STUDY OF BLENDED CONCRETE UNDER IMPACT LOAD

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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OF
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Submitted by:

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CANDIDATE'S DECLARATION

I, Janhavi Singh, Roll No. 2K20/STE/09 student of M.Tech. (Structural Engineering), hereby declare that the project dissertation titled "**STUDY OF BLENDED CONCRETE UNDER IMPACT LOAD**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship or other similar title or recognition.

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CERTIFICATE

I, hereby certificate that the Project titled "**STUDY OF BLENDED CONCRETE UNDER IMPACT LOAD**" which is submitted by Janhavi Singh, Roll No. 2K/20/STE/09, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this university or elsewhere.

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ABSTRACT

The issue of the use of Supplementary Cementitious Materials or SCMs used as a partial replacement of cement in the concrete is gaining importance nowadays. Such materials not only reduce the consumption of cement but also improve the properties of concrete. Further, SCMs like Flyash, Ground Granualated Blast Slag, Rice Husk ash etc are the byproducts from the industries. This solves the disposal problem and proves to be a positive impact on environment.

The present study aims at studying the effect of Impact load on the Blended Concrete Cubes. Cement in the M30 grade concrete is replaced, by 15% Flyash and 50% Blast slag. The 3 Blends of concrete thus prepared have been subjected to Impact load.

Impact loads are sudden load which act on the civil engineering structures with a very small time of contact. Significantly high energy is transferred by the impactor in a very small amount of time. This increases the severity of damage caused. Instances of such Impact loads include falling of objects from heights, falling of one building over another during the earthquake, impact caused by waves on bridge piers etc.

The effect of the impact load has been studied with the help of EMI technique. EMI technique is a novel technique utilizing the admittance signature obtained from new age active sensors – peizosensors, to quantify the damage caused in the different composition of the concrete on varying the number of impacts and height of impact.

FE model of the 3 blended concrete cubes is made on the ANSYS software. A spherical impactor of 5kg weight is modelled to be dropped from 2.5m and 3m height. FE Analysis is done to find the equivalent (von mises) stress , equivalent (von mises) strain and normal strain generated in the three models of cube.

Flyash due to its better binding properties with the cement is found to give a better performance under impact than the M30 and Blast slag cube.

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CHAPTER 1

INTRODUCTION

1.1 CEMENT PRODUCTION

Year by year large amounts of cement and concrete is produced all over the world. With increasing population and increasing efficiency of human capital, is increasing the need to build infrastructures basis. The backbone of the industrialization and urbanization is concrete production. From 2004-2014 there was a 90% increase of production of cement was observed globally [1].

However, the cost of the geometric increment of the human capital resulting in rapid urbanization and industrialization is high carbon dioxide production. Cement clinker production is non neutral for environment. Around 600-700 kg of carbon dioxide is produced for each tonne of cement produced [2].

1.2 SECONDARY CEMENTITIOUS MATERIAL AND BLENDED CONCRETE

Concrete is a heterogeneous mixture of aggregates, water, cement and admixtures mixed in right proportion to obtain workability in fresh state and optimum compressive strength in the hardened state. Cement used in the concrete can be partially with Supplementary cementitious materials. This can also be a medium to reduce the cement production. SCM contains alumino-silicate, silica or silicates, which is responsible for its binding properties. Silica Fume, GGBS, flyash, metakaoline etc [3] are some eco friendly examples as shown in the Figure1.1.

1.3 IMPACT LOAD

A force appearing on a body suddenly and acting for a very small amount of time is called impact load. The momentum transfer takes place instantly and the energy is transferred to the subject in that instance. Such force due to the sudden transfer of the energy, can cause severe damage to the structures. In civil engineering instances of such forces is seen in case of earthquakes when a building drops on another building as shown in figure 2 , impact caused by high speed vehicles on columns [4], object free fall from a height [5], water impact on hydraulic structures or bridge piers [6,7]

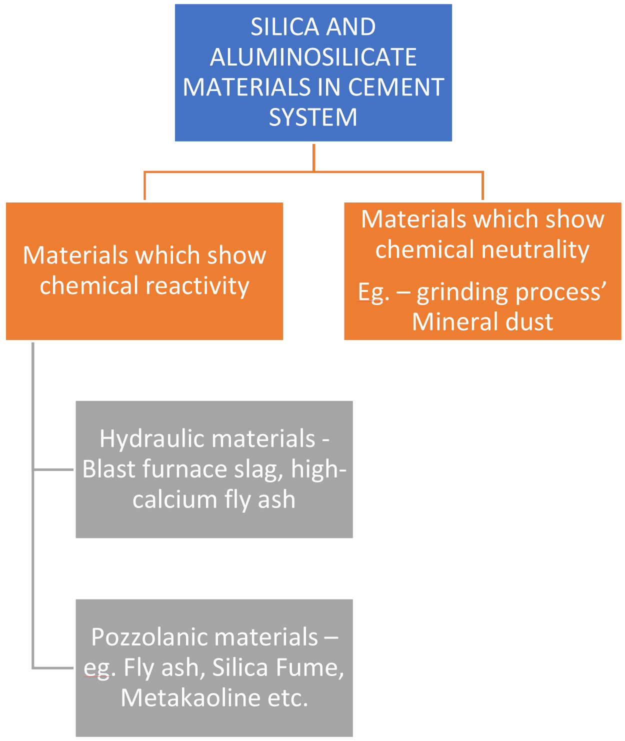

Figure1.1 Examples of SCM used in concrete

Figure 1.2 Impact caused by tall building during earthquake

1.4 ANALYSIS OF BLENDED CONCRETE UNDER IMPACT LOAD

Understanding the importance of the blended concrete, it becomes important to conduct more research in the area of the use of such concrete being acted under different types of load conditions. Impact load being one of the most sensitive and severe damage causing force in the field of civil engineering is considered for the study of blended concrete in this project.

EMI technique used for analysis the admittance signatures acquired via peizosensors, is one of the most powerful technique of damage detection. The data acquired by the peizosensor is in real time, recording the admittance signatures just before and just after the impact of a ball falling from a height on the Blended concrete cubes. The signatures thus obtained can be compared to understand the damage caused by the impact. Further Voltage recorded during the impact using oscilloscope can be used to find the strain generated during the impact.

FEM analysis arised from the need to solve the problem of the deformation the structural elements and non structural elemnts go after being acted upon by different types of forces. ANSYS is used to model geometry of a Ball falling from a height on the Blended concrete cube. FEM analysis gives a clear picture of stress distribution, strain distribution, stability and deformation [8]

1.5 OBJECTIVES

The objectives of the project are as mentioned below

1. To experimentally analyse the damage caused to the Blended concrete under impact using Peizosensors.
2. To find the performance of the Blended concrete cubes with each repeated impacts and compare the performance of concrete made with partial replacement of Flyash and Blast slag under impact.
3. Perform FE analysis of the Blended concrete cubes under spherical impactor in ANSYS and compare the results with the experimental observations.

1.6 ORGANISATION OF DISSERTATION

The present dissertation has been divided into 5 chapters

Chapter 1 – Introduction – discusses the general concepts, definitions and significance of the present study in the contemporary times.

Chapter 2 – Literature Review – reviews the understanding developed by the author while reading the works of other researchers in the same area. It discusses the recent advancement, methodologies and observations made by other authors. This forms the basis of the knowledge to carry out the following study.

Chapter 3 – Methodology – This chapter discusses the step by step methodology adopted to study the blended concrete under impact load. It gives a detailed discussion of the in situ experiments performed and the details of analysis made in ANSYS.

Chapter 4 – Results and discussions – This chapter deals with the observations made by the researcher after performing the methodology step by step. Further the discussion is made for every observation made after conducting the procedure.

Chapter 5 – Conclusion- deals with the final summary and the conclusions drawn by the author after conducting the study

1.7 SUMMARY

This chapter has dealt with the general concepts and the significance of the project. Objectives and layout of the dissertation have also been given.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter begins with discussing the importance of the use of SCMs in the Concrete industry today. It further discusses the use of Peizosensors in getting the admittance signatures which can be used in the SHM. It then discusses the limitations of the existing Global and Local SHM techniques and thus the efficiency of the use of the smart materials in SHM. EMI technique, one of the most reliable techniques used to process the signals obtained from PZT is then discussed. Further some applications of EMI technique are discussed.

