6 have given more realistic results. While the debonding damage in the numerical sample represented by level 2 is the best result, the experimental level has shown to be level 3 which are close to each other. The damage index based on Wavelet analysis has proved its capability in detecting different types and sizes of damages using ultrasonic surface and bulk waves in CFST columns. This could lead us to extend this study to more practical and realistic samples with different materials and different setups.

Keywords: CFST, SHM, Detect of damage, Crack, Compressive strength, Voids

ÖZET

ULTRASONİK DALGALAR KULLANILARAK CFST KOLONUNDAKİ HASARLARIN TESPİTİ

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Beton dolgulu çelik kolon (CFST) elemanlar, dayanım, sertlik ve diğer birçok özellik dahil olmak üzere önemli özellikleri nedeniyle birçok binada ve köprü gibi diğer yapılarda yaygın olarak kullanılmaktadır. Bununla birlikte, bu elemanlar, CFST bileşenleri arasındaki ara bağlantıyı zayıflatan faktörlere maruz kalmaktadır. Bu da beton ile çelik arasında hiçbir bağ olmadığı anlamına gelir. Bu nedenle, ultrasonik dalgalar kullanarak izlemek gereklidir. Bu araştırmada sayısal bir çalışma yapılmış ve bu çalışma deneysel bir çalışma ile doğrulamaya çalışılmıştır. Çalışmaaki sonuçları elde etmek için dalgacık analizi kullanılmıştır. Yapay çatlak (2, 4, 5, 6, 8, 10 mm) ve ayrışma hasarları [(1×10), (1×10), (1×15), (1× 20), (1× 25) ve (1× 30) cm] . ve birkaç boşluk keşfedilir. Daubechies dalgacık kullanılarak Dalgacık analizi yoluyla altı seviye benimsenmiştir. Çatlak sonuçları için, hasar indeksi sonuçları, seviye 3'ün diğer seviyelerin aksine tutarlı ve orantılı bir ilişki verdiğini göstermiştir. Debond hasarında 2. seviye en iyi sonuçları yansıtırken boşluklarda 1. ve 6. seviyeler daha gerçekçi sonuçlar verdi. Seviye 2 ile temsil edilen sayısal örnekteki bağ sökme hasarı en iyi sonuç iken, deneysel seviyenin seviye 3'e yakın olduğu görülmüştür. Dalgacık analizine dayalı hasar indeksi, CFST'de farklı tip ve büyüklükteki hasarı tespit etme yeteneğini kanıtlamıştır. ultrasonik yüzey ve yığın dalgaları kullanan sütunlar. Bu, bu çalışmayı farklı malzemeler ve farklı kurgularla daha pratik ve gerçekçi örneklere genişletmemize yol açabilir.

Anahtar Kelimeler: CFST, SHM, Hasar tespiti, Çatlak, Basınç dayanımı, Boşluklar

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2021

Nashwan Ibrahim SALEH

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SYMBOLS AND DESCRIPTION

Some symbols used in this study are presented below, along with descriptions.

Symbols	Description
CFST	Concrete-Filled Steel Tube
SHM	Structural Health Monitoring
NDT	Ultrasonic Non-Destructive
FRP	Fiber-Reinforced Polymer
L-CFST	L-Shaped Concrete Filled
TTT	Travel Time Tomography
RTM	Reverse Time Migration
PZT	Piezoelectric Ceramics
GFRP	Glass Fiber Reinforced Polymers
SA	Smart Aggregates
%	Percentage
STFT	Short-Time Fourier Transform
DWTM	Discrete Wavelike Transfer Method
FT	Fourier transform
WT	Wavelet Transform
TR	Time-Reversal
DI	Damage Index
Mpa	Mega Pascal
cm	Centimeter
mm	Millimete

1. INTRODUCTION

1.1. Background

In the past few years, a remarkable development is noticed in civil engineering. These developments opened the way for many companies interested in building. Many effective elements appeared in construction. The Concrete-Filled Steel Tube columns (CFST) were among the active elements that are widely used in many buildings and other structures such as bridges due to the important properties of these elements, including resistance to stress, hardness, and many other characteristics. The steel tube filled with concrete has several advantages when compared to reinforced concrete and ordinary steel. Among these advantages are high strength and flexibility (Gupta et al, 2007). The use of CFST helps to reduce costs as it works to increase the spaces, and thus these spaces can be used for other things, and this is very important for tall buildings because they need high cost (Giakoumelis et al, 2004).

However, these elements are exposed to factors that weaken the interconnection between CFST components, which means that there is no bonding between concrete and steel, and thus affects the longevity and durability of the facilities and the weakens its performance so it is necessary to know its effect on (CFST) and diagnose that effect early to prevent the occurrence of disaster and losses in lives and equipment.

There are methods developed for such problems that occur in buildings and other facilities, which are non-destructive methods. There are different types of these methods and ultrasonic technology is one of these advanced, effective, and important methods that have been used and investigated by many researchers. The field of ultrasonic wave-based SHM (Structural Health Monitoring) is widely studied in civil engineering applications. Monitoring structural health is the prediction and warning of the presence of damage and defects in the facilities and the estimation of the remaining life, especially for the old buildings. Non-destructive methods have been used in the last two decades. It also helps to give an early warning of defects and damage and thus get the safety of the building and reduce the cost and maintenance and reduce the time (Mitra et al, 2016).

There are many uses and applications for SHM. Some of them are used in buildings, bridges, cable connections, and in welding to find out the thickness and whether there is a defect in welding. The reason for their frequent use is that it has good features and properties that help it gain this high confidence by workers in this field. The SHM is used in other fields, not only in the case of civil engineering structures and buildings. It is used in the mechanical field (Antoniadou et al, 2015) and also in navy (Soliman et al, 2015).

There are several types of non-destructive methods, but the most common and important one is the ultrasonic wave. These waves used can also be classified into several types, including guided, surface, and bulk waves**.**

They are flexible waves and their transmission is in the form of confined wave packets and that the propagation of these waves lean on the properties of the matter with which these waves travel and also these highly scattered waves (Abbas et al, 2018). Surface wave, which can be known by the name, spreads through surfaces, and that the Rayleigh wave is one of the most important and widely used types of it. Bulk waves are the third type of non-destructive waves, and these waves do not need surfaces for guidance, as they are easy to use.

This study employs ultrasonic surface waves to monitor and detect debonding, voids, and cracks in CFST columns numerically and experimentally. Wavelet transforms with discrete type is to be used as signal processing tools.

To provide a good understanding of the detection process for voids, debond, and crack damages, a numerical study using Comsol Multiphysics software has been used. Moreover, an experimental test has been conducted to verify the numerical results.

1.2. Problem Statement

Concrete filled steel tube column (CFST) is a vital structural composite element. The composite reaction of steel and concrete makes them more durable and have more strength than their two main components. However, its strength and durability are liable to many threats, namely cracks, debonding, and voids. The aforementioned damages weaken the structural behavior of CFST. The classical monitoring methods are invalid in detecting such damages due to the incapability of seeing these internal damages by the bare eye. Therefore, it is necessary to monitor those damages using ultrasonic waves that penetrate the core of CFST and interact with damages by using piezoceramic sensors. This will let to analyze and then detect any potential damage inside the CFST column.

However, due to the complex nature of CFST, where it contained more than one material, and due to the inhomogeneity of concrete, the direct raw waves analyzed in the time domain are not sufficient to give crucial damage detection results. In this study, wavelet transforms analysis is planned to be used in a way that gives more flexibility in signal processing analysis.

1.3. Aims and Objectives of The Study

This study aims to detect the damages and defects of Concrete-Filled Steel Tube columns (CFST) as well as to explain the efficient and accurate methods that help in detecting these faults. Thus, the main objectives for this thesis can be summarized as:

1. To investigate the damage scenarios numerically using multiphysics software.
2. To experimentally detect different types of damages in the CFST column using ultrasonic surface and bulk waves and piezoceramic sensors.
3. To analyze the output data using the wavelet technique.

1.4. Structural Health Monitoring (SHM)

In short, a definition of SHM is knowledge of whether there is damage, knowledge of its location, and extent of damage at origin (Vanik et al, 2000).

SHM technology to monitor, evaluate, and estimate old or newly built bridges have reached a stage of prosperity. Structural health monitoring has been the subject of global research in recent decades (wooden et al, 2004). The facility health monitoring technology in the bridges can provide an assessment of the safety and durability of the bridges and the knowledge of whether they are safe if, in the end, the technology can provide important information in examining the bridges and when they must be maintained (Ko et al, 2005).

In order not to have significant economic losses, SHM technology must be used and the latest technologies and advanced methods can be used to know the damage and the size of the damage early to control it before disasters occur and even preserve it when disaster strikes (Yan et al,2018).

This technology helped many researchers and interested companies in this field in gaining time and safety in buildings and reducing the effort and reducing the cost for that it is difficult to obtain it. In the future, it is expected that this technology will solve many crises to which the buildings are exposed. There are many types of this technology some of which are characterized by the speed in the detection of damage and some of which are accurate and high quality. Buildings are exposed to weather conditions such as rain, wind, snow, and even earthquakes. This reflects negatively on the permanence of origin.

Therefore, changes occur inside the walls, columns, roofs, and other elements of origin through SHM and equipment. To defeat this defect, SHM methods have been put in since the methods have a large ability to reinforce the uniform procedure and upkeep of structures like subway, masonry, bridges, and others (Azemi et al, 2018).

1.5. Ultrasonic Waves

SHM is a wonderful feature of buildings because it detects damage and thus averts life and money waste (Huan et al, 2018). Therefore, the use of this technique is important for the safety of building bridges and others. Treatment is simple and inexpensive when knowing the damage from the beginning. SHM is a region of increasing attention and deserving access to new methods. There are several methods for SHM such as eddy current (Abidin et al, 2010), vibrations (Shih et al, 2013), thermal imaging (Pieczonka et al, 2013), impact echo (Azari et al, 2014), ultrasonic waves (Sharma et al, 2015), acoustic emissions (Ciampa et al, 2010), electrical impedance (Providakis et al, 2014) and thermal imaging (Pieczonka et al, 2013). ultrasonic waves have been used. Ultrasonic waves have frequencies greater than 20 kHz. Ultrasonic waves can be classified into guided, surface, and bulk waves. Guided waves include those waves which require a guiding surface to spread along with them, like lamb waves and shear horizontal (SH) waves. A surface wave is a term for the waves guided waves include those waves which require a guiding surface to spread along with it, like lamb waves and shear horizontal (SH) waves on the surface of the structure rather than through that structure. Rayleigh wave is the most common example of surface waves. Bulk waves propagate in the whole bulk of the body and no guiding surface is required. Shear (transverse) and pressure (longitudinal) waves are the two types of bulk waves.

In this study, ultrasonic surface waves will be used to detect different damages that could be arisen in the composite floor during the applied loading. The process of SHM using ultrasonic waves is composed of three basic elements: sensors, structure, and processing equipment. The bulk waves differ from the ultrasonic guided wave, as the bulk waves do not need any limits to travel and spread. So, these waves are easy to use but these waves cannot travel long distances because they lose their energy with the passage of distances.

Rayleigh waves are surface waves, so they can detect damage to the surfaces of objects. Rayleigh waves are beneficial in monitoring concrete structures due to their power is centered nearby the surface and demands only a single side to arrive at the construction (Kim et al, 2014). Ultrasonic guided waves are very important techniques that use two sensors, one of which sends waves called a transmitter and the other receives waves called a receiver (Shi et al, 2019).

1.6. CFST Columns

CFST has become important in buildings, bridges, and other facilities. Because of its excellent bearing capacity and earthquake resistance, its construction performance is good and it has a good ability to withstand loads (Varma et al, 2004). It was recently used (CFST) vastly in very eminent buildings (Nie et al, 2010). Concrete-Filled Steel Tube (CFST) columns have important engineering properties such as earthquake resistance and high elasticity and have the ability to absorb energy and also increase the efficiency of structural properties and reduce the time in construction because they do not require perpetual molds (Yu et al, 2007). These features that were mentioned about the CFST column have made many construction companies interested in such a field focus on the work of these columns.

CFST is extensively used in new-fangled facilities as well as in bridge works and many other applications, CFST has usually added some additives that reduce the separation of concrete from steel tubes (Wang et al, 2001**).** Despite this vast interest in the CFST, their durability and durability must be monitored and known because they may be exposed to various types of damages such as corrosion and lack of correlation between concrete and steel, shrinkage, and other damages, which leads to damage if not disclosed about it early. Because of the insufficient contraction and compaction when pouring concrete, voids in a steel tube filled with concrete (CFST) between the concrete gist and the external steel tube are activated, which reduces the ability and toughness of the CFST and thus these voids cause damage inside the tube (Dong et al, 2016).

There are several types of damage, such as cracks, the presence of air in the voids, the lack of bonding between the concrete strengthening in the concrete structures and CFST members assess large impendence to the structural integrity (Hola et al, 2011) Monitoring of damages in CFST columns using non-destructive methods is of great importance due to the difficulty of detection of such damage in traditional testing methods. The inaccessible and unseen damage makes destructive testing and visual processing inactive. Therefore, conducting a technical wave based on the monitoring process is of great value. Composite structure damage includes several types such as debonds, cracks, and others.

Many researchers use ultrasound to detect damage to structural elements, but few have been interested in studying it in composite elements, for example, the deflection in CFST columns has been studied by ultrasound (Ke et al, 2019). Guide waves are used to detect nearby damage and are suitable, but if the damage is remote, bulk waves are preferred.

In transmitting and receiving waves, the sensor is used. Many researchers use sensors known as piezoelectric (Lu et al, 2015**)** The size of the shatter, the kind of sensor, and the site of the sensor impact the chosen sort of wave. It is well renowned that lamb waves can detection very small cracks, and therefore, this sort of wave is used to find very small cracks (Mutlib et al, 2016**).** The employ of ultrasonic waves in SHM is credible in guess mechanical and ecological destruction to concrete structures. These applications have properties such as low cost, elasticity, and the capacity to find small damages (Shah et al, 2013).

An ultrasonic system was advanced to find harm and learn about cracking and was used to observe the premature period of concrete (Dumoulin et al, 2012**).** The inner concrete may do inevitably retain irregular or vacuous parts. Thus, using ultrasonic testing technology may not be able to obtain the required signal (Yan et al, 2018). Because of the previously mentioned properties, ultrasonic non-destructive testing (NDT) technology has been vastly utilized for fault examination of concrete structures in civil engineering. Another important reason is its high accuracy (Hola et al, 2011).

1.7. Piezoceramic Sensors

Lead (PZT) Zircon Titanateis one of the most vastly used piezoelectric ceramics since it has superb piezoelectric properties (Banerjee et al, 2006).PZT has been used. It is one of the most important parts that are used in the damage detection system in the facilities. The work of the PZT is to send and receive waves and it consists of three elements Lead, zirconate, and titanate. Piezoelectric sensors are cheap, easy to set up, and can be used as transmitters and receivers. In researches relevant to CFST specimens, piezoelectric sensors are installed either on the surface of the column (mounted) or inside it (embedded) depending on the location of the monitored area and the type of the propagated wave. The use of the sensor relies on where the sensor is placed on the model as well as on the type of wave. In the guided waves, the PZT sensor is placed on the surface of the model (Lu et al, 2013).

As for the bulk waves, the sensor is placed inside the model to be examined by (Xu et al, 2013). The piezoelectric sensor is an active component that converts electrical energy into mechanical energy as well as converts the mechanical energy into electrical energy. So, because of its small size and cheap price. (Kee et al, 2013) have shown that it can be placed inside the concrete during construction and also can be placed on the surface. (Monnier et al, 2006) Showed that to overcome the fragility of PZT and to ensure that there is surface compatibility in curved psoriasis structures, piezoelectric powder, and piezoceramic fiber have been mixed with epoxy resin to form polished membrane sheets as well as to activate wave reception and transmission.

The use of PZT has become widespread in infrared sensors as well as in transformers and motors. Therefore, these devices must be highly efficient and safe but PZT materials are vulnerable to fragility and there is a need to know the factors responsible for this fragility. Indicated (Huang, et al, 1999**)** that many factors affect sensor efficiency and they can be classified into two main groups: the first concerning thermoelectric properties such as reactive elements and the second includes mechanical properties such as cracks and gaps, etc**.** Many researchers worked in the detection of damages in the CFST using the PZT due to its advantages that were mentioned previously.

1.8. Numerical Study

Simulation technology is a technique that helps researchers to save time and give outputs that are very close to the outputs of what is done in the laboratory, as well as to save money and effort. Using simulations leads to reduce in cost and time and it gives good results. Numerical simulation is used to take more models to be examined, thus helping to expand the scope of the search. COMSOL software is used for this purpose and the simulation study helps add more information that is used in CFST monitoring.