2.2 LITERATURE REVIEW

Britannica et. al (2016) a lot of efforts are made in present times to conserve the environment with a special emphasis being laid on waste reduction. Solving the disposal problem of industrial waste is the need of the hour. The industrial waste obtained can be reused and recycled. The best use of the industrial waste containing the pozzolonaic material can be made in the construction industry. The material containing pozzolona, thus exhibiting the binding properties can be used to partially reduce the consumption of cement in the concrete. SCM or pozzolonaic material was first discovered in a place near Naples - called Pozzuli. This has formed the origin of the name.

Farrar et. al. (1998) reported that in case of less severe damage, Global SHM techniques failed to identify the location of damage. It is not always the severity of damage that is in question. It is possible that the damage, though not very severe in nature, is at a critical location. Local damages are not accounted for in the change of the structural global properties in the Global SHM techniques. . Stress waves of long wavelength with low frequency modes, often cross the local crack without sensing.

Boller et. al. (2002)explains the limitations associated with the use of local SHM methods. Equipment has to be moved to the test structure for data recording. This prevents the autonomous application and also restricts the application on a finished structure. This may also result in removal of false ceiling cover or finishes. Further transporting the probe at specific locations in the structure is impractical. So this technique is applied at the selected location.

Locations can be identified by visual inspection or experience of failure in the past. It is tedious to apply such mechanisms in structures that are already in use such as in flight aircraft. Other techniques like x-ray and computer tomography require very high cost equipment. Although they are highly efficient in performance, due to bulkiness and cost, the application is limited.

Park et. al. (2003) The peizosensors are used to non destructively inspect the health of a structure. It has both converse and direct effect. Two most widely used techniques of such detection of damage are- EMI technique and Lamb wave technique. In recent time, such capabilities of these techniques have been utilised to form SHM devices which imbibe the technology to detect damage using both the techniques simultaneously.

Rogers et. al. (1988) In a workshop organised by the research office of US Army and to solve the controversy of the universal definition of smart structure in the 1980s, the topic of the smart structures was pondered over. It was concluded in consensus that the 4 features namely, control mechanism, timely response, sensor and actuators are the qualifying parameters for a system to be called smart.

Fairweather et. al. (1998) attempted to give a definition of active smart materials. Such materials are ones which can convert their material properties in accordance with the external application of stimuli. The stimulus can be generated by thermal stress, mechanical stress, electric field or magnetic field. Examples of such active sensors include- SMAs, ER fluid, Piezoelectric materials and magneto-strictive materials. Such materials can act as actuators and force transducers.

Sirohi et. al. (2000) Creation of electric dipoles is a unique property of piezoelectric material. dipoles are created when the material is subjected to mechanical stress and when the material to experience is electric fields mechanical the formation occurs in the material. commercially such materials are available as Polymers for ceramics. lead zirconate titanate oxide is most commonly used as PZT. having high rigidity, low tensile strength, being low cost, lightweight, high elastic modulus and brittleness are some of the features of such material. it also shows quick response, good energy conversion and stability of long term.

Sirohi et. al. (2000) Traditional use of piezoelectric material is as sensors, accelerometers, pressure transducers or distributed vibration sensors.

Shanker et. al. (2011) EMI technique using the graphs obtained from the PZT patches can be utilized for non destructive SHM. The real time data from the existing structures is extracted using sensitive Technologies which further process is using appropriate software systems. Data thus acquired can be used for SHM. A lot of global and local SHM techniques have been reported in Literature in the past. EMI is the interface between the two. It has both the features-vibrations utilized, as in global SHM technique and real time ultrasonic data used as in local SHM technique.

Bhalla et. al. (2012) Proposed on novel model that uses admittance signature obtained from surface bonded pzt to determine the in-situ stiffness of joint. Such a method is used to find the life of bolted Steel joints. The equivalent stiffness is obtained from the data obtained from the pzt transducer. Equivalent system parameters are identified from the signature obtained. The empirical equation is derived and is used to assess the fatigue life on the basis of loss of equivalent stiffness. The method proposed here is used for the Residual life of the bolted joint in situ.

Bhalla et. al. (2005) made a comprehensive review of use of the the sensor Technologies available till that time. He also mentioned the conditions encountered during the detailed monitoring.

Lim et. al. (2006) Suggested a method to identify damage in a concrete cube , a Beam or a Truss using admittance signatures. The admittance signatures are converted in terms of structural parameters. The equivalent structural parameters does obtained are used for characterization of damage

Hey et. al. (2006) Proposed a novel sensor algorithm which utilised multiplexing of sensor technique which is reduced the the interrogation time of of pzt patch. he further highlighted the the issues encountered while using the EMI technique practically.

Yang et. al. (2008) used ANSYS8.1 to simulate the the pzt structure interaction at a high frequency (almost 1000kHz). he was established that FEM is the possibility to be used as an alternative to experimentation while using a EMI technique

Rickli et. al. (2008) Made a combination of PZT sensor and MSPC or multivariate statistical process control which is used to find the integrity of structure. This resulted in cost reduction of of downtime caused by production which occurred due to quality failures. this also reduced false alarms and established highly efficient identification mechanism using sensor.

Shanker et. al. (2010) Established that the same set of pzt patch can be used for or application as a local EMI and global SHM technique. He conducted experiment on a two storey RC frame using embedded pzt patch to establish that search embedded sensor can be used for both local EMI and global EMI technique. Quick identification of damage data was observed and damages of moderate and severe nature were identified using Global EMI technique. Both the techniques complemented each other well.

Neto et. al. (2011) Has put forward a novel SHM model which can be used to monitor an array of PZT patches.This system will not use digital computers for processing the Fourier algorithms. Not utilising complex computer architecture, this method is simple and low cost. The signals obtained from this system are not only very much similar to that obtained from electrical impedance analysers, but to a much extent better for the industrial application. This method can monitor any size, kind and complexity of a structure.

Yan et. al. (2011) worked on a cracked functionally graded beam and made an analytical model for it. The imperfection in the bonding between the beam and the PZT patch was accounted for by considering the dynamic behaviour of the PZT patch and taking in consideration the viscoelastic law.

Song et. al. (2008) conducted experiments on RC specimens under impact load. PZT sensing mechanism was used to monitor. Modally tuned hammer was used to simulate the loads. The peak voltage associated were then compared. The voltage was found to be in linear variance with load amplitude. It was established that the PZT patches are suitable for impact measurement.

Yuan et. al. (2011) developed a novel model to monitor the impact due to debris, bird etc on aircraft using PZT. This model was based on an online SHM approach.

Annamdas et. al. (2019) used the EMI technique to monitor the soil excavation in Singapore. The study concluded establishing the use of PZT for practical use can be groomed well.

Quinn et. al. (2012) concluded that the health of the concrete under curing can be monitored using wireless sensing systems that can be embedded. This however showed that the embedded sensors are sensitive to formwork removal.

2.3 RESEARCH GAP

Various global and Local SHM techniques are found to have their own set of limitations by many researchers. EMI technique using the admittance signature obtained by peizosensors, is found to have overcome the limitations of both. The sensors can provide the in situ real time damage quantification data. Application of peizosensors have been done in the field of aircraft health monitoring, SHM of bolted joints, SHM of the RC structures etc. Work has also been done in the field of impact load analysis of RC structures using EMI technique. The following literature gap has been identified-

1. Not many Impact load analysis have been done on different plain and RC structural and non- structural elements , using EMI technique.
2. It is found that not much work is done in the field of SHM of Blended concrete.

2.4 SUMMARY

This chapter has illustrated limitations of global and local SHM techniques as discussed by researchers. Further, it discusses the role of EMI technique and damage data acquisition by next generation active sensors in overcoming these shortcomings. The applications of EMI techniques on various civil and mechanical engineering areas have been discussed in brief, including the application of the EMI technique in Impact load analysis.

An effort has then been made to outline the research gap identified after rigorous review of works of previous researchers.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The following chapter discusses the detailed procedure of the tests performed on the bended concrete cubes specimens under impact load to study their behavior under impact. Experiments were performed and then FEM analysis was done in ANSYS. The results thus obtained help us see a clear picture of the damage behavior and resistance of the blended concrete cubes under impact.

3.2 COMPOSITION OF BLENDED CONCRETE CUBES

Mix design of the concrete was done to obtain a target strength 30MPa. For making the blended concrete, the binder cement in the M30 concrete was partially replaced by 15 % using Fly ash and 50% using Blast Slag. Optimum strength properties appear when the replacement with Fly ash is 15% [31] and that with Blast slag is 50% [32].

Thus following mix as shown in Table 1 was obtained for the 1 cum of the three blends of concrete namely M30, F15 and B50

Table 3.1. Composition of the Blended Concrete

Name of the Blend	**Cement (kg)**	**Name and percentage of the SCM used**	**SCM (kg)**	**Coarse aggregate (kg)**	**Fine aggregate (kg)**	**Water (kg)**
M30	450	Nil	0	1221.741	591.072	186
F15	382.5	15% Fly Ash	67.5	1221.741	591.072	186
B50	225	50% Blast Slag	225	1221.741	591.072	186

3.3 CASTING BLENDED CONCRETE CUBES WITH SENSORS

In the investigative study conducted, the three blends of concrete as discussed above were casted in moulds of 150 x 150 x150 mm in size. The components of the concrete were mixed in the calculated proportion in the concrete mixer. The fresh concrete mix thus prepared was put in moulds to the 2/3rd of its capacity. After vibrating the mix on the vibration table, the cube was half filled with compacted concrete. Peizo sensor embedded in epoxy araldite was put in the center of the half filled and compacted cubes and then the rest of the cube was filled in layers and compacted (as shown in Figure 3.1 and Figure 3.2) The concrete was compacted carefully using a table vibrator, the specimens were demoulded after 24 hours of casting(as shown in figure 3.3)

Figure 3.1 PZT- placed in centre of the cube

Figure 3.2. Mould filled with concrete

3.4 USE OF EMI TECHNIQUE

3.4.1 Electrical Impedance

Electrical impedance stands for the electrical circuits where real part of impedance is Resistance R and imaginary part is the reactance X

$Z = R + Xj$

Electrical admittance measures the ease with which the current can pass through the device or circuit. It is the inverse of Impedance.

$Y = 1 = G + Bj\ Z$

G stands for conductance and *B* is suseptance.

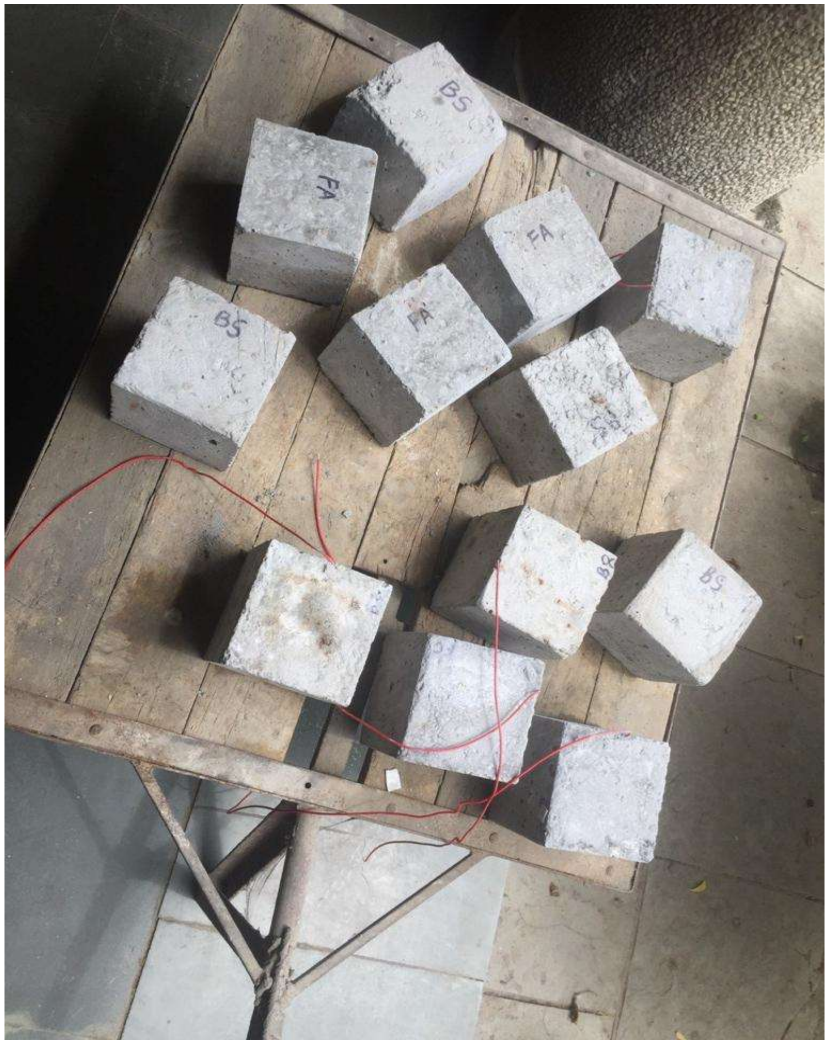

Figure 3.3. Concrete cubes with PZT embedded demoulded after 24 hr

3.4.2 Mechanical Impedance

The mechanical impedance of a structure is an analogy to the electrical impedance. It is the ratio of the driving harmonic force versus resulting harmonic force at a certain point.

A healthy structure may be sought to represent a MDOF system comprising of different mechanical elements.(ie spring, mass and damper)

3.4.3 Damage Detection

These elements could be combined using superimposition theorems. This would result in a single impedance equation. This equation describes the input (ie. Force) and output (ie.velocity) of the structure.

This equation shows the structural response of system wrt frequency. This equation represents the healthy mechanical impedance of system. If the system is cracked by the impact, the effect would be seen on the composition of the mechanical impedance. The damage is seen as the components of the equation show deviation from the original equation.

3.4.4 Obtaining the Admittance signature using LCR meter

The alternating voltage signal of 1 volts rms is imposed by the LCR meter via embedded PZT. Frequency range is specified as 600 kHz. The phase and the magnitude of the steady state current is recorded in the form of admittance signature ie conductance vs frequency and susceptance vs frequency, via LCR meter as shown in the figure 7, for all the three Blends of concrete namely M30, F15 and B50

Electro mechanical admittance signature which comprises of the conductance - G - the real part and susceptance - B - the imaginary part is acquired for the frequency range of 600 kHz.

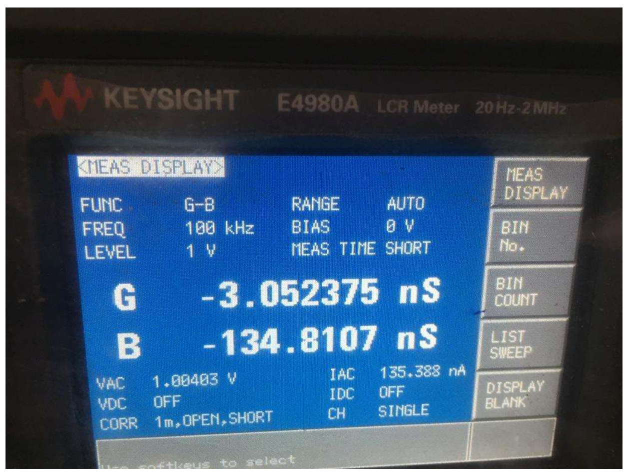

Figure 3.4. Signature as obtained from the LCR meter

3.4.5 PZT Patch details

Commercially circular, rectangular and square PZT patches of different dimensions are available. Figure 3.5 shows a typical commercially available PZT patch used in our research (Courtesy PI Ceramics, 2012).

Both the electrodes are present on one side of the patch. While other side is left for the patch to be attached to the host. Both the electrode is wrapped around the thickness from the bottom edge.

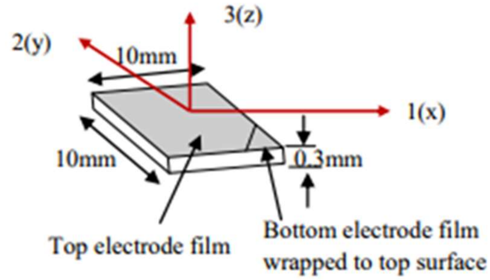

Figure 3.5 Details of a Typical PZT patch
(Courtesy PI Ceramics, 2012)

3.5 EXPERIMENTAL SET UP

Activation of d33 mode is ensured during impact test. The orientation of the sensor is made in such a way that the impact line is parallel to the thickness of the sensor. Strain is introduced along the thickness of the patch. Three blends of cubes were cast with embedded sensors.