The simulated raw wave signals have captured by the receiving sensors are usually processed to extract the potential features using signal processing approaches. In most cases, the time-domain approach is not decisive in detecting existing damages. Therefore, there is a pressing need to employ different domains such as frequency and time-frequency domains. Many signal processing techniques have been used in CFST structures for this purpose.

1.9. Wavelet Transform Analysis

The signal processing technique will be useful in analyzing the raw data. Wavelet transform analysis is an important signal processing technique that can be employed to extract more features from the raw signals. MATLAB software is usually adopted to run the wavelet transform package because of its stability and is user-friendly. Wavelet transforms with both types, continuous and discrete are to be used as a signal processing tool. Analysis by wavelet is an important analysis method that converts the high and low frequencies and signals that are sent from the waves in the model to be examined and converts them with the help of the MATLAB program into a reading task in the computer to give the results that rely on in knowing the location of the failure and the extent of damage to that, so use it in wave analysis Very necessary.

Therefore, there is a pressing need to employ different domains such as frequency and time-frequency domains. Many signal processing techniques have been used in CFST structures for this purpose. Wavelet transforms (Mutlib et al, 2018). fast Fourier transform (Chen et al, 2019), Time Reversal (Yan et al, 2014), and Hilbert-Huang Transform (Ye et al, 2011). Short-time Fourier transform (STFT) is another signal processing tool that presents a time-frequency analysis for non-stationary signals. Because of its good performance regarding readability, resolution, and computational time, it has been selected as a time-frequency estimator (Wongsaroj et al, 2019).

1.10. Thesis Structure

This thesis consists of five chapters:

Chapter 1:It tackles the introduction to CFST, what are its properties, and the problems it faces. It also tackles the non-destructive methods, SHM (Structural Health Monitoring) an ultrasonic wave, problem statement, and objectives.

Chapter 2:The topic is about previous studies conducted by researchers on the existence of damage and defects that afflict CFST and other structural elements and what are their conclusions.

Chapter 3: This chapter explains the tools and methods used in addition to the software used in the simulation, and also reviews the experimental program.

Chapter 4: To show the numerical and experimental results and to analyse the findings.

Chapter 5: Conclusions and discussion.

2. LITERATURE REVIEW

Damage detection in concrete structures using ultrasonic waves has been studied by many researchers. Na et al (2002) have tested the interface between steel and concrete in steel tubes filled with concrete in water. Cylindrical lamb waves are used because of the cylindrical shape of the samples.

Luangvilai et al (2002) have studied the bonding between fiber-reinforced polymer and the concrete surface using ultrasonic waves.

Xu et al (2013) have conducted an ultrasonic wave study on the CFST column to study the debonding occurring under the steel encasement. They used bulk waves to detect such damages and employed a statistical approach to quantify the data of the raw waves.

Arisa et al (2013) have shown that ultrasonic waves could be used to test the interface between steel and concrete, and the results indicated that the height of the wave echo could detect the steel-concrete interface damage.

The epoxy adhesive between steel and concrete was also investigated by (Shen et al 2014) using ultrasonic waves.

Void detection in concrete-filled steel tubes using ultrasonic waves was studied by (Wei Dong et al 2016), they have conducted experimental tests for this purpose. They concluded that ultrasound penetrates the wall of the steel tube and travels in a straight line in the case of CFST samples without voids. But if there are voids in the CFST, ultrasound waves pass through the voids and travel through the concrete, and during their transmission wave, energy gets dissipated.

Mingzhang Luo et al (2016) have employed the lead zirconate titanate (PZT)-based ultrasonic time-of-flight (TOF) method to assess the concrete infill condition of CFFTs. The results showed that the ultrasonic time-of-flight method is able to detect the concrete infill condition of CFFTs.

Bin Xu et al (2017) have conducted a numerical study on the mechanism of active interfacial debonding detection for rectangular CFSTs based on wavelet packet analysis with piezoceramics. Simulation results have shown the spread of stress in the presence of damage causes a change in the wave propagation and the time it is cut off, as well as affecting the volume of pressure waves.

Guofeng Du et al (2018) did a PVDF-Based Sensor for Internal Stress Monitoring of a concrete-filled steel tubular (CFST) column subject to impact loads. The results showed that smart sensors can monitor and detect the internal stress of concrete-filled steel tubular columns under impact loads.

There is also a study that investigates damages in L-Shaped Concrete Filled Steel Tube (L-CFST) Columns with the presence of loads. The detection process was done by using Embedded Piezoceramic Transducers. The test results show that the value of the damage index initially increases linearly, accompanied by an increase in the displacement of the load. This pointer reaches a specific value and remains unchanged. This means that the damage to the concrete increases with the increase of the displacement of the load. They also concluded that in the case of the use of smart aggregates, the concrete core damage is indicated. The study used smart photoelectric aggregate in monitoring the internal concrete defect in columns (Juan Zhang et al, 2018).

Beta Zima (2019) has studied the propagation of waves in the detection of partial peripheral damage to concrete structures, and the results indicated that the increase in the size of the damage leads to an increase in the wave velocity propagating in beams. Also, the lower frequencies, the less sensitive to detecting damage. Hai Liu et al (2019) have employed Reverse time migration of acoustic waves for imaging-based defects detection in concrete and CFST structures. They concluded, through numerical experiments, that in the case of using only Travel Time Tomography (TTT). It can detect the damage and cannot determine its shape and size when Combining TTT with reverse time migration (RTM), air cavities can be found in concrete as well as in CFST columns, and that the size and location of the damage can be found with high accuracy and also, they summarize that detection it is effective for damage to the model using high-resolution images.

Nadom K. Mutlib (2019) has conducted a study on the evaluation of concrete compressive strength in CFST column using ultrasonic bulk waves speed. The results showed that the relationship between the concrete compressive strength and the speed of the wave signal is proportional.

Hongbin Sun et al (2020) have studied the non-destructive estimate of concrete structures and buildings using one of the methods of evaluation, which is the high-frequency ultrasonic-guided wave method.

Ultrasonic guided waves have been utilized to recognize internal defects and to estimate the bonding between steel bar and concrete. If there is a difference in the amplitude of the wave signal, this means that there is a defect of the propagating waves in the damage zone. Also, damage affecting the integrity of concrete and steel was explained by using piezoelectric sensors. Their results indicated that the technique of embedded piezoelectric sensors and actuators is effective in detecting the separating of damages between steel reinforcement and concrete (Zhu et al, 2013).

The signal energy decreases with increasing operating frequencies. Some researchers have demonstrated through their study of concrete compressive strength in a PZT-based steel tube filled using the time-reverse method. Through their results, they found that the use of the suggested sensors, namely PZT-based and a smart aggregate (SAs), has great possibility for feasible application in detecting damages that are inaccessible to CFST engineering facilities (Shi Yan et al, 2014).

Lei Qin et al (2014) have shown how to monitor damage and defects to concrete structures with reliance on piezoelectric resistance. The results showed that the use of piezoelectric monitoring can noticeably well detect the concrete defect also they showed the presence of a defect in the sample can be related to deflection of the conductor spectrum. The more defect, the greater the change in the deviation.

DujianZou et al (2015) have experimentally studied the health monitoring of concrete structures and buildings under the influence of different environmental temperatures using piezoelectric transducers. The results showed that the amplitude of the monitoring signal increases with increasing temperature since the lower frequencies are more affected by the temperature change.

Ai Demi et al (2016) have investigated the sensitivity of a new kind of embedded active PZT sensor in structural impact damage detection through theoretical and experimental analysis. Then the embedded PZT sensors were qualitatively compared with surface-bonded ones in the experiment of detecting a concrete beam that was damaged by successively knocking off concrete covers. a new baseline-changeable RMSD index was also proposed to evaluate the impact effect for the two types of PZT sensors. It was found that the embedded PZT sensor can effectively filter out the impact effect in structural damage indication and quantification, which benefits the accurate evaluation of structural damage.

Y. L. Mo et al (2017) have shown the importance of an ordinary, dynamic inner pressure sensor based on PZT implant for concrete under influence. The results showed that it is evident that the PZT-based embedded sensor is effective in measuring the mechanical stress of concrete materials under the influence of loads and that this sensor has a rapid response to the impact of the loads on concrete materials.

The results obtained indicated that this method can detect the winding site and also assess the severity of damage based on the proposed matrix. Here is the signal, the pressure wave, the attenuation ratio is related to the crack strength, and when using two different actuators. The PZT sensors can obtain important information about the location of the cracks (Guofeng Du et al, 2017).

S. Yanet al (2018) have proposed a feasible method to detect the interface debonding of CFST members using piezoceramic ultrasonic guided wave technology. Artificial damages were employed to simulate the detection of the interfacial debonding. By comparing the healthy received signals to the received ones with debonding damage, the change rule of the received signal is analyzed and a signal energy-based identification algorithm is proposed according to the signal amplitude. The experimental results show that the amplitudes of the received signals vary with the occurrence of the debonding damage and the proposed algorithm can be feasibly used to monitor debonding damages of CFST columns.

Guoqi Zhao et al (2018) have investigated the detecting faults and damages affecting buildings and concrete structures using one of the non-destructive technology methods which is the ultrasound method with Piezoceramic Transducers and the Time reflex Method. The results obtained by the researchers showed that this method (Piezoceramic Transducers and the Time Reversal Method) can detect and evaluate damage along the length of the steel-reinforced concrete and that the images of the defects obtained were accurate. Their results also showed that the signal sources inside the reinforced concrete can be localized using (UT) and this helps the researcher engineer in detecting various damages inside the structure of reinforced concrete if these damages are not far from the other.

Juan Zhang et al (2018) have studied the embedded piezoceramic transducers are used to monitor the damage of core concrete of CFSSTC joints under cyclic loading and surface-bonded piezoceramic disks are used to monitor the debonding damage of the steel tube and core concrete of two specimens. The experimental results show that the amplitude of the transmitted signal in the model decreases with the appearance of damage in the joints and the degree of attenuation of the signal increases with the increase in the damage. The results also showed that the attenuation of the signal is not clear in the supple phase and that increased load leads to continuous deformation of the joints.

Piezoceramic Transducer and carried out by the time echo method was conducted by (Linsheng Huo et al, 2018). Their results showed that the signal sent within the model to be examined changes linearly, this means the loss of mass to the steel bar, meaning that there is damage, and they proved that this method can be used to detect corrosion due to its high ability to detect damage. It is obtained that the maximum values of the signal obtained from the time reflex process are linearly related to the degree of corrosion.

Real-time bond-slip between glass fiber reinforced polymers (GFRP) and concrete was studied using Piezoceramic Transducer-Enabled Active Sensing. The results showed that testing with a PZT-assisted active sensor is effective in accurately detecting the slip between glass fiber reinforced polymers (GFRP) and concrete and that the stress wave energy is greatly reduced. This technique provides a reliable way to find out the damage to reinforced concrete structures of glass fiber reinforced polymers (Kai Xu et al, 2018).

Tianyong Jiang et al (2019) have studied the detection of cracks in FRP reinforced concrete beams using piezoceramic smart aggregate. Their results show that the Piezoceramic-based active sensing method, although it is inexpensive, can monitor damage caused by cracks and estimate the degree of damage. It also can give an early warning of cracks and the development of fiber-reinforced polymer beams. The embedded smart aggregates (SA) wave decreases when damage occurs due to cracks, with the increase in load, the damage caused by cracks increases, causing languor of the transmitted wave signal. The detection of multiple cracks and damages to pipelines was studied by an indicator matrix based on a piezoceramic transducer to enable strain wave propagation.

Concerning the detection of cavities and voids occurring in metal-concrete structures monitored by piezoelectric transducers, there have been several researchers, including (Paritosh Giri et al, 2019), they that this method is very important as it is possible to detect voids in steel pipes filled with concrete as well as in detecting very accurate voids and predicting them early before the disaster strikes and this helps to take precautions, not the occurrence of the disaster and prevent losses in lives and equipment.

Therefore, the use of (piezoelectric transducers at various environmental temperatures) technique is important in detecting damage in buildings that suffer from temperature change. In observing damage and cracks in underwater concrete construction, it was spotted by Piezoceramic-Based (Jianfeng Si et al, 2020). The results proved that the use of piezoelectric transducer technology in detecting the damage caused by the explosion of concrete materials underwater is very effective as well as in determining the degree and depth of damage.

Hansong Huang and Ramesh Talreja (2006) have conducted a numerical simulation of matrix micro-cracking in short fiber reinforced polymer composites initiation and propagation. The simulation results showed the effect of micro-structures of the fibers on local failure stress that may be associated with the onset of macroscopic damage. Simulation results correlate well with the obtained experimental results.

Hun Sun et al (2003) have employed an active wave-based sensor to detect interference occurring in concrete structures. In their research, a system was developed that helps to detect interference on the composite structures. This technique is to combines the analysis by a wavelet with an active sensor. The results were that the proposed damage detection algorithm can identify the defect in the composite plate.

Hani Melhem and Hansang Kim (2003) have studied Fourier and Wavelet analyzes to detect damages in the concrete structure. The results obtained confirm that the analysis using the wavelet has a great ability to detect damage in concrete and that the analysis with the wavelet has more advantages compared to other conventional methods. Also, this method of analysis can be used on large samples of similar or close sizes. From the actual structures, they also deduced the analysis utilizing the wavelet showing that it could be an effective tool for identifying damage and oversight structural health.

Piervincenzo Rizzo and Francesco Lanza di Scalea (2005) have used ultrasound to test steel wire lines with the aid of a wavelet. From their findings, the discrete wavelet transform method (DWT) is effective in detecting damage as well as reducing the energy required by the monitoring system. They also showed that the main advantage of (DWT) is noise removal which means the detection of very fine defects that are far from the probes. When comparing (DWT) with the other conventional signal, it turns out that it is effective due to its computational efficiency and it is also economical in terms of energy.

M. M. Reda Taha et al (2006) have studied the wavelet transform to monitor the structural health, and the advantages of using this method. (DWT) has a direct relationship to the level of damage and they also showed that using digital models to detect damage, the results are exaggerated. V. Bakrashi et al, (2007) have conducted a study of structural damage detection using the wavelet kurtosis technique. Their research demonstrates this analysis by wavelet in coupling with kurtosis-based damage calibration can help identify damage and locate it. Although the wavelet method is efficient for determining damage and its location, the kurtosis method with the wavelet is also useful in detecting damage.

Pedro Montes-García et al (2010) have investigated the risks that occur to concrete due to erosion, and this study was carried out using a wavelet. The results obtained showed that this technique can be used in the analysis because of its ability to monitor corrosion, and also it can tell whether there is corrosion, which can detect early and can distinguish the patterns of corrosion that it results from various sources such as variation in cover depth and pollution with chlorides.

Wei Huang and Guo–jing (2011) have conducted a study on detecting damage in a steel tube filled with concrete in the form of a bridge by sending waves, where its results were of the typical analysis obtained were compared with the results of the analysis by Wavelet Transform. They showed that there is a great match between the results of the two analyzes, as well as Wavelet, was programmed with MATLAB. The method is efficient and reliable.

X.Q. Zhu et al (2011) did a study to detect the damage in the (RC) structures, and the analysis is done by using a wavelet. The analysis was used in this way to find out the damage and its extent in the concrete structures. Their results showed that this technique is effective for detecting the damage and determining its location in structures and therefore this method can be used in oversight the damage and assessing the building.

Diego et al (2013) studied the relevance of a wave-based damage detection study in reinforced concrete structures exposed to seismic stir. They concluded through their results that the analytical technique by wavelet can quantify damage in rebar rods and showed that the normal range of extent heights obtained from the Wavelet discrete transformation method.

Tyler Epp and Young-Jin Cha (2016) have studied Air-coupled impact-echo damage detection in reinforced concrete using wavelet transforms. Through the results obtained, they found that the wavelet transform method can detect damage and also showed that it can cover a large area and this helps decrease the experiment time, as well as greatly reducing the number of sensors when monitoring reinforced concrete. Even when the sensors are far from each other. So, this method gives accurate results.

This technique has proven to be able to deal with abundant limitations of the vastly used Fourier transform (FT). They also showed the efficiency of this technique in detecting damage and determining the position and extent of damage including major damages such as bridges and others, including small damages. The widespread popularity of this technology made it interested researchers. The description of the concrete surface was by using Rayleigh wave phase velocity and wavelet parametric analyzes, Through the results obtained from their research, these results showed a consensus between the analysis by the suggested wavelet transform (WT), the phase velocity, the depth of damage, the location of the damage in addition to the grade of its tendency which makes it efficient to estimate and characterize the surface degree of concrete, especially when the wavelength is better than the depth of damage (Foo Wei Lee et al, 2017).