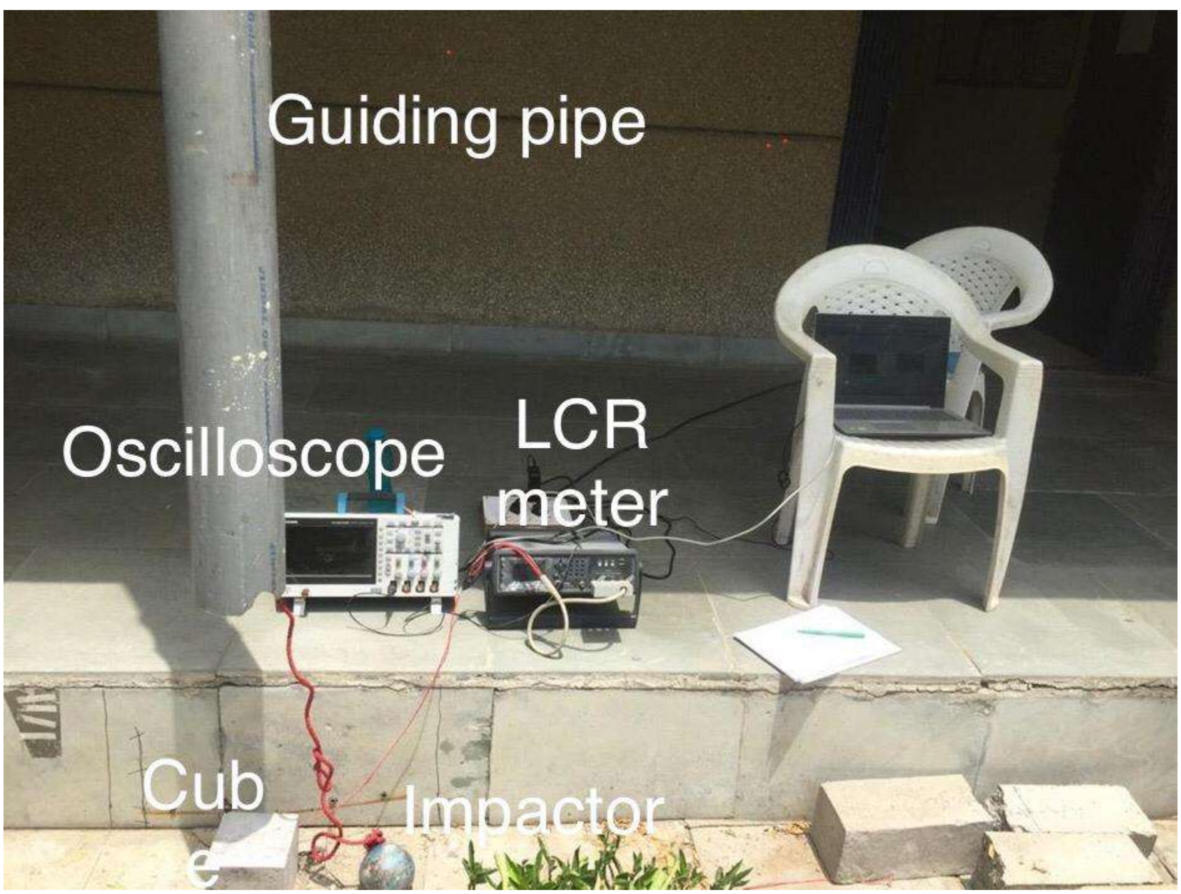

Figure 3.6. Experimental set up for impact test

A free falling ball of 5kg from the height of 2.5 m and 3m makes impact on the test cubes laced horizontally on the ground. The ball is guided by a PVC pipe of internal diameter 150mm (equal to the side length of the cube), as shown in Figure 9.

The PVC pipe is mounted on the walls using clamps, the top of the ie is open for the ball to be dropped from. The ball aided by the tube, is guided to fall exactly at the centre of the cube. The pipe are prevents safety from the swaying of the ball t the time of lifting and dropping. The swinging of ball otherwise would have caused serious injuries. The base or the ground where the cube is placed is made of rigid concrete. This provides the cube rigidity against the dropping ball.

The time histories of the impact load are very minute. The loading has its distinctive features as highly evasive in nature. So, digital oscilloscope was used to obtain data at the time of the impact. The oscilloscope is capable of recording data for a time period as small as1 micro second.

Voltage generated in the PZT patch at the time of impact episode was recorded by the oscilloscope. The strain generated in the cube at the center is a direct function of the Voltage captured by the oscilloscope.

Specimen was inspected for any visible surface cracks after each impact. LCR meter captured admittance signatures ie conductance vs frequency and suseptance vs frequency graphs after every impact.

3.8 PLACEMENT OF PZT PATCHES

In the EMI technique, the actuation and sensing zone is localized. Esteban (1996) [33] estimated that the sensing zone is closely related to the host materials and density and is about 0.6m in concrete For the purpose of our study we have used embedded piezo sensors placed at the centre of the concrete cube, during the casting.

The mix design prepared was poured in the mould and vibrations from the vibrating table were rendered till the mould was half filled. Peizosensor packed in epoxy was then gently put in the center of the half filled mould and rest of the concrete was filled on the sides. Vibrations were made to make the sensor fit and be fixed in the centre position firmly. Then the cubes was completely filled with concrete and the vibrating table was switched on.

3.9 ACQUISITION OF SIGNATURE USING LCR METER

The PZT patch is normally excited by the LCR meter with an alternating voltage signal of 1 volt r.m.s. (root mean square) over the user specified frequency range. Here this range is taken as 600 kHz.

Both Open and short measurement corrections are made for the LCR meter before the use. Then the settings of the LCR meter are changed to obtain the function G-B and the measurement time is set to “short time”. After these initial settings readings were taken.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

The blended concrete cubes thus casted are tested under impact by peizosensors and patterns of the Peak developed in the admittance signature are analysed, to quantify the damage caused. Further FEM analysis is done to obtain the Stress developed and strain developed due to impact on the cubes.

4.2 ADMITTANCE SIGNATURE FOR THE 3 BLENDS OF CONCRETE

The LCR meter via the peizosensor, measures the value of conductance and susceptance for varying frequency. The conductance (G) vs frequency (f) and the susceptance (B) vs frequency (f) graphs are thus obtained for the 3 blends of concrete, are as shown in the Figure 4.1- Figure 4.12

4.2.1 ADMITTANCE SIGNATURE FOR M30

The conductance (G) vs frequency (f) and the susceptance (B) vs frequency (f) graphs are thus obtained for M30, are as shown in the Figure 4.1- Figure 4.4

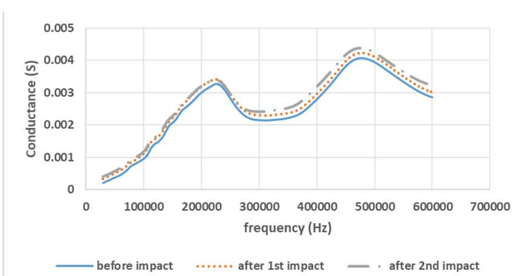

Figure 4.1. G vs f for M30 under 3m impact

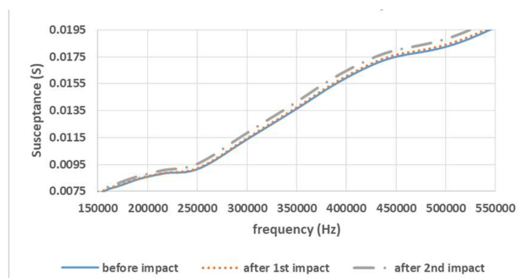

Figure 4.2. B vs f for M30 under 3m impact

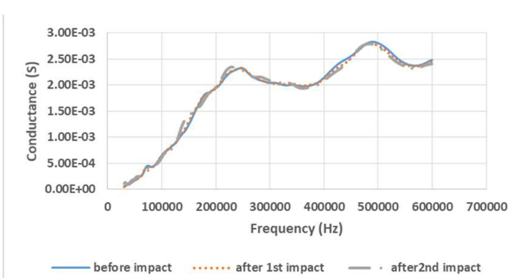

Figure 4.3.G vs f for M30 under 2.5m impact

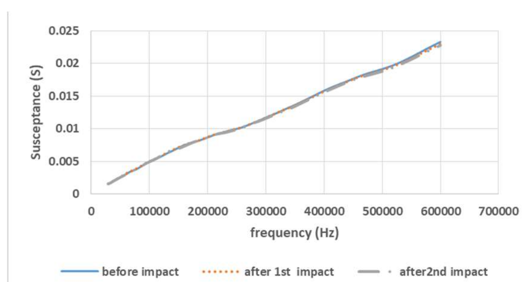

Figure 4.4. B vs f for M30 under 2.5m impact

1. Two peaks are obtained in the conductance vs frequency graph, before impact and after each impact which suggests that the readings taken are correct.
2. Admittance signature varies for different specimens. These signatures are dependent on different factors like host surface, temperature, casting condition, placement of PZT, bonding of the patch etc. It can be observed that the grapg change after every impact. This suggests that the mechanichal impedance changes after every impact. Impact on the specimen results in change of mass, stiffness and damping of the cube. The change in these properties causes the conductance in the cube to change.
3. The peaks of the conductance signature are observed to increase with each impact. So it can be concluded that after every impact the damage is increasing.
4. Susceptance vs frequency curves are found to be consistent throughout the testing. This indicates that PZT patch is intact [25].
5. The peak is observed to increase by 55.55% with increasing height of impact from 2.5m to 3m.