Warning of micro-crack presence in concrete based on analysis of wavelet beams this study was by (Dong Lei et al 2017), Their conclusions which are obtained shows that the analysis method using the wavelet packet can predict the onset of micro cracks. It can also give an early warning of the edges of the cracks and can know the location of cracks and the extent of damage accurately. It is useful to predict the damage and control the safety of the building.

Jing Xu et al (2018) have conducted a study on the health monitoring of joints based on active sensing technology using piezoceramic transducers. In their research, the wavelet packet analysis method and time-reversal (TR) method were used to find out the energy of the transmitted signal between the PZT points placed on the model through which it was possible to find out if there was a connection issue in joints to ensure the safety of the steel building.

Ying Tzu Ki et al (2019) have used the STFT method for evaluating the bonding between steel plates and CFST member substrates. However, the STFT method was found to produce a slow-frequency spectrogram. The Welch method is the different frequency domain approach used to extract the feature of the signal.

Lingzhu Zhou et al (2020), have investigated the debonding that occurs between FRP / steel rods and the concrete, and this is done using piezoceramic transducers based on wavelet energy analysis. The results revealed that this method (analysis by wavelet energy ratio index) can determine the failure of the bonding of steel bars and concrete materials and can efficiently identify the failure mechanism, including the mechanical damage of the various reinforcing bars and materials. Concrete this means that this method is very important because it gives accurate products.

3. METHODOLOGY

The first section deals with the details of the process, devices, tools, and methods used. The second section will tackle the simulation. The program used for simulation in COMSOL Multiphysics. The last section deals with analysis using MATLAB software.

3.1. Materials and Methods

Concrete filled-steel tube samples are prepared using the required materials in the labs. ACI code followed in the casting process. Oscilloscope and function generator shown in (Figure 3.1) below were used in the wave detection process. The wave signal was created and transmitted using the wave generator using an arbitrary wave function. After that, the piezoelectric transmitter sensor transferred the signal into the sample and the receiver sensor convert the wave back into an electrical signal to be captured and saved by the oscilloscope.

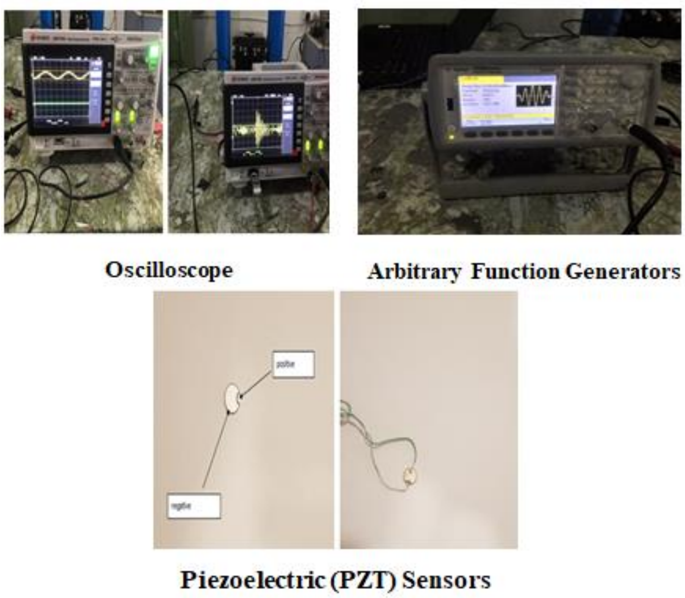

Figure 3.1. The Oscilloscope, function generator devices, and piezoelectric transmitter sensor use in study.

The materials that form the concrete-filled steel tube (CFST) are taken and the model is cast according to the required dimensions in the laboratory and artificial damage has been made for each model. After that, the sensors were placed on the surface of the model. One of them sends the waves and the other receives them. To find out the failure, its location, size, and other details related to the failure created within the model, the transmitted sensors are connected to the function generator, and the received sensors are connected to the oscilloscope, which in turn sends the signals to the computer and the computer analyzes the raw signals using MATLAB. The steel tube of the sample has been prepared in the laboratory according to the designed dimensions. To simulate the artificial damage (debonding), polystyrene foam material has been used with suitable dimensions designed in this study. When the concrete is poured inside the steel tube the polystyrene pieces will form rooms that mimic debonding damage. After casting the concrete, the test has been conducted after 28 days to allow the concrete to gain its compressive strength. Sensors are placed to send and receive waves and the waves are being worked. Many checks are made on the model with the wave and many sensors are placed to give accurate results about the location of the failure its size and other details. After completing an ultrasound scan of the sample and sending it to a computer via an oscilloscope, the results obtained are analyzed by MATLAB and also by using Microsoft Excel. After performing the analysis on a computer, the location, and size of the failure and its impact are known.

3.1.1. Sensor (PZT)

It is one of the important tools and parts in the process of detecting cracks and damages in the model by transmitting waves through sensors connected to the arbitrary function generators and are received through the sensors connected to the oscilloscope. There are many types and shapes of sensors that differ in size and efficiency. The sensor that was used in this study is Piezoelectric (PZT). These devices are lightweight and cheap. (Song et al, 2008) suggested that the sensor could be placed inside concrete but placed inside a smart aggregate to protect it from damage and pressure of the concrete. The specifications of the sensors (size: 10×1 mm (disk), material PZT-4 electrode layout: on the same side, electrode material: silver). There are several components involved in the manufacture of the sensor namely lead, zircon, and titanate. These properties and features that were mentioned about these sensors made them of wide interest to researchers and they were used widely. Piezoelectric materials can transform signals from mechanical fields into electrical signals and can also convert them backward (Tadigadapa et al, 2009). Piezoelectric sensors can be used embded inside the structure or mounted on the surface. In the later case, the sensors need suitable adhesive material to fix them on these surfaces.

3.1.2. Preparation of sample

Samples were prepared in a workshop for steel pipes. As for the casting materials, they were used according to ACI codes. These materials are cement, sand, water, and gravel. It must be poured into the laboratory according to the proportions that will be mentioned in the experimental procedures. As for the sensors, they were imported and shipped from China because they are sensors with special properties for the devices function generators and Oscilloscope the artificial failure was done in the laboratory according to the measurements and dimensions. Each model has a failure that differs from the other. Samples were poured in good weather. Leaving the models to gain resistance, devices and sensors are brought into the lab. Sensors are placed on the models in the selected places and linked to the devices. How wave is generated, transmitted, and received will be mentioned later in experimental procedures.

Three CFST samples were selected with dimensions of 30 x 30 cm base and one-meter height. The thickness of the steel plate is 2 mm. each sample has a different debonding damage size and different compressive strength. There are different shapes of CFST including square, rectangular, and round. Whereas rectangular steel tubes filled with concrete have the advantage of combining the high compressive strength of concrete and interaction with the ductility of steel (Tort et al, 2004). In the study, polystyrene foam has been used to simulate the debonding damage inside the CFST column. After the samples have gained their hardness, a fuel liquid material poured through previously made holes connecting the upper surface of the concrete to the places where the polystyrene foam has been put. The reason beyond this step is to remove the polystyrene material using this liquid leaving the rooms which perform the debonding damage. The concrete-filled steel tube, the dimension of the damage, and cubes are shown in (Figure 3.2).

Figure 3.2. The sampling (20 Mpa, 30 Mpa, 40 Mpa)and the dimensions damages.

3.1.3. Experimental procedures

Many buildings and structures are exposed to damage and cracks that affect strength and durability. So it is necessary to know and discover this effect on the building and other installations beforehand. The technologies that operate in this discipline have been discovered. These technologies helped many contracting companies, engineers, and researchers in this field to earn time, save lives and equipment, and reduce losses from the techniques used in this study.

Likewise, large waves have been used. Using sensors and other devices. The location and extent of the failure and current damage in the model can be determined. There are several steps in the experiment the first of which is to determine the dimensions of the model and the work of the steel tube and the three models are cast with dimensions (0.3×1) m to form a steel tube filled with concrete. Artificial failure is caused by using polystyrene foam material, as each of the three models has different failures. See (Figure 3.3) shows the experimental procedure.

Figure 3.3. Experimental setup.

These sensors are connected to two devices (transmitters, receivers), a cable connected to the device’s port, and clips on the sensor, as shown in the figure below.

Figure 3.4. Cable connected and clips.

The compressive strength test of the cubes of their dimensions was also performed (0.15×0.15)m (Figure 3.5) shows the method of examination.

Figure 3.5. Test of Compressive Strength and Cubes Failed.

3.2. Simulation

A simulation is an active tool that supports researchers to conduct their studies in a virtual environment. Some researches are difficult to be carried out experimentally due to different reasons, simulation could be a good alternative. It is also easier in testing samples and helps researchers to complete their research in a short time and give them good results. In the simulation process, Comsol Multiphysics software was used. It has been noted that this program is used in many applications by researchers, and the reason is due to its accurate results, speed in designing models, flexibility in use, and other features. In this program, 18 models were designed which differed from each other in artificial failure, location, and shape. The dimensions of these models are the same (0.3×1) m, the thickness of this plate is (2mm) and the height is 1 m, as is the case for the other side plate. The piezoelectric sensor has a diameter of 0.01 and 0.001 thickness. The sensors were used to send and receive waves after completing the drawing of models by using Comsol Multiphysics Program. This mesh has been done to divide the model into several areas forgiving precision in the work. The number of models used in this measurement is 3 models that differ from each other using resistance (20, 30, 40) MPa. Also, for cracking models that differ from each other by showing the beginning of the cracks that start with (2,4,5,6,8, 10 mm), some models simulate the collapse in the form of (debond) 6 models [(1×5),(1×10), (1×15), (1×20), (1×25) and (1×30)cm]. Three models have been designed which containing fabricated voids. One of these voids has fewer voids and the second has more voids than the first case and the last one has more voids of the second and the first.

3.2.1. Comsol multiphysics program

In this study, a simulation was used to test the model several times with COMSOL Multiphysics software. It is considered an important software used in simulation and model analysis because it gives very accurate results. One of the advantages of this program is that it helps researchers to reduce time and effort. Through this program, more than one model in a short time can be drawn and analyzed.

It is a program that covers a wide range of applications of those interested in this regard. There are other features of the program including that it is flexible to use. This program is used in many applications related to mechanics, electricity, physics, and other applications. This program is a power filter active environment for modeling and repairing all scientific and engineering problems that researchers face.

Comsol Multiphysics Program can be defined in more detail. It is a set of commercial operational programs used to simulate and solve engineering problems and other problems based on differential equations. One of its most important features is that it is possible to design a set of 2D and 3D models simultaneously for all fields of engineering and science (Dickinson et al, 2014).

The models are designed by the program COMSOL Multiphysics according to other required dimensions. After drawing the models, the type of sensors required is chosen and placed on the model. Thesesensorsarealready in the meant program. Sensors of type (PZT 4) have been chosen, which is the same type that was chosen in the laboratory. The material of the model and the required sensor are selected from a window in the program called (material B). The failure and the location of the sensors are in a window called (geometry). The time that travels of the wave sent from the sensor to the receiver sensor and choosing the appropriate amplitude is also calculated from equations that are mentioned below. The appropriate frequency according to the equations that are mentioned later. The mesh is a window to increase the accuracy of the results. After that, a run is done to give a sign to the program for sending and receiving the wave and exporting the results to the excel program through a window in the device and how the thermal transfer of the wave can be displayed.

Several tables were used regarding the materials used by the COMSOL Multiphysics 4.3b program.

Table 3.1. Property concrete used in the model in COMSOL Multiphysics 4.3b

Property	Value	Unit
Density	2300	kg/m^3
Young'smodulus	25×10^9	Pa

Table 3.2. Basic of concrete

Property	Expression	Unit
Coefficient of thermal expansion	10^{-6}	1/K
Density	2300	Kg/m^3
Thermal conductivity	1.8	W/m·k

Table 3.3.Young's Modulus of concrete

Property	Expression	Unit
Young's Modulus	25×10^9	Pa

Table 3.4. Property structural steel use in the model in COMSOL Multiphysics 4.3b

Property	Value	Unit
Density	7850	kg/m^3
Young's Modulus	200×10^9	Pa

Table 3.5. Basic of structural steel

Property	Expression `	Unit
Heat capacity at constant pressure	475	J/kg×K
Thermal conductivity	44.5	W/m·k
Electrical conductivity	4.032×10^6	S/m

Table 3.6.Young's Modulus structural steel

Property	Expression	Unit
Young's Modulus	200×10^9	Pa

Table 3.7. Property Piezoelectric Devices (Lead Zirconate Titanate (PZT-4D)) use in the model in COMSOL Multiphysics 4.3b

Property	Value	Unit
Density	7600	kg/m^3

$$\text{2-Couplingmatrix} = \begin{vmatrix} 0 & 0 & -4.7303 & 0 & 0 & -4.7303 \\ 0 & 0 & 15.2586 & 0 & 13.0952 & 0 \\ 13.0952 & 0 & 0 & 0 & 0 & 0 \end{vmatrix} \text{c/m}^2$$

Table 3.8. Basic of Piezoelectric Devices

Property	Expression	Unit
Density	7600	kg/m^3

Stress-charge form of Piezoelectric devices

$$\text{1- Coupling matrix} = \begin{vmatrix} 0 & 0 & -4.7303 & 0 & 0 & -4.7303 \\ 0 & 0 & 15.2586 & 0 & 13.0952 & 0 \\ 13.0952 & 0 & 0 & 0 & 0 & 0 \end{vmatrix} (\text{c/m}^2)$$

Table 3.9. Piecewise

Start time	End time	Function
0	0.00005	$10\pi Sin(2\pi \cdot 10^{3t}) \cdot Sin(2\pi \cdot 100^{2t})$
0.00005	9^{-5}	0×t

Table 3.10. Time-dependent

Entry method	Step
Start	0
Step	0.0000005
Stop	30 ×10^{-5}

The equations used in COMSOL Multiphysics 4.3b and the constants that were used.

1. Linear Elastic Material

$$\text{Time} = \frac{6}{\text{frequency}} \tag{3.1}$$

$$\text{Step} = \frac{1}{20} \times \text{frequency} \quad (3.2)$$

$$\text{p}\frac{\partial^2 \text{u}}{\partial \text{t}^2} - \nabla\sigma = \text{Fv}, \qquad \sigma = \text{S} \quad (3.3)$$

$$\text{s} - \text{S}_\text{o} = \text{C}_\text{E}{:}\,(\epsilon - \epsilon_\text{o}) - \text{e}^\text{T} \times \text{E} \quad (3.4)$$

$$\epsilon = \frac{1}{2}[(\nabla\text{u})^\text{T} + \nabla\text{u}] \quad (3.5)$$

where;

C = (E,υ) Young's modulus & Poisson's ratio

E = Young's modulus

υ = Poisson's

ρ = density

2. Piezoelectric Material

$$\epsilon = \frac{1}{2}[(\nabla\text{u})^\text{T} + \nabla\text{u}] \quad (3.6)$$

$$\nabla \cdot \text{D} = \rho_\text{v} \quad (3.7)$$

$$\text{s} - \text{S}_\text{o} = c_E{:}\,(\epsilon - \epsilon_\text{o}) - \text{e}^\text{T} \cdot \text{E} \quad (3.8)$$

$$\text{D} - \text{D}_r = e{:}\,(\epsilon - \epsilon_\text{o}) - \epsilon_s \cdot \text{E} \quad (3.9)$$

$$\epsilon = \frac{1}{2}[(\nabla\text{u})^\text{T} + \nabla\text{u}] \quad (3.10)$$

$$\text{E} = -\nabla\text{v} \quad (3.11)$$

$$\epsilon_s = \epsilon_0 vac^{\epsilon} rs \quad (3.12)$$

When

C_E = elasticity matrix

e = coupling matrix

ϵ_{rs} = relative permittivity

ρ = density

3.3. Analyzing

In this section, It can be explained how to analyze the results obtained then the failure, its location, and its extent can be drawn and explain the results.

3.3.1. Wavelet analysis

To analyze the results, a high-performance technical software MATLAB was used that provides highly accurate analyzes. This program has been used in many applications and sciences. Due to its great popularity, its use is increasing day by day. MATLAB is an acronym from Matrix Laboratory and it is a high-perform language that contains data and tools for editing and debugging (Houcque, 2005). Due to its ability to correct and solve problems, this program is used by many researchers. After the work in the laboratory is fully completed as well as the completion of the simulation and the analysis of the results. The results of the damage are discussed. Wavelet analysis has many applications, not only in civil engineering but also in many sciences such as mathematics, etc. After completing the design process in the COMSOL Multiphysics program or the laboratory, forming the models, and conducting the examination process, the results are extracted for analysis as well as knowing the properties of the materials used and the required equations that will be mentioned later in the form of tables. The raw wave of each model was analyzed into six levels to increase the accuracy of the result and this was done by (wavelet 1D) and the analysis is calculated by equation (3.14) called DWT(discrete wavelet transform). There are many names that the analysis system uses including Gabor, Gaussian, Haar, Daubechies, bi-orthogonal, Coiflets, Symlets, Morlet, Mexican Hat, and Meyer.Daubechies has been used(db).

$$\mathrm{DWT}(\mathrm{m},\mathrm{n}) = \mathrm{a}_0{}^{-\frac{m}{2}} \int f(t).\varphi \cdot (\mathrm{a}_0{}^{-\frac{m}{2}} \cdot t - nb_0)dt \tag{3.13}$$

where;

m, n = Dyadic variables.

a_0, b_0= Constants determining sampling inter vals along the scale and time axes, respectively.

$\Psi\times$ (t) = The complex conjugate of Ψ (t) (the wavelet function).

3.3.2. Damage index (DI)

To quantify the data analyzed using the wavelet transform, damage index indicator (DI) is used by many researchers. The most common DI used in SHM and many other fields is RMSD DI (Root Mean Square Diviation). It can be calculated through the equation that has been developed by researchers (Park et al. 2006; Song et al. 2007; Xu et al. 2013), see equation(3.15). This technique indicates that the higher values of DI the higher possibility of damage occurrence and vice versa.

$$RMSD\,\% = \sqrt{\frac{\sum_{i=1}^{N}\left(y_i - x_i\right)^2}{\sum_{i=1}^{N} x_i^{\,2}}} \times 100 \qquad (3.14)$$

where;

i=1,2,3,….N,

N= Number of sampling points of the wave,

x_i= Amplitude of signal before the damage,

y_i= Amplitude of signal after the damage.

The damage index has been used in this research to assess the artificial damage in the model. It has been used by many researchers. It is the indicator through which it is possible to know the extent of damage to the facilities and this damage can also be estimated and also helps in calculating the costs of building maintenance(Blong, 2003). Ther are factors that affect the values of (DI)which makes these values consistent. This occurs in many structures. One of these factors is the loss of some of the wave’s energy while traveling inside the concrete compounds due to the properties of the compounds and thus affect the values of (DI).

4. RESULT AND DISCUSSION

As mentioned earlier, a comsol multi-physics program was used to plot those models. Three models have been implemented that differ in terms of failure. These models are cracking, voids, and debonds. For each model, there is a difference in the size and dimensions of the failure. The time used, the frequency, and the required equation was calculated. The sensors were placed in the required position and the function of these sensors is to send and receive waves then the comsol multi-physics program runs.

The results have been got by two steps. First, by using an excel system then by shifting the results to the Matlab system for analyzing by the method of wavelet analysis. The waves were plotted for each model. The original wave for each model has been analyzed into six levels to get more accuracy. Using the Wavelet analysis method by (Matlab) software waves are plotted according to statistics in Excel. After that, these drawings have exported and saved as a word program which was in the simulation program.

In the laboratory, three samples of CFST columns have been prepared with compressive strength of 20, 30, and 40 MPa. These models have left for 28 days to get more strength. The device needed has been brought for work which are random function generators (transmitters), oscilloscope (receivers), and PZT4 sensors. Then the PZT4 sensors have fixed on the surface of each model by using epoxy adhesive. Waves are generated by the function generator device that sends them through the sensor placed on the side tip of a model. At the bottom of the side of the model, the wave is received by another sensor that sends it to the so-called oscilloscope. From the oscilloscope, the data is taken via the (USB) port. After that, data has been shifted to the computer then to Excel to draw the waves and Matlab has been used to analyze this data into six levels to give more accuracy through wavelet analysis.

4.1. Results of a Simulation Study

4.1.1. Cracking

Six models with different cracks were designed by the user software. The waves were plotted with Excel and analyzed by wavelet at the beginning of the cracks that start with (2,4,5,6,8,10 mm). Figure 4.1 shows the heart diagram of the wave propagation in the model (2 mm). Where the wave travels from the transmitter sensor on the surface of the model from one side through the damage that falls in the middle. Also, the figure shows decreasing at a certain angle to draw the crack. It moves to the receiving sensor on the same side of the transmitter sensor and also on the surface. It has been noticed the wave glows at first then it gradually begins to reduce. The wave starts from the lowest displacement which is represented with the blue color to the highest value of the red displacement. The wave loses some of its energy due to the steel, the concrete as well as the distance. The presence of cracks in the path of waves leads to losing some of the energy.

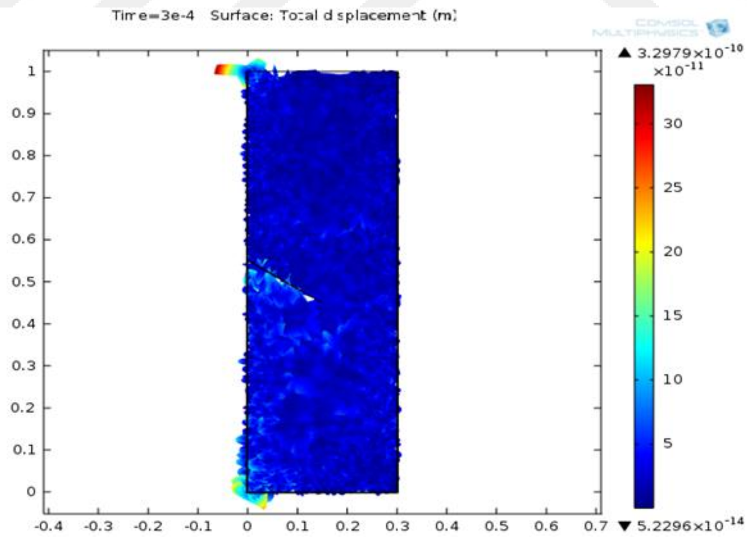

Figure 4.1.Wave transmission and model shape by Comsol Multiphysics for crack (2 mm).

4.1.1.1. Time domain results

The beginning of the cracks that start with (2,4,5,6,8,10 mm) the data for all models which are taken from (Comsol Multiphysics) program was drawn for each model in (Figure 4.2) that shows the comparison between the waves from these models. The wave amplitude is big when the crack is small and the crack increases when the amplitude of the wave begins to decrease. This affects the wave propagation and therefore when the wave propagation amplitude decreases this gives a high probability of failure. The figure below shows the wave pattern for all styles.

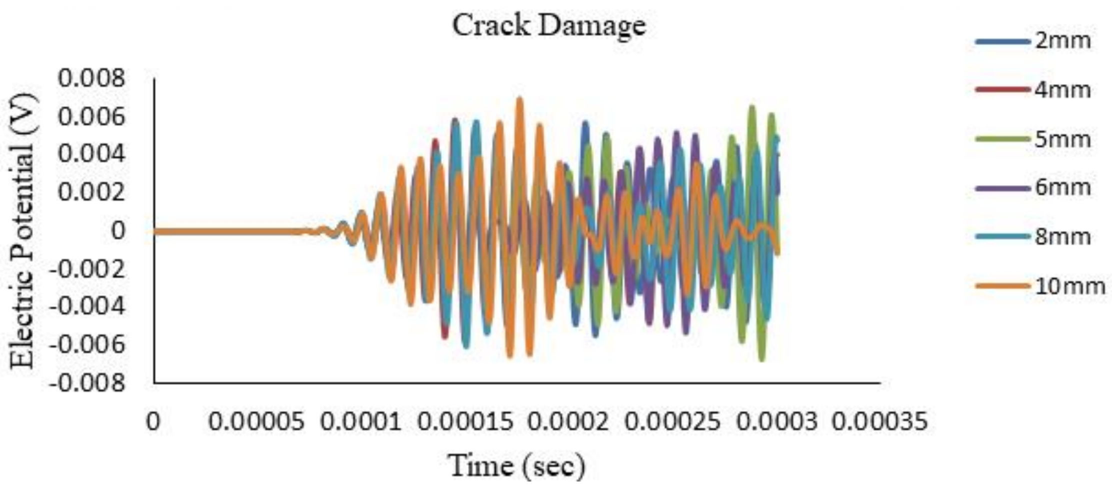

Figure 4.2. Schematic diagram showing time domain of all crack models.

4.1.1.2. Wavelet result

After completing the data transfer to Matlab, the analysis has done by (wavelet - 1D) into six levels to give the greatest accuracy. In (Figure 4.3) shows the original wave and the six analyzed levels. It is noted that the first level wave is close to the original wave due to its high frequency that is close to the original wave frequency. Then the waves in the other levels begin to reduce their amplitude because of decreasing the frequency as in the sixth level. Low frequency is better accuracy and less noise than higher frequency.

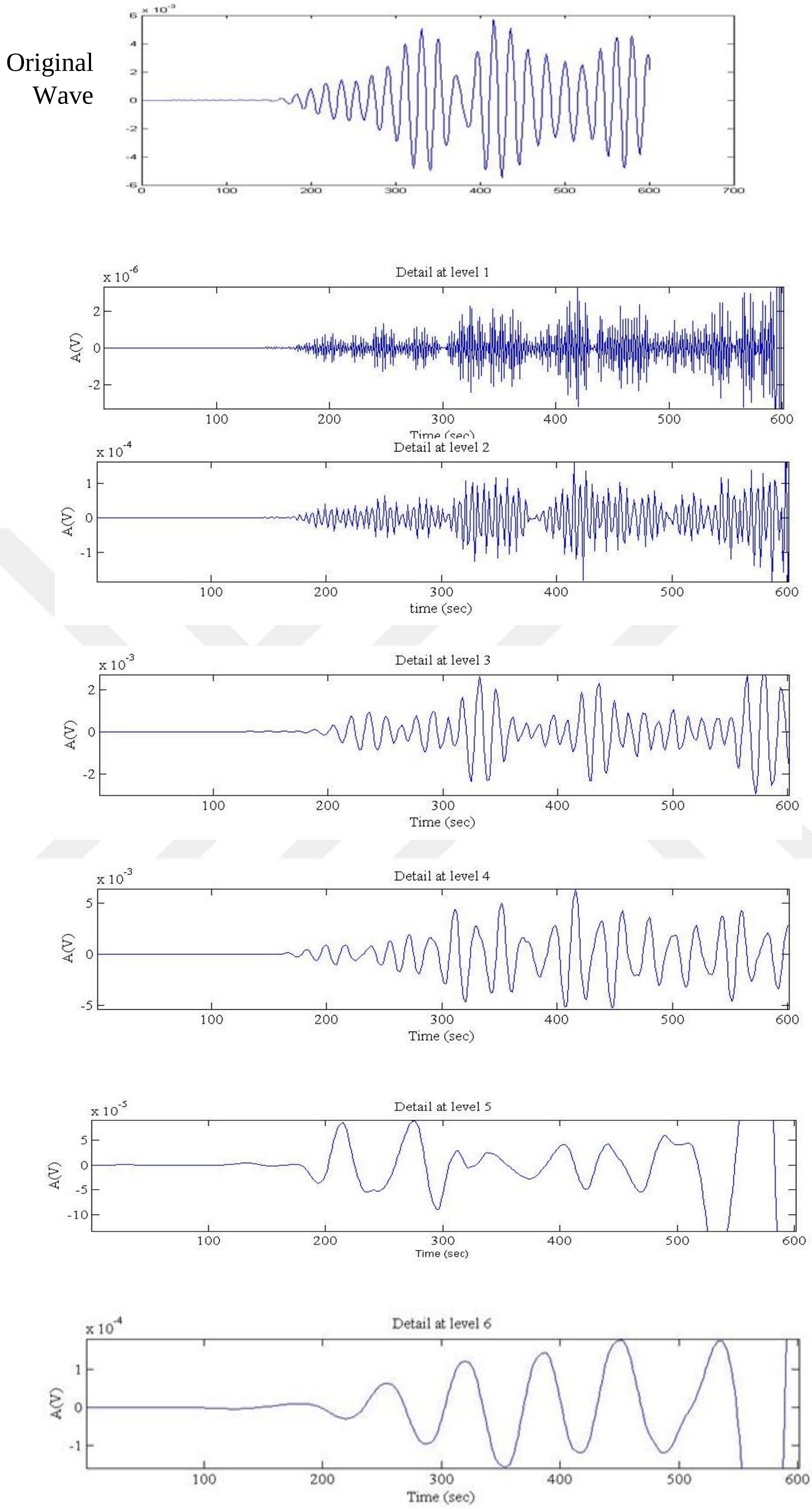

Figure 4.3. The six levels of crack (2 mm) were extracted by Wavelet Transform.

4.1.1.3. Damage index

After completion of the wave analysis into six levels, the damage index was extracted for all levels of the six patterns. The third level for all models was chosen because it is the appropriate one. It is noted that the damage index increases with the increase of the cracking. So this gives important information about the detection and presence of cracking. Other levels do not qualify as the wave propagation is irregular between high amplitude and slope. Therefore, the analysis of waves is complicated and unstable. In (Figure 4.4) shows the damage index and how it increases with increasing cracking. As a wave passes through these cracks, it loses some of its energy. When the wave loses some of its energy, this means there is a possibility of damage occurrence.

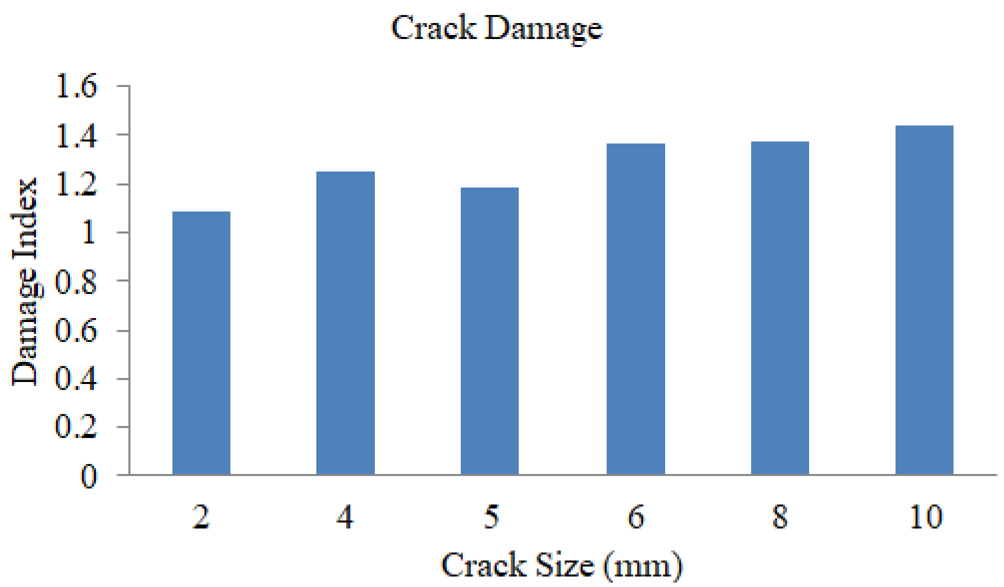

Figure 4.4. The damage index of all cracks models (Third level).

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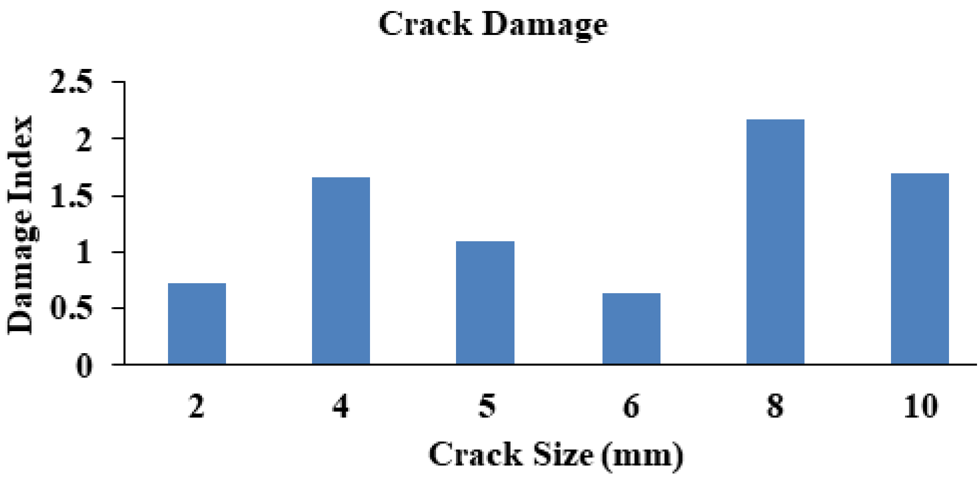


Figure 4.5. The sixth level of Wavelet Transform showing disproportionate relation between the crack damage and DI.

4.1.2. Debond

Debond was designed by the mentioned design program and it has used more than one frequency (50, 80, 100, 120 kHz). The frequency has been adopted (100 kHz) for being the best in giving results. Many damages are used [(1×5),(1×10),(1×15),(1×20),(1×25) and (1×30)cm].Among the models, A length of (1×5 cm) has been used to study in detail. Although all models have the same frequency and the same location of damage, they differ in the dimension of debonding. This model was drawn in the design of the program that was mentioned earlier.