4.2.2 ADMITTANCE SIGNATURE FOR F15

The conductance (G) vs frequency (f) and the susceptance (B) vs frequency (f) graphs are thus obtained for F15 are as shown in the Figure 4.5- Figure 4.8

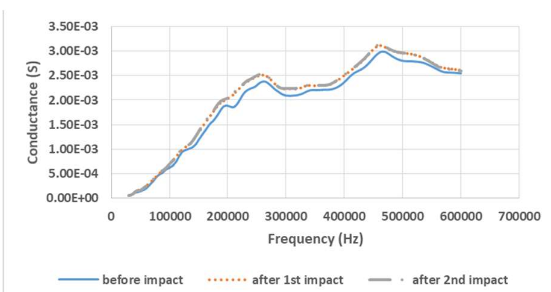

Figure 4.5. G vs f for F15 under 3m impact

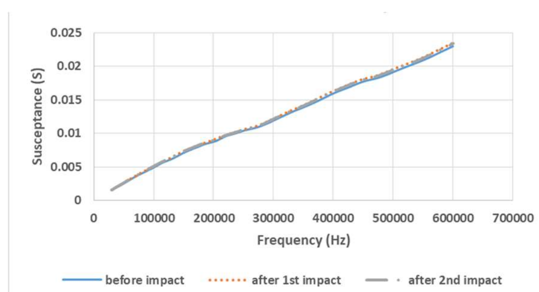

Figure 4.6. B vs f for F15 under 3m impact

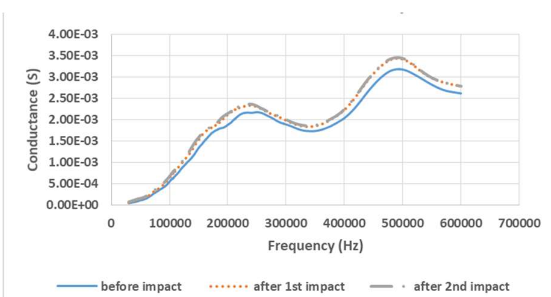

Figure 4.7. G vs f for F15 under 2.5m impact

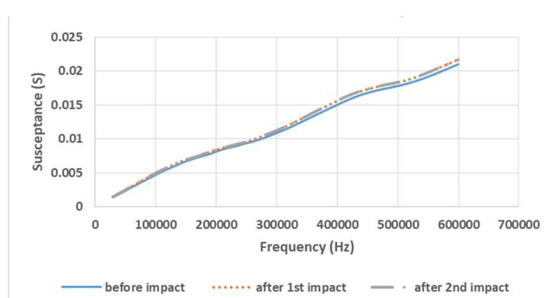

Figure 4.8. B vs f for F15 under 2.5m impact

1. Two peaks are obtained in the conductance vs frequency graph, before impact and after each impact which suggests that the readings taken are correct.

2. Admittance signature varies for different specimens. These signatures are dependent on different factors like host surface, temperature, casting condition, placement of PZT, bonding of the patch etc. It can be observed that the grapg change after every impact. This suggests that the mechanichal impedance changes after every impact. Impact on the specimen results in change of mass, stiffness and damping of the cube. The change in these properties causes the conductance in the cube to change.
3. The peaks of the conductance signature are observed to increase with each impact. So it can be concluded that after every impact the damage is increasing.
4. Susceptance vs frequency curves are found to be consistent throughout the testing. This indicates that PZT patch is intact [25].
5. The peak is observed to increase by 11.12% with increasing height of impact from 2.5m to 3m.

4.2.2 ADMITTANCE SIGNATURE FOR B50

The conductance (G) vs frequency (f) and the susceptance (B) vs frequency (f) graphs are thus obtained for B50 are as shown in the Figure 4.9- Figure 4.12

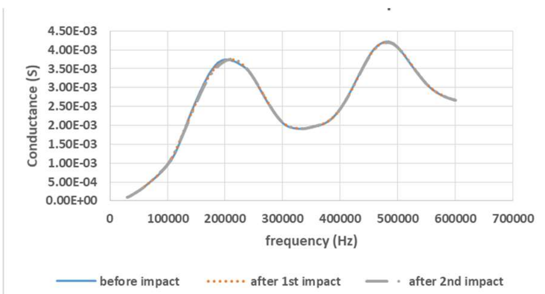

Figure 4.9 G vs f for B50 under 3m impact

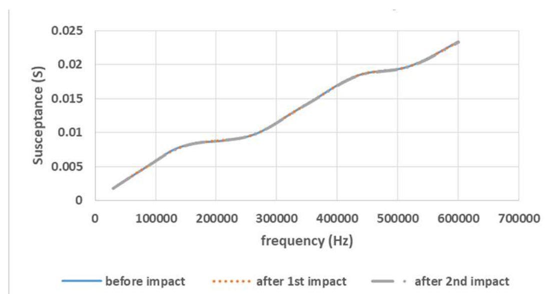

Figure 4.10 B vs f for B50 under 3m impact

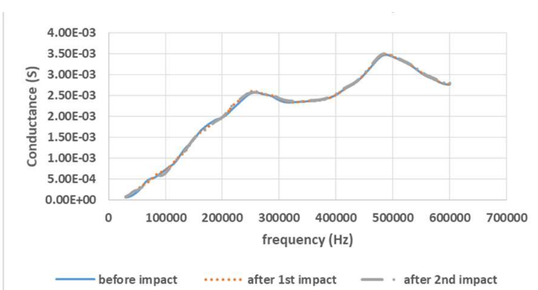

Figure 4.11 G vs f for B50 under 2.5m impact

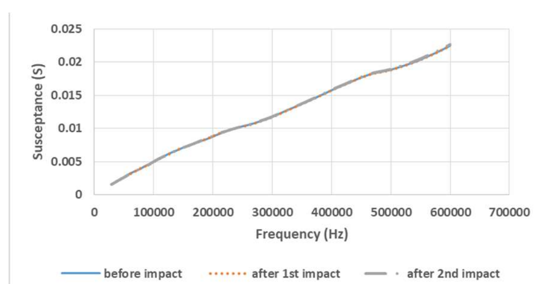

Figure 4.12 B vs f for B50 under 2.5m impact

1. Two peaks are obtained in the conductance vs frequency graph, before impact and after each impact which suggests that the readings taken are correct.
2. Admittance signature varies for different specimens. These signatures are dependent on different factors like host surface, temperature, casting condition, placement of PZT,

bonding of the patch etc. It can be observed that the grapg change after every impact. This suggests that the mechanichal impedance changes after every impact. Impact on the specimen results in change of mass, stiffness and damping of the cube. The change in these properties causes the conductance in the cube to change.

3. The peaks of the conductance signature are observed to increase with each impact. So it can be concluded that after every impact the damage is increasing.
4. Susceptance vs frequency curves are found to be consistent throughout the testing. This indicates that PZT patch is intact [25].
5. The peak is observed to increase by 50% with increasing height of impact from 2.5m to 3m.

4.3 RESIDUAL STRENGTH AFTER IMPACT AS MEASURED FROM CTM

After the impactor was dropped on the concrete cube from the height of 2.5m and 3m respectively, minor cracks appeared on the cube. This sample with only 1st impact was then put in CTM. Residual strength was then found using CTM. Results are shown in Table 4.1

Table 4.1. Strength in the concrete cube as obtained from the Compressive testing machine

Name of the Blend	**M30**		**F15**		**B50**	
Height of impact	2.5m	3m	2.5m	3m	2.5m	3m
Ultimate Compressive Strength before 1st impact (MPa)	32	32	39	39	38	38
Ultimate compressive strength after 1st impact (MPa)	13.2	14.8	19	17.6	10.2	12.7

1. Residual Strength in the concrete was observed to be more in cubes subjected to low impact height than those subjected to high impact heights.
2. Residual strength was observed to be more in FA15 > M30 > B50

4.4 ROOT MEAN SQUARE DEVIATION (RMSD)

RMSD is a computational techniques which can be used for the comparison of two signatures, one of which is the baseline signature of the healthy structure and the other one is the signature after an unknown damage.

The RMSD index is defined by Giurgiutiu et al., 1998 [34] as

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

where x and y (i = 1,2,3. . .N) are the digital admittance signatures obtained from the PZT bonded to the structure before and after the damage is incurred, respectively. The results obtained are reported in the Table 3

Table 4.2. RMSD after 1st impact

Name of the Blend	**M30**		**F15**		**B50**	
Height of impact	2.5m	3m	2.5m	3m	2.5m	3m
RMSD after 1st impact	6.5	1.39	8.2	6.1	0.679	1.25

With increasing height of impact the RMSD value is decreasing in case of M30 and F15. While it is decreasing in case of B50. Hence, it does not provide damage related information regarding the impact severity consistently. This is not unexpected since RMSD is only a statistical quantifier. It was also reported in the literature that the raw conductance signatures as well as the RMSD index are not very dependable as they only provide a qualitative information about the damage Bhalla et al [35]. To gain further insight into the phenomenon, the impedance spectrum is studied closely.

1. The variation of the RMSD index can be studied in light of the degradation of actual stiffness of the specimen with the increase in damage due to impact energy.
2. Among the 3 blends, after first impact, RMSD value is highest for F15 and lowest for B50. So, it can be stated that the stiffness parameter is highest for F15 blend and Lowest for B50 Blend

4.5 COMPARISION OF THE ADMITTANCE SIGNATURE PEAKS WITH VARYING HEIGHTS OF IMPACT FOR DIFFERENT BLENDS OF CONCRETE

The Conductance vs frequency graphs as shown in Figure 4.13 to 4.22 were studied closely and the shift in the peaks were analysed to understand the qualitative degree of damage caused in each blend of concrete. Table 4.3 shows peak conductance value from the signatures obtained