The transmitted sensor is located at the bottom of one side of the model on the surface and the receiver is on top of the model on the same side. It can be noted that the site of the breakdown through the difference in the displacement when it starts with the lowest displacement represented by the blue color down to the highest displacement represented by the red color. This process is done during a time of 3×10^{-4} seconds. This indicates that when the wave reaches the refraction site, it loses some of its energy. Finally, the location of the damage can be determined. In (Figure 4.6) shows the propagation of the wave across the damage.

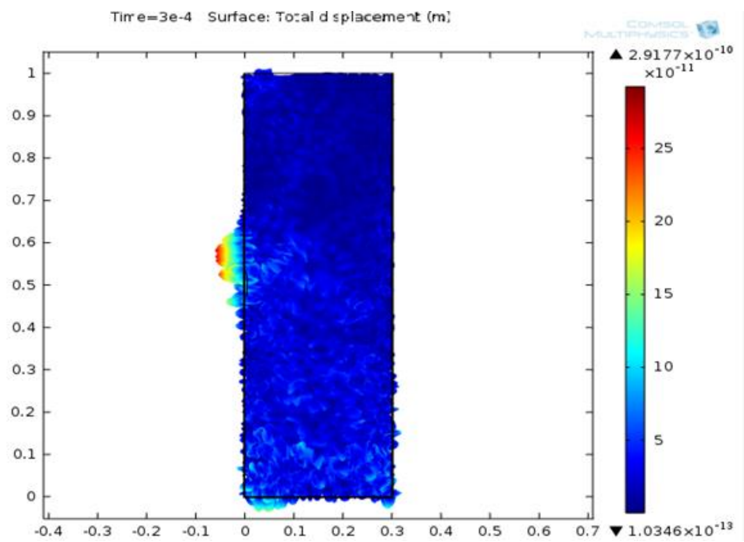


Figure 4.6. The wave transfer from the sent sensor to the receiving sensor and was done by a program Comsol Multiphysics for debond 5 cm model.

4.1.2.1. Time domain results

Using the data in Excel, the wave was plotted for all models [(1×5),(1×10),(1×15),(1×20),(1×25) and (1×30)cm].and compared to each other. It can be noted whenever the size of the debonds increases, the wave propagation, and its energy decreases. This is important to detect the damage through the loss of some wave energy. As (Figure 4.7) shows a comparison of these waves by plotting them.

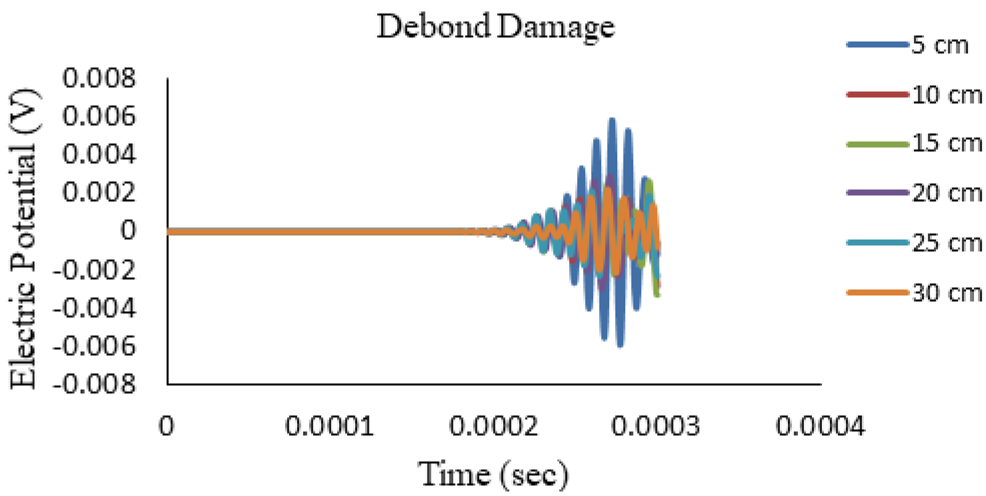


Figure 4.7. Time-domain of all debonds models.

4.1.2.2. Wavelet result

When analyzing the wave from Excel to Matlab using (wavelet - 1D) into six levels, it has been noticed that the wave energy is decreased gradually from the first level, which has the largest frequency and the wave is similar to the original wave, to the sixth level which has the lowest frequency. The wave lost a lot of its energy due to the low frequency. This indicates that the higher frequency at the first level is less accurate and noisier than the lower frequency at the sixth level. Figure 4.8 shows the original wave and the six analyzed levels.

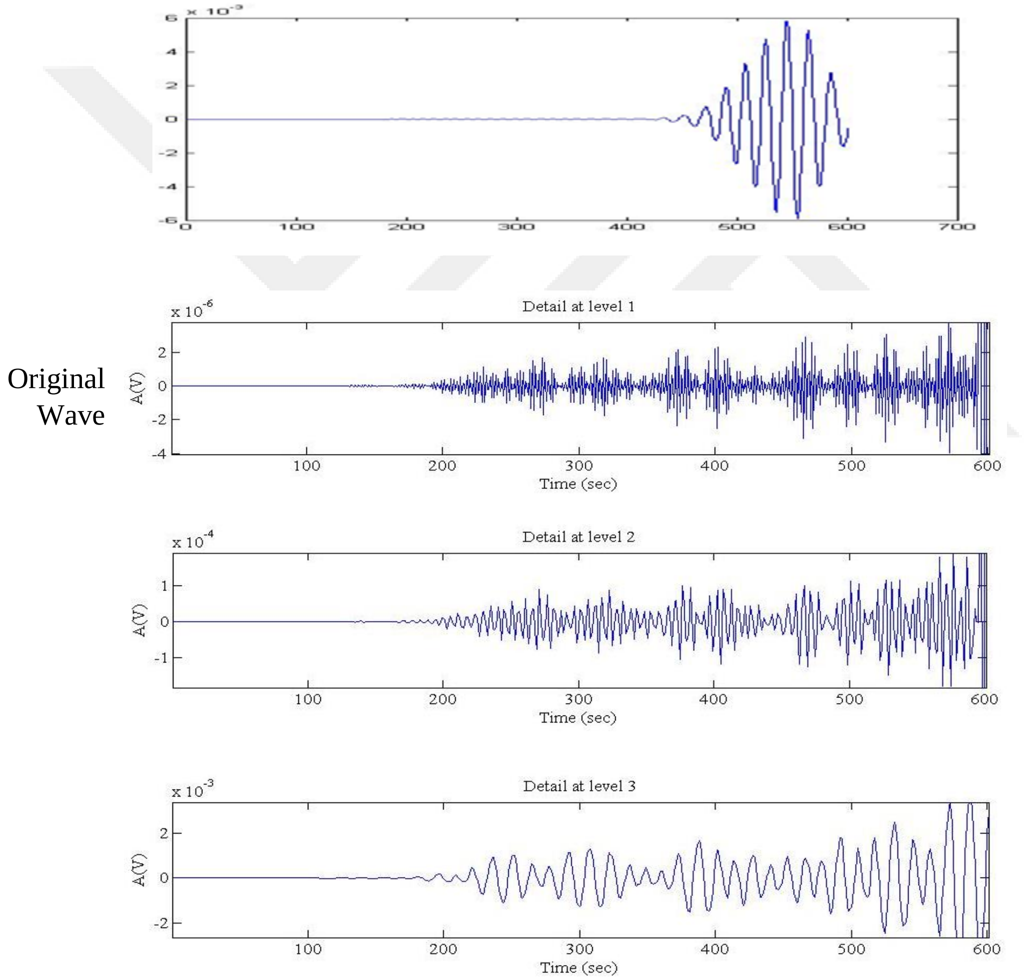


Figure 4.8. The six levels were extracted by Wavelet Transform for 5 cm debonding damage

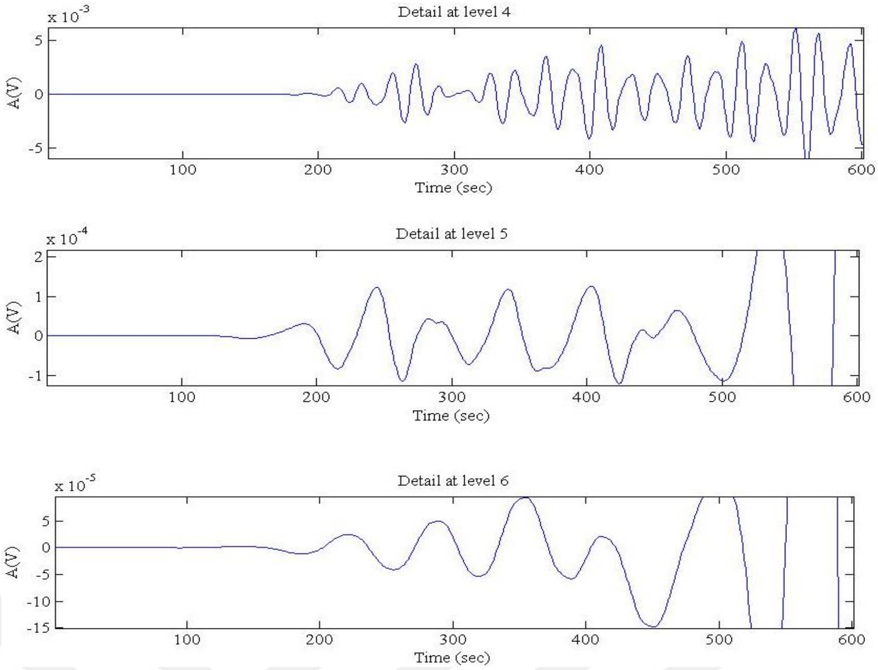


Figure 4.9. The six levels were extracted by Wavelet Transform for 5 cm debonding damage(Continiue) .

4.1.2.3. Damage index

After designing all debond models and plotting their data as a wave, and analyzing these waves into six levels, a damage index of them has been extracted. From the graph in (Figure 4.9), It has been noticed when any increase in debond dimension leads to an increasing in damage index. The second level has been used for each model from the sixth model because the second level gives the appropriate results to get important information to detect the damage. As the wave is transmitted and collides with the debond, it loses some of its energy to detect the location of the damage. The other levels are not appropriate because they are complicated and it is difficult to be analyzed, unlike the second level. The graph below shows the debond with the damage indicator, when the debond increases, the damage index increases also.

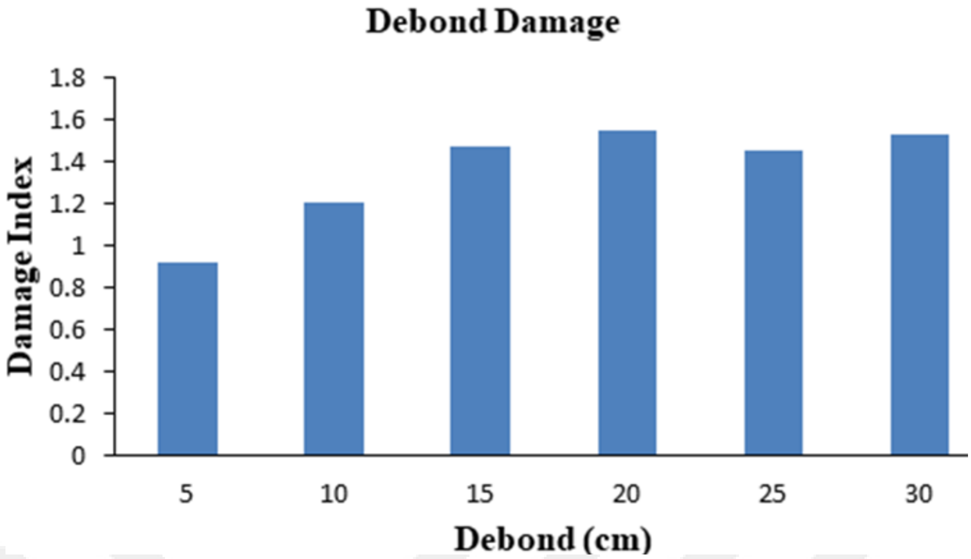


Figure 4.10. Damage index for all models of debonding (second level).

4.1.3. Voids

Three models have been designed which containing fabricated voids. One of these models has fewer voids and the second has more voids than the first case and the last one has more voids of the second and the first. The model was drawn by a software designer. See (Figure 4.10) shows the transmission and propagation of the wave. Steel also affects the wave propagation, the frequency and reduces its amplitude.

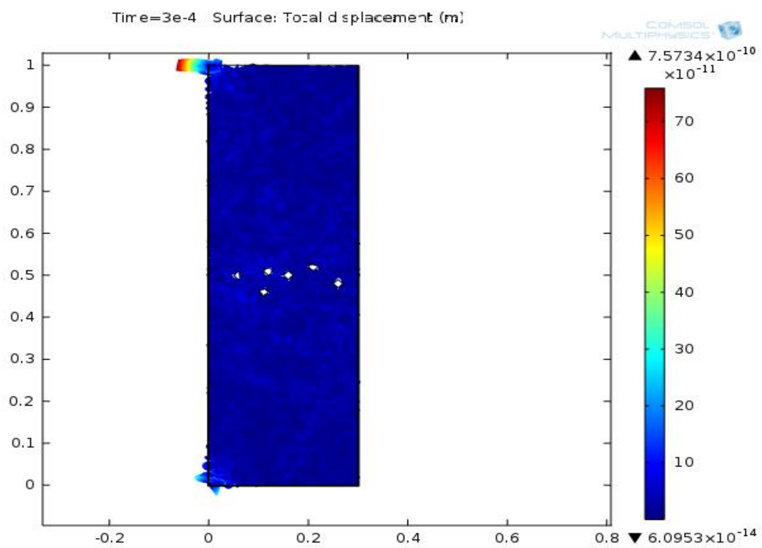


Figure 4.11. The shape of the wave transmission and the number of voids.

4.1.3.1. Time domain result

The waves of all the models were compared by drawing them in the Excel program. As shown in (Figure 4.11), It is noticed that with an increase in the number of voids, the wave is dispersed. That means the dispersion of the wave in a specific area of the model leads to the presence of damage in the examined model.

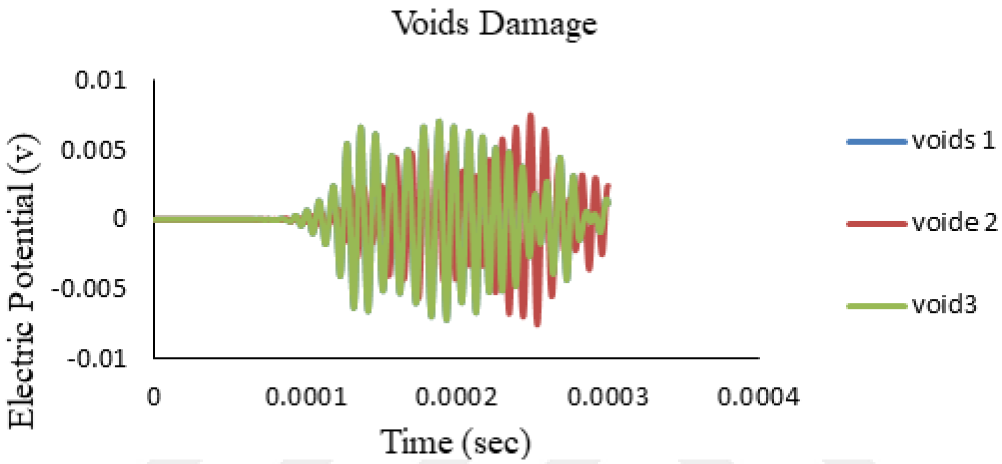


Figure 4.12. The comparison between signals for different voids values.

4.1.3.2. Wavelet result

To get an accuracy of the results, it is important to analyze the wave of the model which contains few voids to six levels by (wavelet -1D).In (Figure 4.12), it shows that with increasing frequency, the wave is noisier and less accurate as indicated in the first level which its wave and its frequency are similar to the original wave, unlike the sixth level which is less frequency, more accurate, and less noisy.