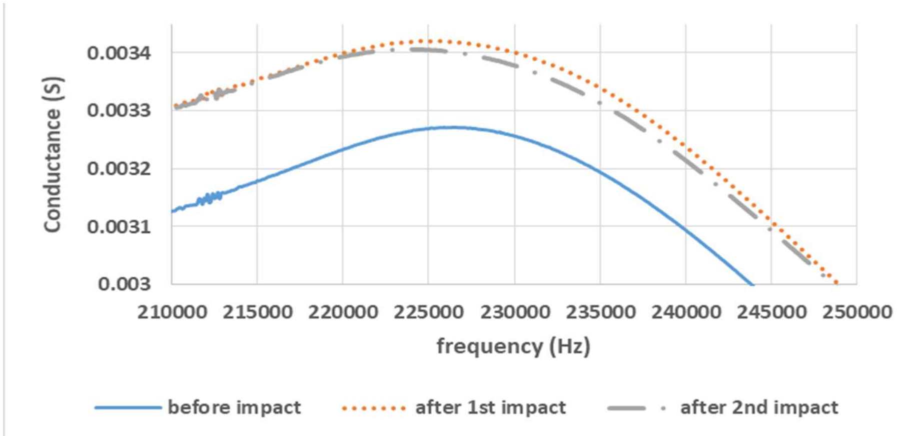

Figure 4.13 G vs f for M30 under 3m of impact

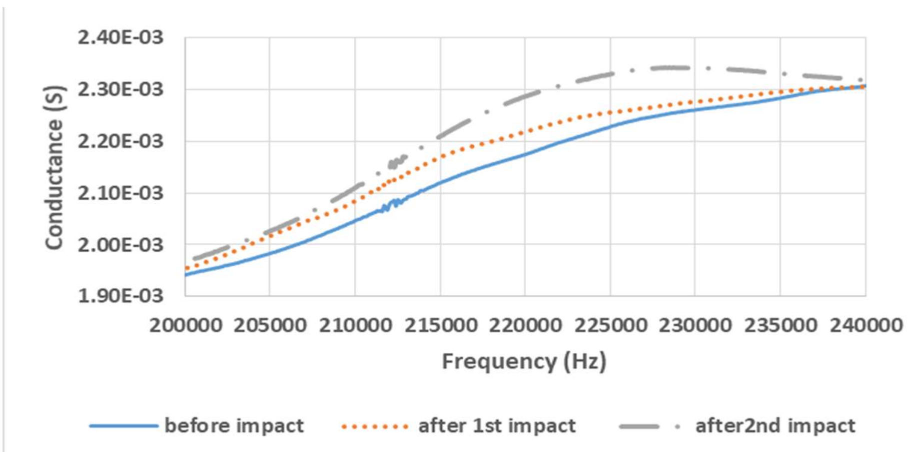

Figure 4.14 G vs f for M30 under 2.5m of impact

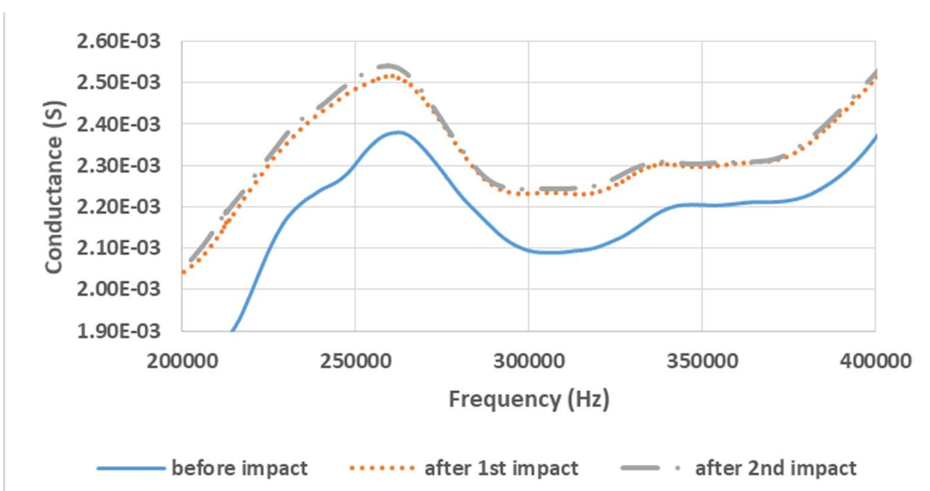

Figure 4.15 G vs f for F15 under 3m of impact

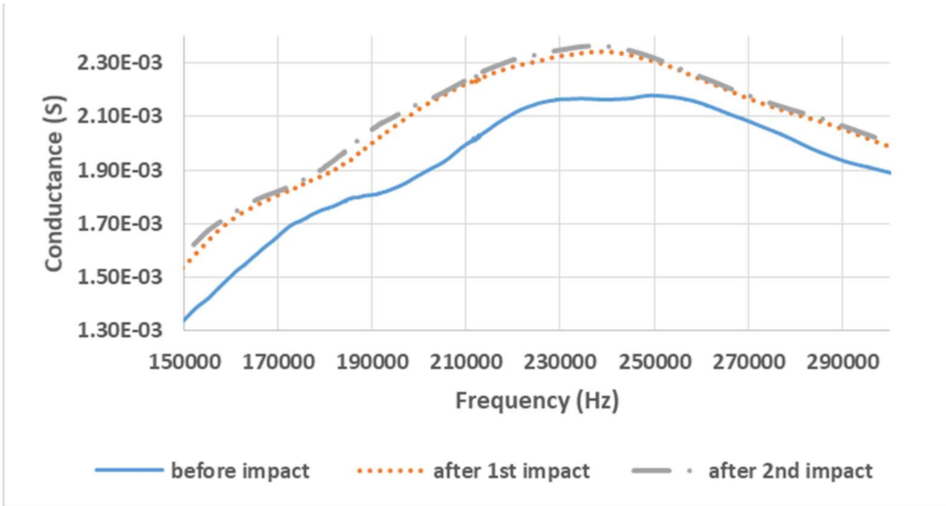

Figure 4.16 G vs f for F15 under 2.5m of impact

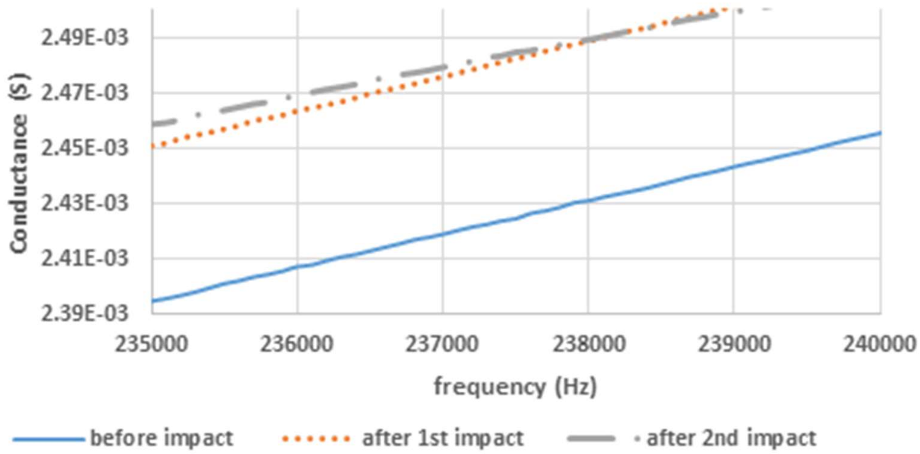

Figure 4.17 G vs f for B50 under 2.5m of impact

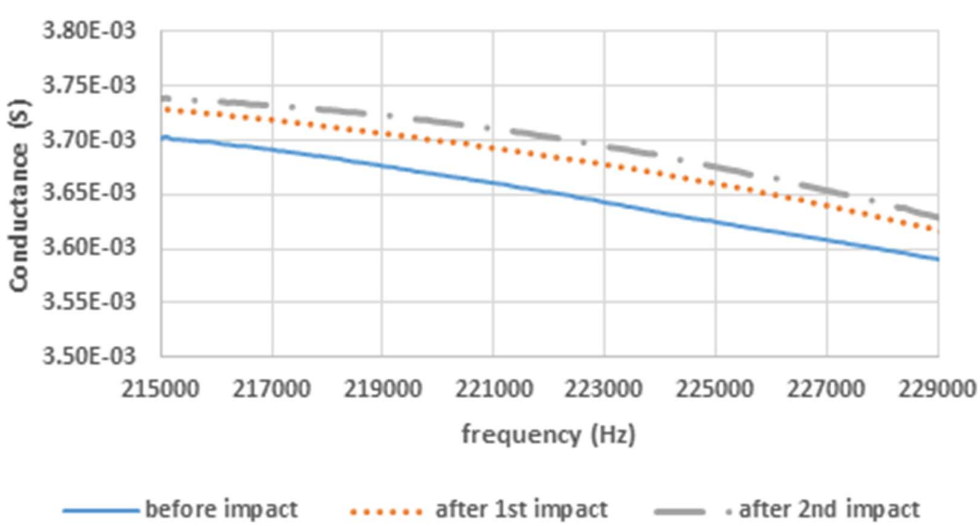

Figure 4.18 G vs f for B50 under 3m of impact

Table 4.3 Peak conductance value observed from admittance signature

	M30		F15		B50	
Height of impact	**2.5m**	**3m**	**2.5m**	**3m**	**2.5m**	**3m**
Peak conductance value before impact	0.00225	0.00328	0.00217	0.00238	0.00242	0.00365
Peak conductance value after 1st impact	0.00227	0.0034	0.00231	0.00251	0.002476	0.0037
Peak conductance value after 2nd impact	0.00235	0.00341	0.00234	0.00255	0.00248	0.00371

Table 4.4 Percentage increase in the conductance peak on each impact

	M30		F15		B50	
Height of impact	**2.5m**	**3m**	**2.5m**	**3m**	**2.5m**	**3m**
Percentage increase in the peak after 1st impact	0.89	3.6585	6.45	5.47	2.31	2.37
Percentage increase in the peak after 2nd impact	3.52	0.29	1.29	1.59	0.16	0.27

1. The peaks of the G vs f signature are higher in the case of impact under 3m height than that under 2.5m height, in the case of M30, FA15 and BS50 respectively. This resonates with the fact that higher impact height causes more damage.
2. Table 4.3 and Table 4.4 shows respectively the Peak conductance value observed from admittance signature for each specimen and Percentage increase in the conductance peak on each impact.
3. It can be observed that percentage increase in the peak is more the case of 3m impact than the 2.5m impact in all cases, showing more damage caused due to more transfer of energy.
4. Percentage increase in the peak is the most in the case of F15 than in M30 than in B50.
5. Further it can be observed that the peaks of the conductance are higher for B50 than the M30. Also peaks of conductance for F15 is lower than M30. Thus is can be concluded that impact resistance of F15 > M30 > B50

4.6. FEM ANALYSIS OF THE THREE BLENDED CONCRETE ON ANSYS

FE Analysis of the three blended concrete cubes of size 150mm X 150 mm X 150 mm has been conducted on software in the current research. 2 Binary Blends of concrete have been considered by with the cement replaced with fly ash and Blast slag, Properties of which has been taken from the work of Jeong-Eun Kim et al [36] and is given in the Table 4.5.

Table 4.5 Properties of Blended concrete

Property	F15	B50	M30
Density (kg/cum)	2344	2349	2400
Young's Modulus (GPa)	26.3	25.5	30.9
Compressive Strength (MPa)	44.6	48	30
Ultimate Tensile Strength (MPa)	3.5	3.2	5

A spherical ball of diameter 130mm and and weight 5 kg is being dropped from the height of 2.5m and and 3m

The cube is Fixed at base as shown in Figure 4.19.

Mesh size = 10mm (Figure 4.20)

End time = 0.3 ms

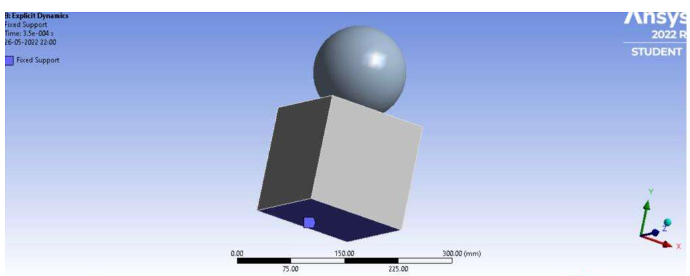

Figure 4.19. FE model of Cube fixed at base

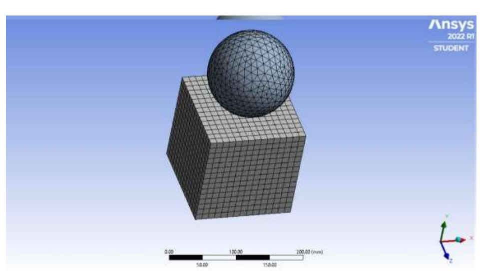

Figure 4.20. Meshing of the cube and the spherical impactor

Values of von mises stress, von mises strain and normal strain are calculated after the analysis. Results are shown in the Table 4. The results of the von mises stress and normal strain for BS50 under 2.5m height of impact are shown in the Figure 4.21 to 4.22

Table 4.6 Equivalent stress and Normal Strain obtained after FE Analysis

EQUIVALENT STRESS (MPa)			
Height	F15	B50	M30
2.5m	354.87	372.93	327.85
3m	371.9	392.1	338.9
NORMAL ELASTIC STRAIN (mm/mm)			
Height	F15	B50	M30
2.5m	0.0011767	0.0013208	0.00084971
3m	0.00213	0.0014059	0.0008783