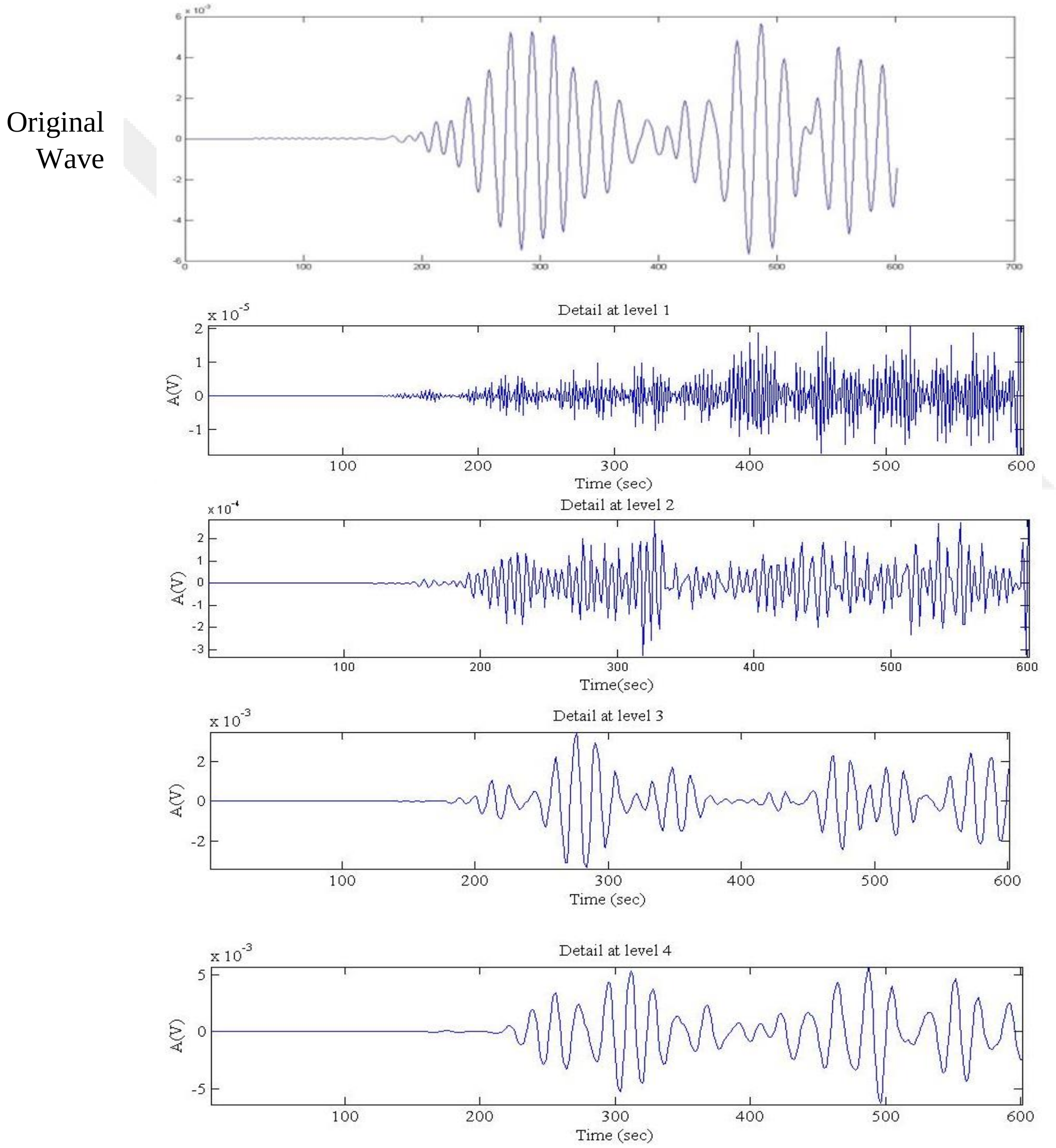


Figure 4.13. Wavelet Transform levels for the case of many voids

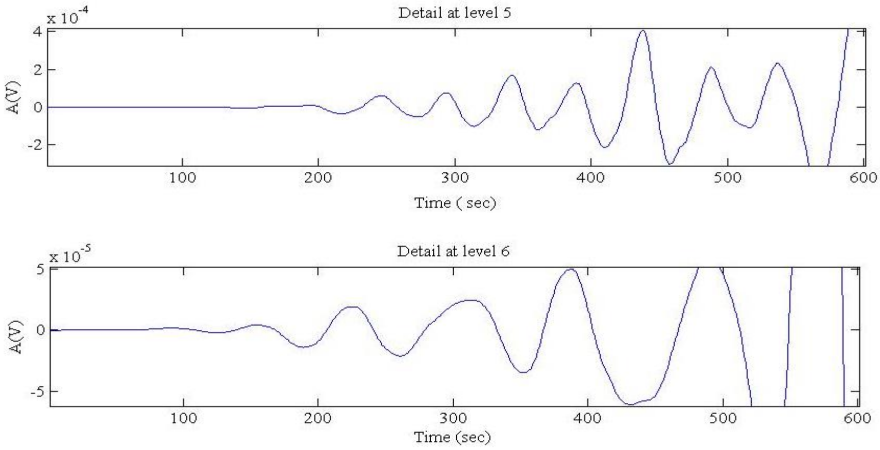


Figure 4.14. Wavelet Transform levels for the case of many voids (Continiue).

4.1.3.3. Damage index

To draw the damage index, it is needed to analyze all the models to six levels. The sixth level was chosen because of its appropriate results which show the relationship between the number of voids and the damage index. It is noticed that increasing the number of voids leads to an increasing the damage index as indicated in (Figure 4.13). For the other levels, the first level was also good and showed that more voids lead to increasing the damage index. The other levels were inappropriate. This may be attributed to the matching between voids size and number from a side and the level of frequency from another side.

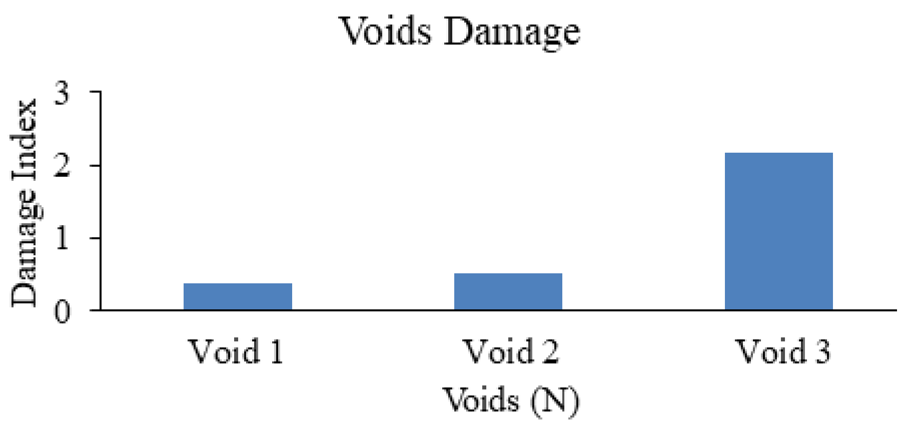


Figure 4.15. Damage index for all cases of voids (Sixth level).

4.2. Experimental Verification

4.2.1. Experimental result

After 28 days from casting, the cubes were examined. Table 4.1 shows the results obtained.

Table 4.1.The compressive strength values of the concrete specimen.

Compressive strength(Mpa)	Model 1	Model 2	Model 3
20	28	26.08	26.08
30	34.3	29.7	31.5
40	34.5	35.5	36.2

When casting these models according to the mixing ratio mentioned at the beginning of the practical explanation to obtain different compressive strength(20, 30, 40 MPa), the results in the laboratory are not always expected to get what is wanted from the strength.

4.2.1.1. Compressive strength

The model was cast according to the concrete mixture with the ratio (1: 2.68: 1.98) and W / C (0.5) to obtain this resistance. Figure (4.14) shows the drawing of the wave that was drawn by a device (oscilloscope). This wave was generated by function generator and sent by sensors that are located at the top on the side of the model surface. This wave passes through the artificial failure that was placed inside the model with dimensions (1 ×5 cm) to the receiving sensor at the bottom of the model on the surface as well. The wave propagation through the sample can be affected by the inhomogeneity of the concrete material. The energy of the propagated wave is dissipated throughout the concrete material in a specific limit. This limit varies depending on the material mixing ratio and consequently the material strength. This indicates that whenever the strength increases, the mixing ratio increases also that finally affects the propagation of the wave.

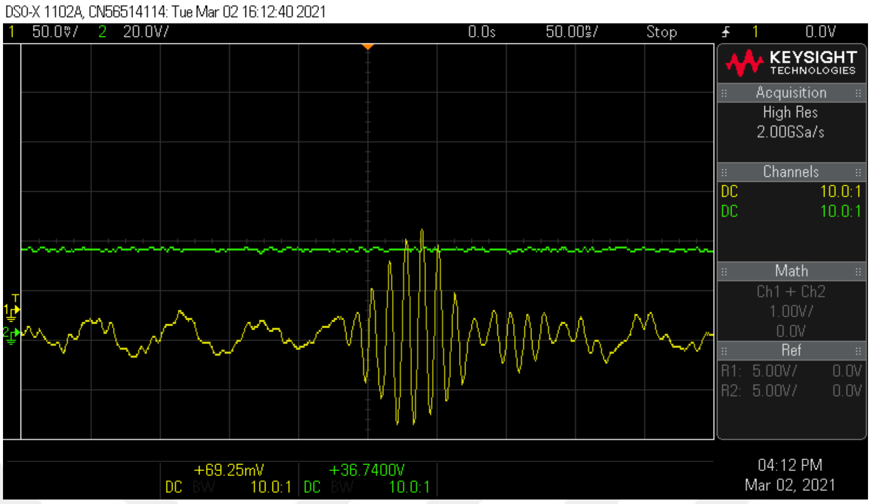


Figure 4.16. The raw wave was extracted by oscilloscope for 20 MPa compressive strength.

4.2.1.1.1. Wavelet result

The wave that was drawn by oscilloscope and analyzed by (wavelet - 1D) into six levels, It is noticed that the first level is high-frequency with more noise and less accuracy. Whenever the wave frequency increases, the attenuation of the signal increases. While the level whose frequency is lower, its accuracy is better and its noise is less. It is important to know that the shrinkage of concrete affects the mechanical behavior of the sensors that affect the propagation of the wave. In (Figure 4.15) shows the main wave and its six levels of a (20 Mpa) model examined in the laboratory.

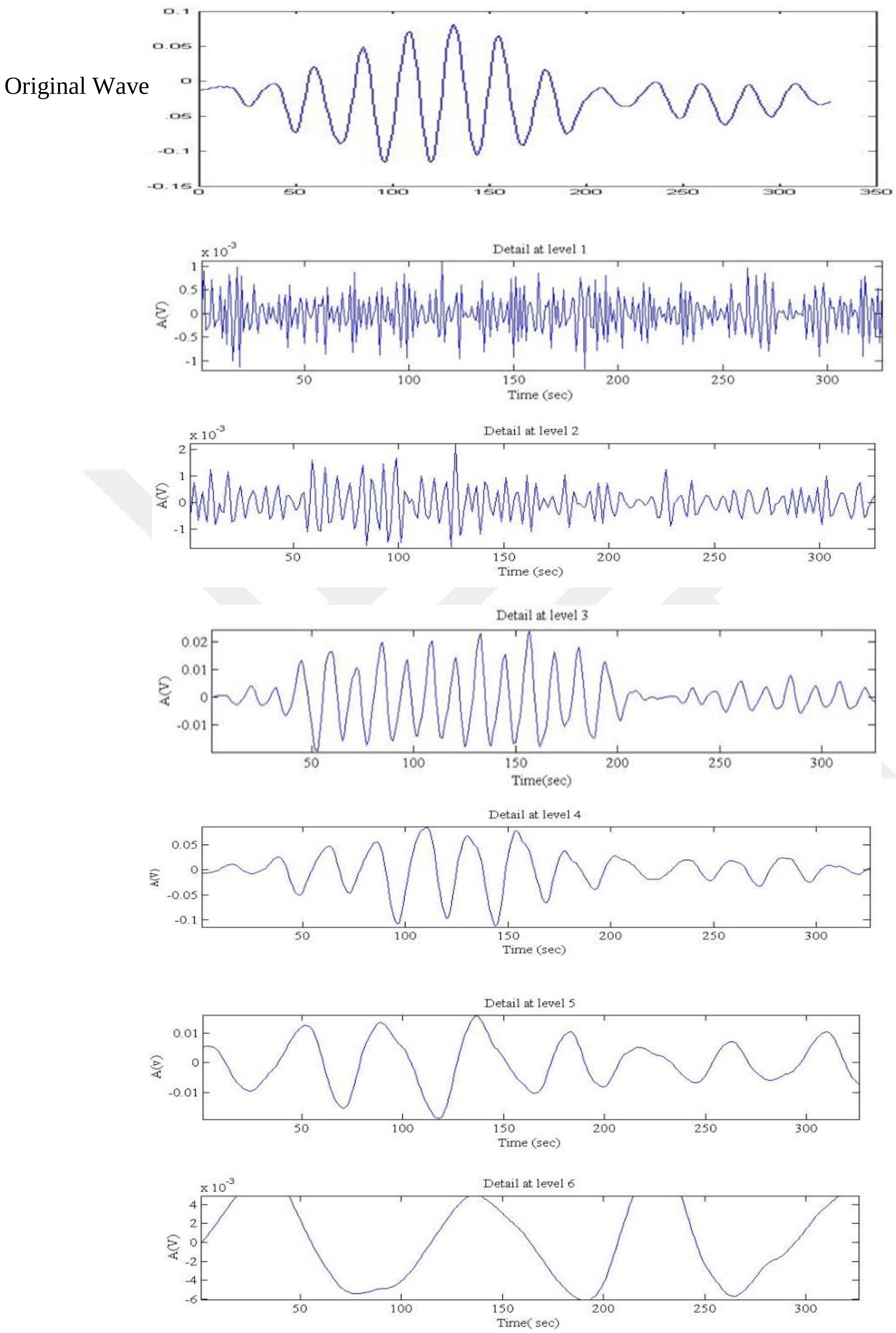


Figure 4.17. The original wave and its six levels of the (20 MPa) model that was examined in the laboratory.

4.2.1.1.2. Time domain

A mix ratio of compressive strength (20 MPa) was (1: 2.68: 1.98) and W / C (0.5).While the mix ratio for obtaining strength (30 MPa) was (1: 1.86: 2.57) W / C (0.48) and the mix ratio for obtaining strength (40 MPa) was (1: 1.68: 2.41) W / C (0.45). Figure (4.16) below shows how the wave is affected by the increase in compressive strength which is affected by the properties of the concrete. This increase in the resistance was happened because of the increase in the mix ratios which affect the spread of the wave. When the wave collides with the failure, the wave loses part of its energy. This is important to give good results in case the wave loses its energy. This means there is a damage.

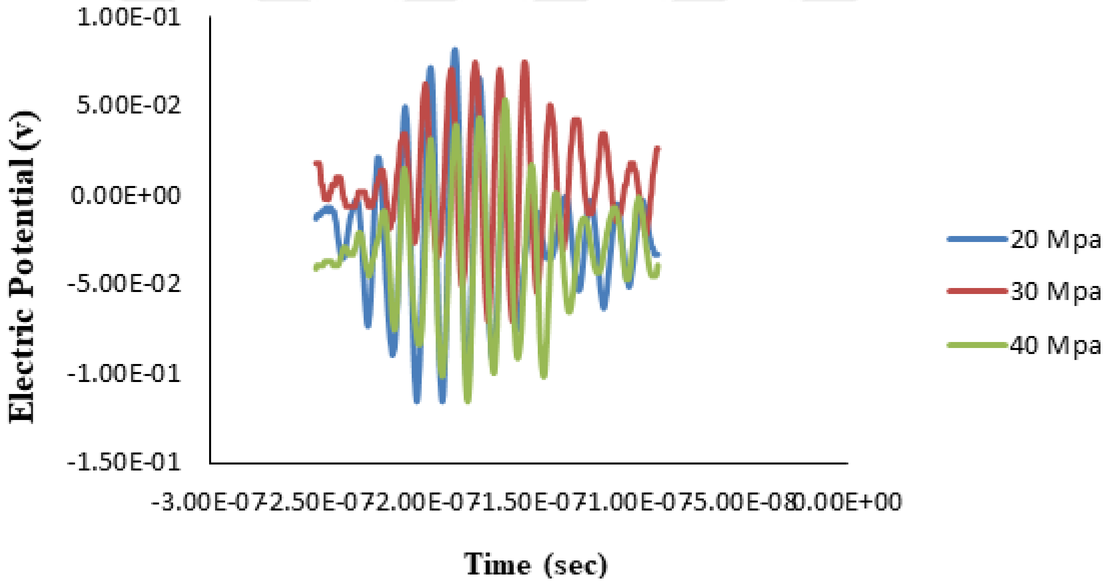
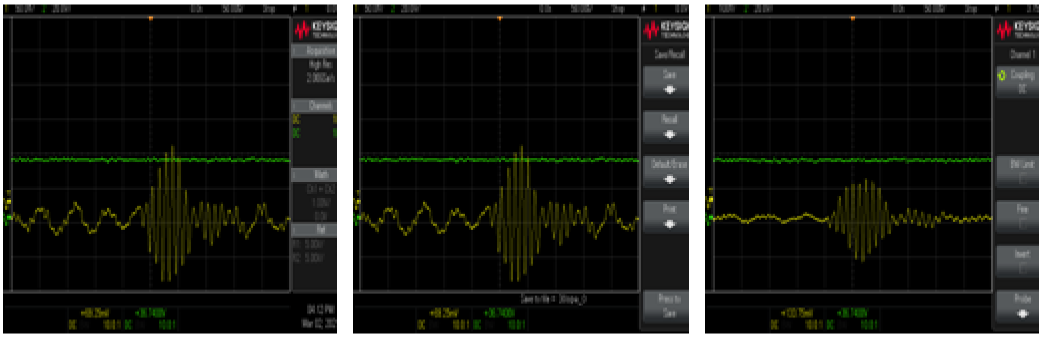


Figure 4.18. A comparison of the compressive strength of waves (20, 30 & 40 Mpa) for laboratory-examined models.