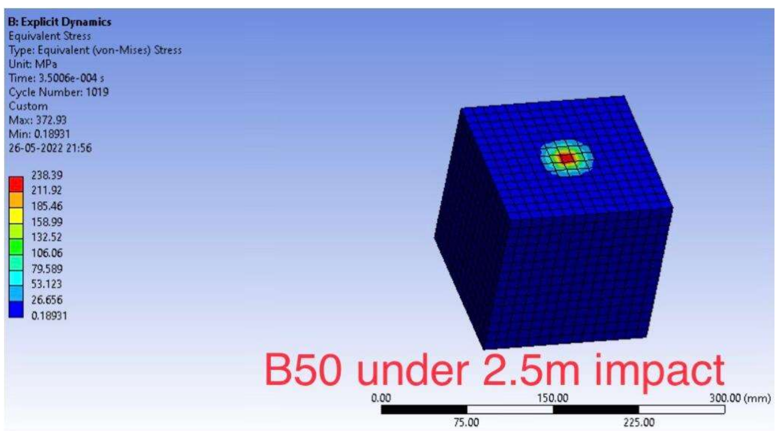

Figure 4.21 Equivalent (von-Mises) Stress under 2.5 m impact height

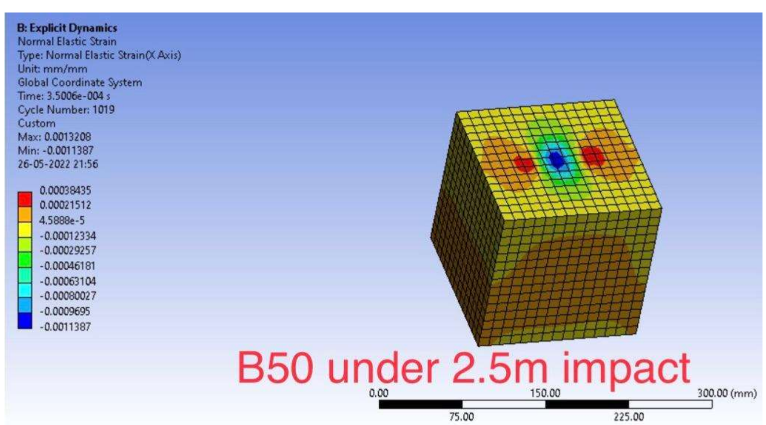

Figure 4.22 Normal strain under 2.5m impact height

1. Maximum equivalent stress and strain is generated at the centre of the cube.
2. Stress and Strain generated at the height of impact 3m is higher than that in 2.5m.
3. Strain generated in B50 is higher than than in M30 which is further higher than that in F15.
4. So, it can be concluded that the resistance of the F15 under impact is better than in M30 which is better than that in B50.

4.7 COMPARISION OF NORMAL STRAIN OBTAINED EXPERIMENTALLY AND ANALYTICALLY WITH ANSYS

Shanker et.al. [36] gave the following relation to find the strain generated at the point of embeddment when the Voltage across the PZT is known.

V= (D31)(Y)(h)(S1)/(E33)

Where

D31 = peizoelectric strain coefficient (m/V) = 5 E-12 m/V

Y = complex Young's modulus (N/ sqm) = 5.5 E+12 N/sqm

h = thickness of the peizosensor (m) = 0.2 mm

S1 = strain in the direction 1 (mm/mm)

E33 = complex electrical permitivity in direction 3 (Farad/m) = 3.01 E-8

V = voltage across the peizosensor (V)

The value of the voltage as obtained from the oscilloscope, after first impact from the height of 3m on F15 cube = 0.64 V

Thus the value of the strain calculated by the formula is 0.000347mm/mm

The value of strain calculated at the centre of the cube by ANSYS is 0.00034358 mm/mm

The difference in the calculated values is less than 10%. Therefore the strain calculated experimentally matches the normal strain calculated by ANSYS.

4.8 CRACK DEVELOPMENT

The Figure 4.23 to 4.25 show the crack development in the cubes under impact testing and under compression testing.

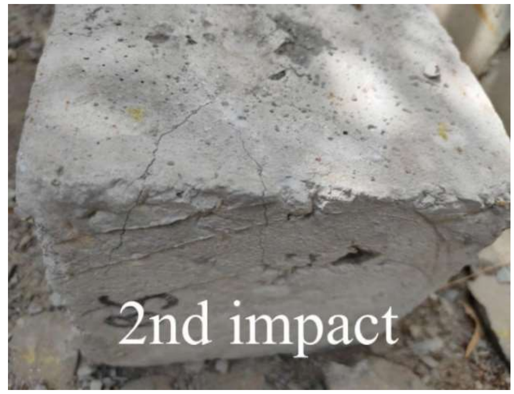

Figure 4.23 first impact at the centre of cube

Figure 4.24 cracks widening after 2nd impact

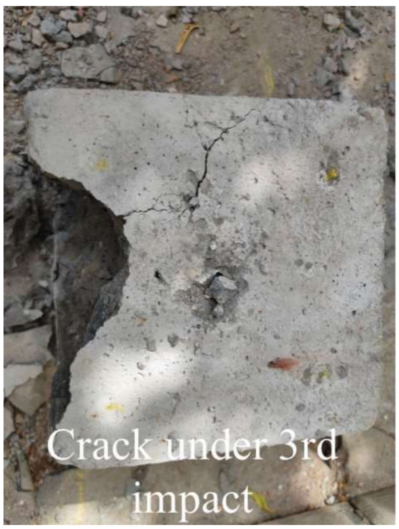

Figure 4.25. Cracks under third impact

Figure 4.26 Progress of crack in 2nd impact

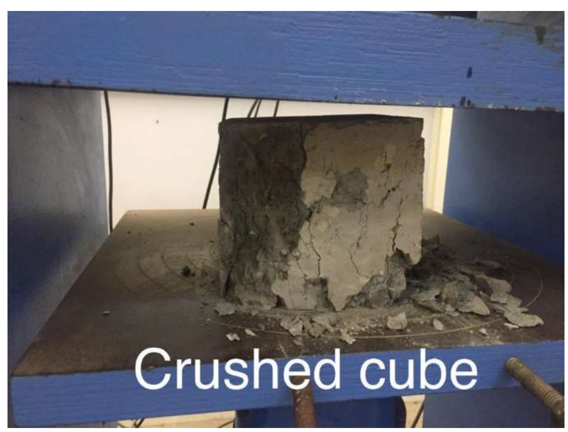

Figure 4.27 Vertical cracks in CTM

Figure 4.28 Crushing of cube in CTM

1. The crack developed under the impact test are horizontal to the surface. The crack developed under the compressive testing are vertical in nature. This is because the impact load is a sudden load for the very short time in which it interacts with the cube, the maximum of the energy is consumed by the top layers of the cube. It is because of

this that most of the damage occurs at the point of impact, with decrease in the width of the crack as one goes away from the impact point. As the number of the impacts increase the existing trajectory of the minor cracks gets widened. The failure occurs on a defined line of crack and the cube split opens in two parts.

2. In case of the CTM the load transfer is uniform for the top surface of the cube. Further the energy is increased very slowly not suddenly. Therefore the energy causing damage is spread uniformly in whole volume of the cube and crushing occurs.
3. The cubes that failed under the impact test were observed to be split open in two parts while those under the CTM got crushed.

4.9 SUMMARY OF THE CHAPTER

In this chapter, the admittance signatures obtained from the LCR meter after every impact have been analysed. Results of the Equivalent stress, equivalent strain and normal strain for the 3 compositions of the concrete under spherical impact obtained from the FE analysis in the ANSYS software have been discussed. Crack development in the cubes under impact have been observed.

CHAPTER 5

CONCLUSION

5.1GENERAL

In the current research, the Blended concrete cubes of 3 different compositions are being analysed under the impact load, experimentally by peizosensors and analytically by FE analysis in ANSYS. The results obtained experimentally and analytically complement each other.

5.2 CONCLUSION

The following conclusions can be drawn

- Conductance signatures obtained from the LCR readings, shows that the peak of the graph rises with every impact on the cube, signifying the increase in the Damage after every impact.
- Further, a reduction of about 40 % in residual strength of the Blended concrete , obtained from CTM after the first impact, was observed . This further enforces the previous conclusion that the damage in the concrete has increased after the Impact.
- Higher peaks are obtained for higher impact height, meaning more damage caused due to high impact energy.
- Blended concrete with 50% of Blast Slag undergoes more damage under impact than the conventional M30 concrete, which further undergoes more damage than the Blended concrete in which 15% Flyash is used as partial replacement.
- In FE analysis about 4% lower stress is generated with increase in height and about 6 % lower strain in generated with increase in height of impact for all the 3 blends of concrete.
- In FEM analysis 7% lower stresses and 20 % higher strains are generated in the 15% Flyash Binary Blend of concrete, than that in M30 concrete. 14 % higher stresses and 25% higher strains are generated in the 50 % Blast slag than that in M30 concrete.
- Flyash gives better performance under impact load, due to its better binding property as a cementitious material.
- Cracks horizontal to the surface are developed under the impact load, which varies from the cracks developed under continuous loading under CTM (vertical cracks).

- The cubes under impact load split open in two parts, while that in CTM get crushed.

5.3 LIMITATIONS AND FUTURE PROSPECTS

The current study has considered Flyash and Blast Slag as the SCM for the partial replacement in the concrete. Other SCMs like Silica, rice husk ash and metakaoline can also be investigated for their performance under impact.

Further, only Binary blends of concrete have been considered under the present work. Ternary blends of concrete containing 2 SCMs can also be investigated.

The research can be further reinforced and more detailed study of the cubes under impact can be done using other forms of peizosensors like - surface bonded and non bonded peizosensors.

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