A wave of 20 Mpa **A wave of 30 Mpa** **A wave of 40 Mpa**

Figure 4.19. The three-wave diagram (20, 30 & 40 Mpa) illustrated by a device oscilloscope.

4.2.1.1.3. Damage index

Three models have been used to get a different strength. It is worth mentioning that not no resistance has got in the laboratory is the same that is wanted. For example, in the case of 20 Mpa, it may get less or more resistance than the required resistance because the laboratory results are not accurate like simulation results. After completing the examination of the three models to detect the artificial damage inside them and taking the results and analyzing them by MATLAB, the wave of each model was analyzed into six levels to increase the accuracy of the results. After the completion of the analysis and knowing the six levels, it was found that the second level is the best to give important results. Whereas the increase of compressive strength, the damage index increases and this increases the likelihood of failure and detect it early. Figure 4.18 shows the relationship between the damage index and compressive strength and whenever the compressive strength increases, the damage index increases also.

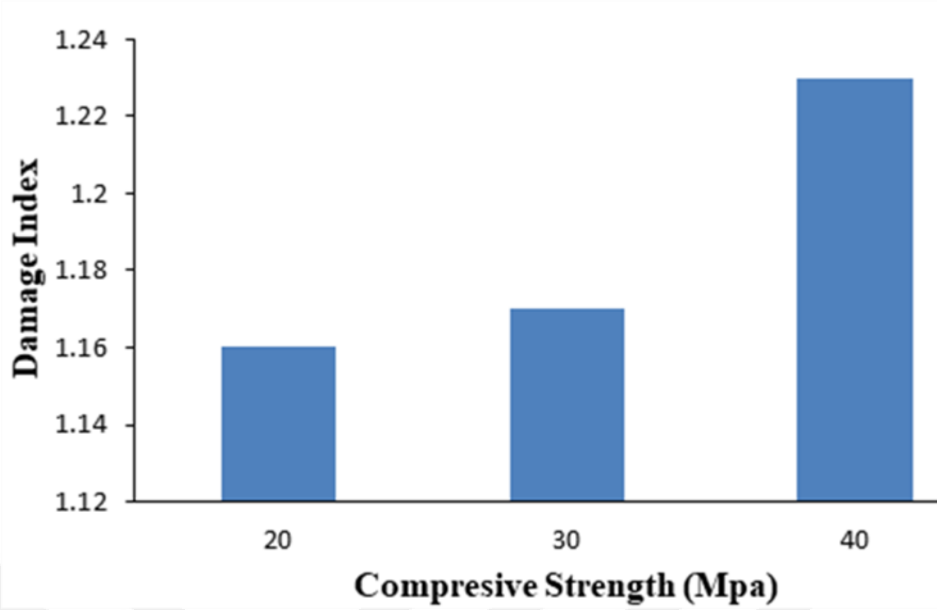


Figure 4.20. The relationship between damage index and compressive strength for the second level and all models examined in the laboratory.

4.2.2. Verification

The first level of the wave (20 MPa) that drawn by COMSOL Multiphysics was compared with the second level of the wave (20 MPa) examined in the laboratory with noting that it has the same frequency (100 kHz) as well as the same dimensions of damage (1×5cm). In COMSOL, waves are sent and received through sensors already in the program. While in the laboratory the waves are created by the function generator that sends them to oscilloscope that plots this wave and stores the data.. It has been observed that with the increase in compressive strength, the damage index increases. In (Figure 4.19), the comparison between damage index and compressive strength for the first level in simulations with the second level of all the models that were examined in the laboratory. This is important in giving results of damage detection. The reason for choosing the first level of simulation with the second level of practicality is that they have the same frequency and are close to each other. The simulation case is a typical one that means choosing a compression strength (20 Mpa), the same resistance has been got without increasing or decreasing. In the laboratory, (20 Mpa) has never the same value required.

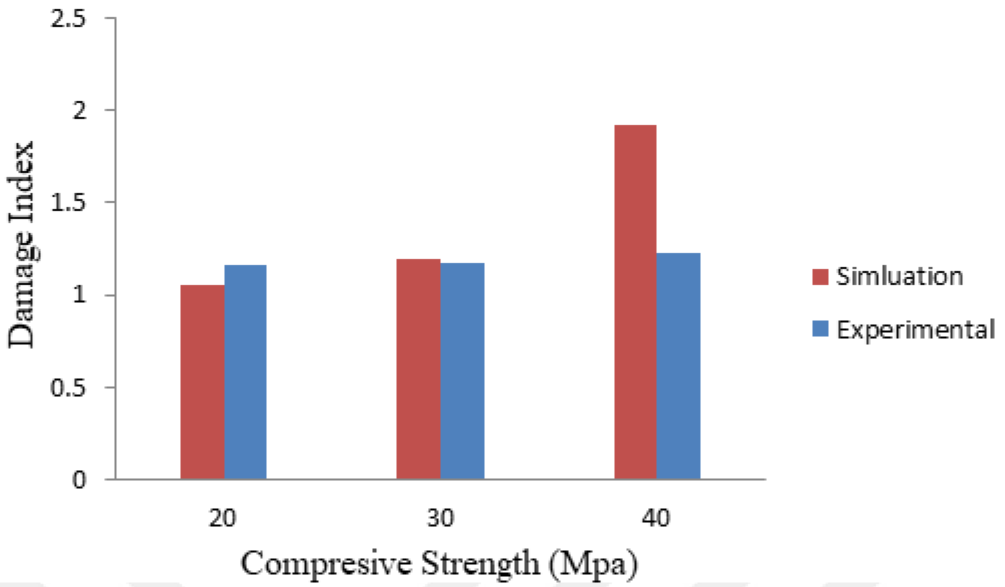


Figure 4.21. The comparison between damage index and compressive strength for the first level in simulations with the second level of all the models that were examined in the laboratory.

Figure 4. 20 shows the comparison between two waves of two models having the same compressive strength and the same synthetic failure but one of them was designed by the software and the other model was examined in the laboratory with mixed ratios (1: 2.68: 1.98) and W / C (0.5) to obtain it. The results showed that the simulation wave is typical and does not contain deformation unlike the wave of the experimental model. The spreading of laboratory model waves affects the properties of concrete that leads to deforming and loses part of its energy.

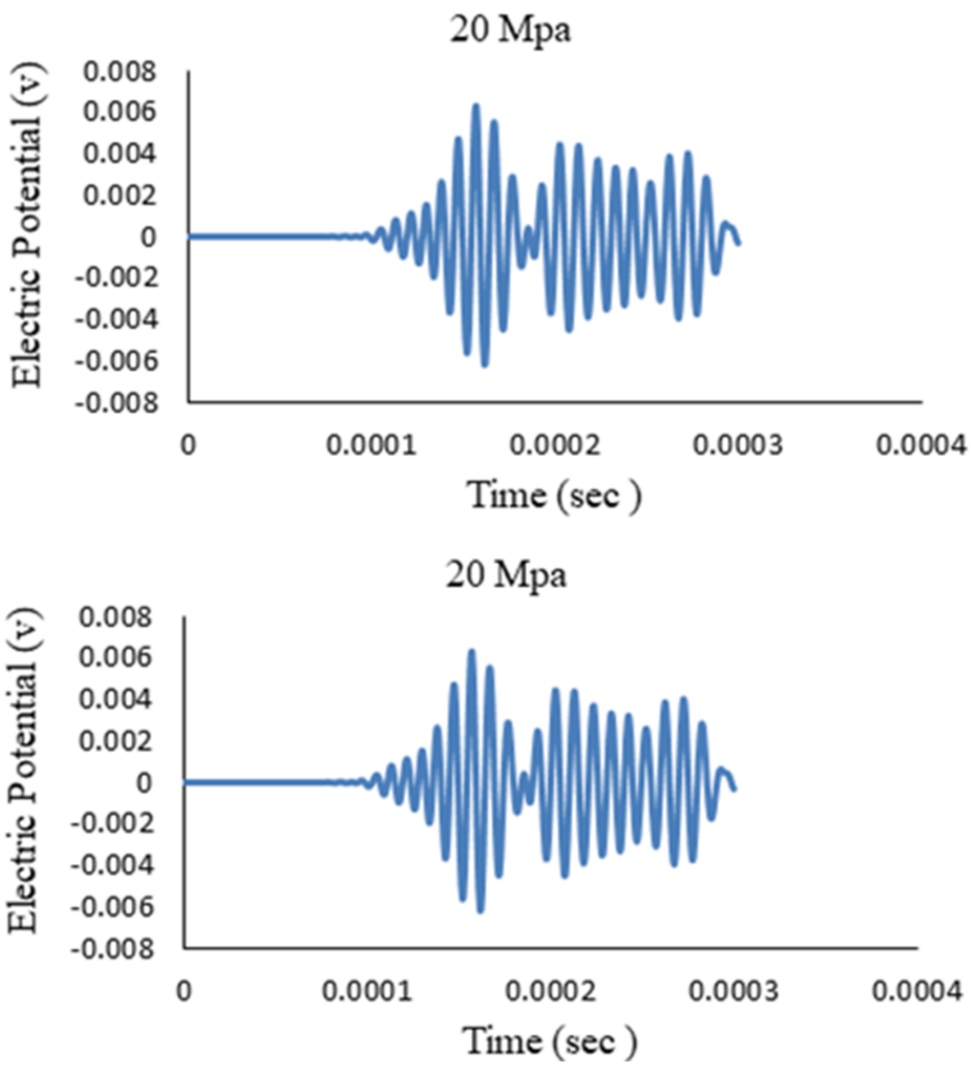


Figure 4.22. waveforms of the 20 MPa model, Experimental (upper side) and simulation (lower side).

4.3. Comparison With The Literature

Several models have been studies. Each one of them has a different damages. In crack damage, the results indicated that whenever the size of crack increases the damage index increases which leads to an increased probability of damage detection. This agrees with what had been studied by (ZHU Jinsonget al, 2012). They indicated that the cracks decrease the power of the probagated wave through the interaction with damage. This means that whenever the cracks increase, the wave losses a part of its energy.

In the case of compressive strength, the results indicated that with any increasing compressive strength the damage index increases that helps to measure compression strength and describes the properties of concrete, and detect any deterioration early.

In the case of failure, which happened because of deboned, models have been used. These models have different dimensions drawn by comsol multi-physics and analyses these results in the MATLAB program. The results showed that with an increase in the debond size, the damage index increases also. This was noted in the work of (Bin Xu et al, 2013) which indicated that the damage index increases with the increasing of the size of debonding and this agrees with these results.

5. CONCLUSION

1. The wavelet analysis has shown that crack detection is varied throughout the wavelet levels. Among six levels, the third one has given the best result. The deviation of other levels results may be attributed to the compatibility of the frequency with the crack size.
2. For debond damage, level 2 has shown a better performance than other levels. The same reason for the crack detection could be the cause beyond these results.
3. Voids results have been seen to be consistent more than other damages types. Damage index results in both levels No.1&6 reflect the trend of the relation between DI and void numbers.
4. The experimental results have shown close results to that of numerical ones. The best wavelet level is found to be level 2. As compared to numerical results which showed that level 3 is the best, it is worth mentioning here that the ideal environment of the numerical study as compared to the practical situation of experimental study regarding the material type, damage representations, and even the wave detection all participated in this difference. However, levels 2 & 3 are still close to each other because of their frequency levels.
5. The damage index based on Wavelet analysis has proved its successfulness in detecting different damage types. This is due to its richness in providing a wide range of frequency levels.
6. The current study contributes to the field of structural health monitoring of civil engineering structures.

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GENİŞLETİLMİŞ TÜRKÇE ÖZET

(EXTENDED TURKISH SUMMARY)

ULTRASONİK DALGALAR KULLANILARAK CFST KOLONUNDAKİ HASARLARIN TESPİTİ

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ÖZ

Beton dolgulu çelik kolon (CFST) elemanlar, dayanım, sertlik ve diğer birçok özellik dahil olmak üzere önemli özellikleri nedeniyle birçok binada ve köprü gibi diğer yapılarda yaygın olarak kullanılmaktadır. Bununla birlikte, bu elemanlar, CFST bileşenleri arasındaki ara bağlantıyı zayıflatan faktörlere maruz kalmaktadır. Bu da beton ile çelik arasında hiçbir bağ olmadığı anlamına gelir. Bu nedenle, ultrasonik dalgalar kullanarak izlemek gereklidir. Bu araştırmada sayısal bir çalışma yapılmış ve bu çalışma deneysel bir çalışma ile doğrulamaya çalışılmıştır. Çalışmaaki sonuçları elde etmek için dalgacık analizi kullanılmıştır. Yapay çatlak (2, 4, 5, 6, 8, 10 mm) ve ayrışma hasarları [(1×10), (1×10), (1×15), (1× 20), (1× 25) ve (1× 30) cm] . ve birkaç boşluk keşfedilir. Daubechies dalgacık kullanılarak Dalgacık analizi yoluyla altı seviye benimsenmiştir. Çatlak sonuçları için, hasar indeksi sonuçları, seviye 3'ün diğer seviyelerin aksine tutarlı ve orantılı bir ilişki verdiğini göstermiştir. Debond hasarında 2. seviye en iyi sonuçları yansıtırken boşluklarda 1. ve 6. seviyeler daha gerçekçi sonuçlar verdi. Seviye 2 ile temsil edilen sayısal örnekteki bağ sökme hasarı en iyi sonuç iken, deneysel seviyenin seviye 3'e yakın olduğu görülmüştür. Dalgacık analizine dayalı hasar indeksi, CFST'de farklı tip ve büyüklükteki hasarı tespit etme yeteneğini kanıtlamıştır. ultrasonik yüzey ve yığın dalgaları kullanan sütunlar. Bu, bu çalışmayı farklı malzemeler ve farklı kurgularla daha pratik ve gerçekçi örneklere genişletmemize yol açabilir.

Anahtar Kelimeler: CFST, SHM, hasar tespiti, Çatlak, basınç dayanımı ve boşluklar

1. GİRİŞ

Son birkaç yılda inşaat mühendisliğinde dikkate değer bir gelişme fark edilmektedir. Bu gelişmeler, inşaatla ilgilenen birçok firmanın yolunu açmıştır. İnşaatta birçok etkili unsur ortaya çıkmıştır. Beton dolgulu çelik kolon (CFST) elemanlar, dayanıklılık, sertlik ve daha birçok özellik gibi önemli özellikleri nedeniyle birçok binada ve köprü gibi diğer yapılarda yaygın olarak kullanılan aktif elemanlar arasındadır. Bununla birlikte, bu unsurlar, CFST bileşenleri arasındaki ara bağlantıyı zayıflatan faktörlere maruz kalmaktadır. Bu da beton ile çelik arasında hiçbir bağ olmadığı anlamına gelir ve bu nedenle tesislerin uzun ömürlülüğünü ve dayanıklılığını ve performansının zayıflamasını etkiler. Can ve mal kayıplarının yaşanmaması ve afetlerin meydana gelmemesi için onu etkileyen bu olayını erken teşhis edilmesi ve bilinmesi gerekli hale gelmiştir.

Binalarda ve diğer tesislerde meydana gelen bu tür sorunlar için geliştirilmiş tahribatsız yöntem denilen yöntemler vardır. Bu yöntemlerin farklı türleri vardır ve ultrasonik teknoloji, birçok araştırmacı tarafından kullanılan ve teşvik edilen gelişmiş, etkili ve önemli yöntemlerden biridir. Ultrasonik dalga tabanlı SHM (Yapısal Sağlık İzleme) alanı, inşaat mühendisliği uygulamalarında yaygın olarak incelenmektedir. Yapısal sağlığın izlenmesi, özellikle eski binalar için yapısal hasar ve kusurların varlığının öngörülmesi ve uyarılması ve özellikle eski binalar için kalan ömrünün tahmin edilmesidir.

2. MALZEMELER VE YÖNTEMLER

Beton dolgulu çelik kolon numuneler gerekli malzemeler kullanılarak, ACI yönetmeliğinin öngördüğü doğrultusunda hazırlanmıştır. Dalga algılama işleminde Şekil 1'de gösterilen osiloskop ve fonksiyon üreteci kullanılmıştır. Dalga sinyali, rastgele bir dalga fonksiyonu kullanılarak dalga üreteci kullanılarak oluşturulmuş ve iletilmesi sağlanmıştır. Bundan sonra, piezoelektrik verici sensörü, sinyali numuneye aktarmakta ve alıcı sensör, dalgayı, osiloskop tarafından yakalanacak ve kaydedilecek bir elektrik sinyaline geri dönüştürmektedir.

Şekil 1. Osiloskop, fonksiyon üreteci cihazları ve piezoelektrik verici sensörü

Deneyde kullanılacak beton dolgulu çelik kolon (CFST) için gerekli malzemeler alınarak laboratuvarda model gerekli ölçülere göre dökülerek her model için yapay hasar oluşturulmuştur. Bundan sonra, modelin yüzeyine yerleştirilen sensörlerden biri dalgaları gönderir, diğeri dalgayı alır, yönlendirilmiş dalgaları ve toplu dalgaları oluşturur.

Hasarı, yerini, boyutunu ve model içinde oluşturulan hasar ile ilgili diğer ayrıntıları belirlemek için, fonsiyon üreteci tarafından hazırlanan dalgalar osiloskop tarafından okunur. Akabinde bu dalgala dönüştürücülere ve bilgisayara iletilmekte ve sonrasında MATLAB programı kullanılarak sonuçlar analiz edilmektedir.

Numunenin çelik kısmı, tasarlanan ölçülere göre laboratuvarda hazırlanmıştır. Yapay ayrışma hasarını simüle etmek için bu çalışmada tasarlanan uygun boyutlarda polistiren köpük malzeme kullanılmıştır. Beton, çelik borunun içine döküldüğünde, polistiren parçalar, ayrışma hasarını taklit eden odalar oluşturacaktır. Beton döküldükten sonra, betonun basınç dayanımını kazanması için 28 gün sonra test yapılmıştır.

Sensörler dalga alış-verişi için uygun yerlere yerleştirilir ve dalgalar çalıştırılır. Dalgalı model üzerinde birçok kontrol yapılır ve hasarın yeri, boyutu ve diğer detayları hakkında doğru sonuçlar vermek için birçok sensör yerleştirilir. Numunenin ultrason taraması tamamlandıktan ve osiloskop ile bilgisayara gönderildikten sonra, elde edilen sonuçlar MATLAB ve ayrıca Microsoft Excel kullanılarak analiz edilir. Bilgisayarda analizi yapıldıktan sonra, hasarın yeri, boyutu ve etkisi bilinir. Bu sayede binaya verdiği zararı bilinebilir.

Numunenin Hazırlanması

Numunelerin çelik kısmı için döküm malzemeleri ACI yönetmeliğine uygun olarak atölyede hazırlanmıştır. Bu malzemeler çimentoanlatıldığı, kum, su ve agregadır. Bu malzemeler numune hazırlanırken deneysel işlemlerin bölümde bahsedildiği oranlara göre laboratuvarda dökülmelidir. Sensörler ise, Çin'den ithal edilmiştir. Bu cihazların fonksiyon jeneratörleri ve Osiloskop için özel özelliklere sahip sensörler olduğundan, yapay hasar, numune ölçülere göre laboratuvarda yapılmıştır. Her modelin diğerinden farklı bir hasarı oluşabilmektedir. Örnekler uygun bir ortamda dökülmüştür. Sensörler, seçilen yerlere modellerin üzerine yerleştirilir ve cihazlara bağlanır. Dalganın nasıl oluşturulduğu, iletildiği ve alındığı daha sonra deneysel prosedürlerde anlatılmıştır.

Taban boyutları 30×30 cm ve 1 m yüksekliğine sahip olan üç CFST numunesi seçilmiştir. Çelik levhanın kalınlığı 2 mm'dir. Her numune, farklı bir ayrışma hasarı boyutuna ve farklı basınç dayanıma sahiptir. Kare, dikdörtgen ve yuvarlak dahil olmak üzere farklı CFST şekilleri vardır. Bu çalışmada, polistiren köpük, CFST kolonundaki ayrışma hasarını simüle etmek için kullanılmıştır. Numuneler sertlik kazandıktan sonra betonun üst yüzeyini polistiren köpüğün konulduğu yerlere bağlayan daha önce açılan deliklerden akaryakıt bir malzeme dökülür. Akaryakıt dökülmesinden amaç bu sıvıyı kullanarak polistiren malzemeyi yok ederek ayrıştırma hasarı oluşturmaktır.

Şekil 2. Farklı dayanıma sahip örnekler (20 Mpa, 30 Mpa, 40 Mpa).

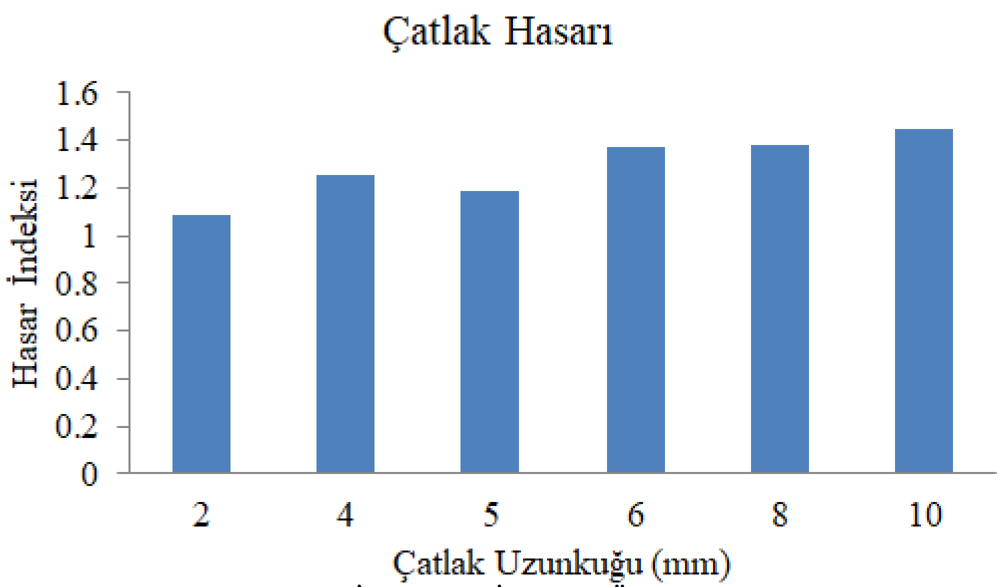
3. SONUÇ VE TARTIŞMA

Çatlak Hasarı İçin Yapılan Simülasyon Çalışmasının Sonucu

Farklı uzunluklara sahip (2,4,5,6,8,10 mm) çatlak içeren altı model tasarlanmıştır. Modeller seçilerek, bu modellere uygulanacak dalgalar, Excel programı ile çizilmiş, dalgacık ile analiz edilmiştir.

Hasar Endeksi

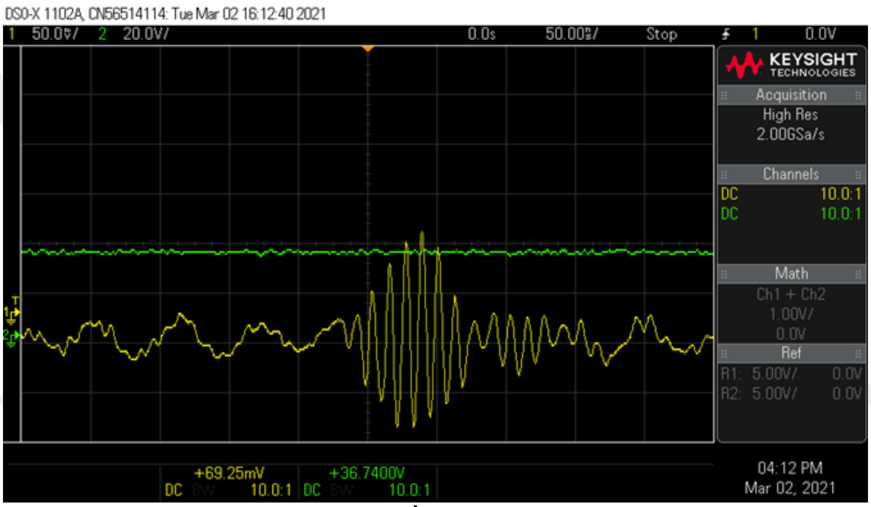
Dalga analizinin altı seviyede tamamlanmasından sonra, altı modelin tüm seviyeleri için hasar indeksi çıkarılmıştır. Dalgacık analizinde 6 seviye arasında, tüm modeller için uygun olduğu için 3. seviye seçilmiştir. Çatlama arttıkça hasar endeksinin de arttığı görülmektedir. Bu da çatlamanın tespiti ve varlığı hakkında önemli bir oluşum sağlamaktadır. Diğer seviyeler, dalga yayılımı yüksek genlik ve eğim arasında düzensiz olduğu için geçerli değildir. Bu nedenle dalgaların analizi karmaşık ve istikrarsız olmaktadır.



Şekil 3. Tüm Çatlak Modelleri İçin Hasar İndeksi (Üçüncü seviye).

Deneysel Sonuç (20 Mpa)

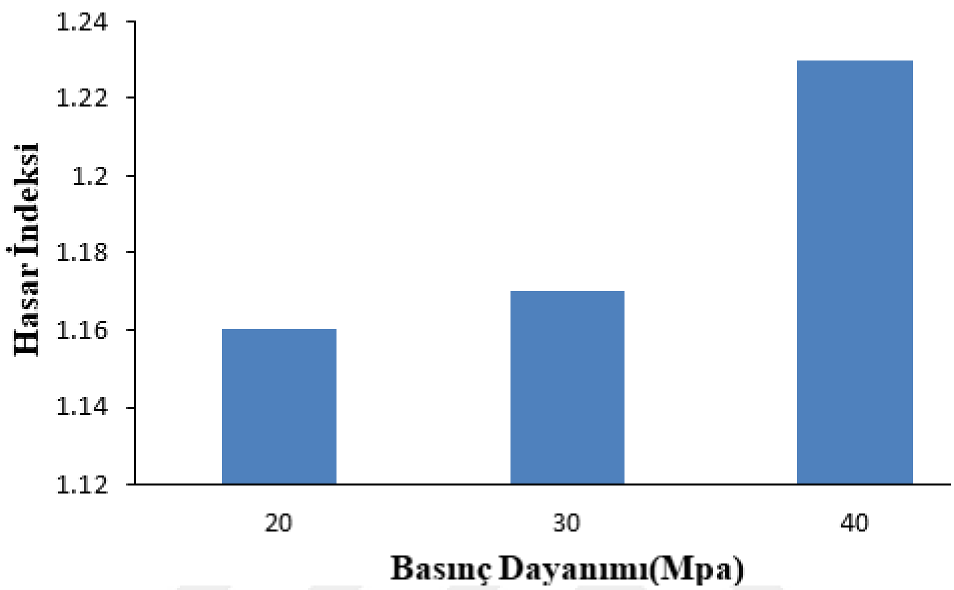
Bu dayanımı elde etmek için model (1:2.68:1.98 Mpa) buyutlarında ve su/çimeto: (0.5) oranında beton karışımına göre dökülmüştür. 20Mpa dayanıma sahip numune için osiloskopta elde edilen dalga Şekil 4'te verilmektedir. Bu dalga, model yüzeyinin yan tarafında üstte bulunan cihaz (fonksiyon üreteçleri) sensörleri aracılığıyla gönderilmiştir. Bu dalga modelin içine yerleştirilen yapay hasardan (2×5cm) modelin alt kısmında bulunan alıcı sensöre de yüzeyde geçer. Oluşan hasarların tespiti için bu model incelenerek elde edilen sonuçlar, iletilen dalganın karışım oranlarından etkilendiğini göstermiştir.



Şekil 4. 20Mpa Dayanıma Sahip Numune İçin Osiloskopta Elde Edilen Dalga

Hasar endeksi

Farklı dayanım elde etmek için üç model kullanılmıştır. Laboratuvarda hiçbir direnişin olmamasının istenenle aynı doğrultuda olmadığını belirtmekte fayda vardır. Örneğin, 20 Mpa dayanım durumunda, laboratuvar sonuçları simülasyon sonuçları kadar hassas olmadığı için, gerekli duyulan dirençten daha az veya daha fazla dirençle karşılaşılabilir. İçlerindeki yapay hasarı tespit etmek için üç modelin incelenmesi tamamladıktan ve sonuçlar MATLAB ile analiz edildikten sonra, sonuçların hassasiyetini artırmak için her modele ait dalga altı seviyede analiz edilmiştir. Dalganın altı seviyesi belirlenmesiyle, 2. seviyenin önemli sonuçlar vereseviyeler arasında en iyisi olduğu belirlenmiştir. Buna karşılık, basınç dayanımındaki artış, hasar indeksi de artış anlamına gelmekte ve bu da hasar olasılığını artırır ve hasarın erken tespitini sağlar. Hasar indeksi ile basınç dayanımı arasındaki ilişki Şekil 5'de verilmektedir.



Şekil 5. Laboratuvarda incelenen tüm modellerde 2. seviye için hasar indeksi ile basınç dayanımı arasındaki ilişki.

4. SONUÇ

1. Dalgacık analizi, çatlak tespitinin dalgacık seviyeleri boyunca değiştiğini göstermiştir. Altı seviye arasında üçüncüsü en iyi sonucu verdiği belirlenmiştir. Diğer seviyelerdeki sonuçlarının sapması, frekansın çatlak boyutu ile uyumluluğuna bağlanabilir.
2. Ayrışma hasarı için, seviye 2, diğer seviyelerden daha iyi bir performans göstermiştir. Çatlak tespiti için aynı neden, bu sonuçların ötesinde bir neden olabilir.
3. Boşluk hasarına ilişkin sonuçlarının diğer hasar türlerinden daha tutarlı olduğu görülmüştür. Her iki seviyedeki 1 ve 6 numaralı hasar endeksi (DI) sonuçları, hasar indeksi ile boşluk adetleri arasındaki ilişkinin eğilimini yansıtır.
4. Deneysel sonuçlar sayısal olanlara yakın sonuçlar göstermiştir. En iyi dalgacık seviyesi 2. seviye olarak bulunmuştur. Seviye 3'ün en iyisi olduğunu gösteren sayısal sonuçlarla karşılaştırılması durumunda, burada sayısal çalışmanın ideal ortamının, malzeme ile ilgili deneysel çalışmanın pratik durumuna kıyasla tip, hasar gösterimleri ve hatta dalga tespiti bile bu farklılığa katıldığını bahsetmekte fayda vardır. Bununla birlikte, seviye 2 ve 3, frekans seviyeleri nedeniyle hala birbirine yakındır.
5. Dalgacık analizine dayalı hasar endeksi, farklı hasar türlerini tespit etmede başarılı olduğunu kanıtlamıştır. Bu, çok çeşitli frekans seviyeleri sağlama zenginliğinden kaynaklanmaktadır.
6. Mevcut çalışma, inşaat mühendisliği yapılarının yapısal sağlık izlemesi alanına katkıda bulunacağı umulmaktadır.

CURRICULUM VITAE

He studied at the Northern Technical University- Technical Engineering Collage of Mosul and graduated BSc / Department of Building and Construction Technologies Engineeringin 2017. He started his MSc. Program of Civil Engineering in Institute of science of Van Yuzuncu Yil University in Van /Turkey, in February 2019.

T.C
VAN YÜZÜNCÜ YIL ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
LİSANSÜSTÜ TEZ ORİJİNALLİK RAPORU

Tarih: 05.06.2021

Tez Başlığı / Konusu:

DETECTION OF DAMAGES IN CFST COLUMN USING ULTRASONIC WAVES

Yukarıda başlığı/konusu belirlenen tez çalışmamın Kapak sayfası, Giriş, Ana bölümler ve Sonuç bölümlerinden oluşan toplam 58 sayfalık kısmına ilişkin, 05.06.2021 tarihinde şahsım/tez danışmanım tarafından TURNİTİN intihal tespit programından aşağıda belirtilen filtreleme uygulanarak alınmış olan orijinallik raporuna göre, tezimin benzerlik oranı % 8 (Sekiz) dır.

Uygulanan filtreler aşağıda verilmiştir:

- Kabul ve onay sayfası hariç,
- Teşekkür hariç,
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- Gereç ve yöntemler hariç,
- Kaynakça hariç,
- Alıntılar hariç,
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- 7 kelimeden daha az örtüşme içeren metin kısımları hariç (Limit inatch size to 7 words)

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