بِسْمِ ٱللَّٰهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

PERFORMANCE EVALUATION OF ECC-CONCRETE COMPOSITES UNDER IMPACT LOADS USING FINITE ELEMENT ANALYSIS

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PROJECT APPROVAL

This is to certify that the study titled "**Performance Evaluation of ECC-Concrete Composites under Impact Loads using Finite Element Analysis**" submitted by M. M. Rezwan, Foysal Ahmed, Fairuz Ahmed, Tasnimul Hasan has been approved as partial fulfillment of the requirement for the Degree Bachelor of Science in Civil Engineering (CE) at the Islamic University of Technology (IUT).

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DECLARATION OF CANDIDATE

We declare that the undergraduate research work stated in this thesis has been executed by us under the supervision of Dr. Saima Ali. Proper precautions have been taken to certify that the work is original. This work has not been plagiarized and submitted elsewhere for any other purpose (except for publication).

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DEDICATION

Our thesis is dedicated to our family. We express a debt of gratitude of appreciation to our devoted parents. We would like to convey our deep thanks and genuine appreciation to our supervisor, Dr. Saima Ali, Assistant Professor, Department of Civil and Environmental Engineering, Islamic University of Technology, for her generous leadership, insightful advice, and never-ending encouragement.

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"In the name of Allah, the Most Gracious, the Most Merciful."

All gratitude is due to Almighty Allah (SWT) for providing us with the strength and fortitude to accomplish our Undergraduate Thesis successfully. Our parents have been a continual source of motivation and support for us, and we want to express our thanks to them.

We would like to convey our deep thanks and genuine appreciation to our supervisor, Dr. Saima Ali, Assistant Professor, Department of Civil and Environmental Engineering, Islamic University of Technology, for her generous leadership, insightful advice, and never-ending encouragement.

We would like to thank all of the Departmental faculty members for their assistance and support. We were able to attain our goals thanks to their unwavering support and understanding.

ABSTRACT

Engineered Cementitious Composite (ECC) is a type of composite material made out of limited fibers and a range of additional additives that enhance ductility, shock resistance, and other properties. ECC is a very effective approach to minimize the brittleness of concrete and increase its ductility. Because traditional concrete and fiber reinforced concrete are fragile, they shatter easily under environmental and mechanical pressures, reducing construction durability. A 1m*1m*150mm concrete panel was used as a basic model to evaluate the displacement over time to identify shock absorption capacity using the Abaqus FEM 2017 software. After that, the concrete thickness was lowered and ECC layers were added. For every trial the thickness of ECC-Concrete layers, impact forces were changed.

Key Words

Engineering Cementitious Composite, Finite Element Modeling, C40 Concrete, Abaqus, Shape-memory alloy, Polyvinyl alcohol, Displacement, Shock absorption capacity, etc.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Concrete has traditionally been the major building material for critical civilian infrastructure and defense constructions. Under dynamic stresses, concrete's low tensile strength promotes brittle disintegration, jeopardizing structural integrity and safety within and around protective systems.

Engineered Cementitious Composite (ECC) is a fiber-reinforced cementitious composite that was first introduced in the early 2000s. ECC exceeds standard fiber-reinforced concrete (FRC) in terms of tensile properties, with a strain capacity of up to 8% [1].

ECC has demonstrated great potential for the building of protective structures due to its outstanding mechanical features, remarkable micro-cracking potential, energy absorption capacity, and shock resistance. ECC's high tensile ductility, compared to regular concrete, leads in superior impact resistance and energy absorption capacity, making it great for use in impact-resistant structures [2].

Uses of ECC:

- Engineered cementitious composites are used in dynamic loaded shear members, mechanical components of beam and column composites, and primary structural maintenance.
- These compounds are commonly used in dampers [3], steel component junctions, and hybrid steel connectors in constructions with a greater energy retention.
- These materials can be used as a protective layer to improve the corrosive endurance of structures in addition to other structural purposes. Subsurface constructions, bridge decks [4] and roadway pavements are probable targets for engineered cementitious composites.

In this study a panel of 1 m x 1 m x 150 mm was designated for testing, and an impact force was delivered in the center. Numerous thicknesses of ECC and concrete panels were used in the suggested composite model, as well as different combinations.

Then, by varying the ECC mixes, thickness of ECC, impact force, and so on, certain parametric investigations were carried out by doing Finite Element Modeling (FEM). Abaqus FEA software was used to make some basic models.

Tensile strength: Tensile strength is defined as the quantity of force that may be given to a material before it tears apart.

Compressive strength: The capacity of a material or structure to withstand stresses that cause it to decrease in size is referred to as compressive strength.

Young's modulus of elasticity: Young's modulus of elasticity or modulus of elasticity in short is the ration of a material's capacity to endure changes in length when subjected to longitudinal tension or compression. Modulus of elasticity is denoted as $E = \sigma/\varepsilon$; where, σ = stress and ε = strain.

Dilatation Angle: The angle of dilatation, which is assumed to be constant throughout plastic yields, controls the amount of plastic volumetric strain caused during plastic shearing.

Fiber-reinforced concrete: FRC, or fiber-reinforced concrete, is a form of concrete that incorporates fibrous material to boost structural strength. It is composed of short discontinuous fibers that are randomly spread and oriented.

Finite element method: In construction and mathematics, the finite element method (FEM) is a frequently used methodology for efficiently partial differential equation. The classic domains of mathematical modeling, thermal expansion, fluid mechanics, transport networks, and radiofrequency potential are typical issue points of reference.

Shape-memory alloy: A form-memory alloy is a metallurgical alloy that, while cold, may be twisted yet keeps its shape when warmed. Memory alloy, memory metal, muscle wire, smart metal and smart alloy are all variations on the same conception. It has been found from study [5] that SMA fibers are being used in ECC mixes.

Polyvinyl alcohol: Due to its superior chemical and mechanical qualities, polyvinyl alcohol (PVA) is a type of water-soluble polymer that has already been extensively used in a variety of sectors. For its highly viscous, PVA is used as a bonding agent for construction products and when used in cementitious materials, it reduces the workability of the fresh mixture. Addition of PVA increases permeability.

C40 concrete: C40 concrete is a high-strength commercial-grade concrete mixture that is often used in road building, footings, agriculture, foundations, and the construction of structural and support beams. C40 has a strength of 40 - 44 $N.mm^{-2}$/28 days [6].

1.2 BACKGROUND

This comparative research was conducted with the purpose of determining how an ECC-concrete composite behaves when a sudden impact force is applied, as well as other parametric modifications, instead of a standard concrete.

When exposed to dynamic stresses, an ECC-Concrete multiplayer composite could indeed withstand more impact than a concrete wall. Such, in this experiment, it will be figured out how various types of ECC-Concrete composite behave under different sudden impact forces.

1.3 OBJECTIVES OF THE STUDY

The objectives of this study are given below:

- The stress absorption capacity of several ECC-Concrete combination compositions is evaluated using FEM.
- To find out effects of varied impact-force on the ECC-Concrete composite.
- To determine how different ECC compositions affect the ECC-Concrete composite's shock absorption capabilities.

1.4 METHODOLOGY

A panel of 1 m x 1m x 150 mm was selected for testing purpose, then a impact force was applied at center. For proposed composite model, different thickness of ECC and concrete panels were taken, including different configurations. Then, some parametric studies were done by changing the ECC mixtures, thickness of ECC, impact force etc.

1.5 RESEARCH FLOW DIAGRAM

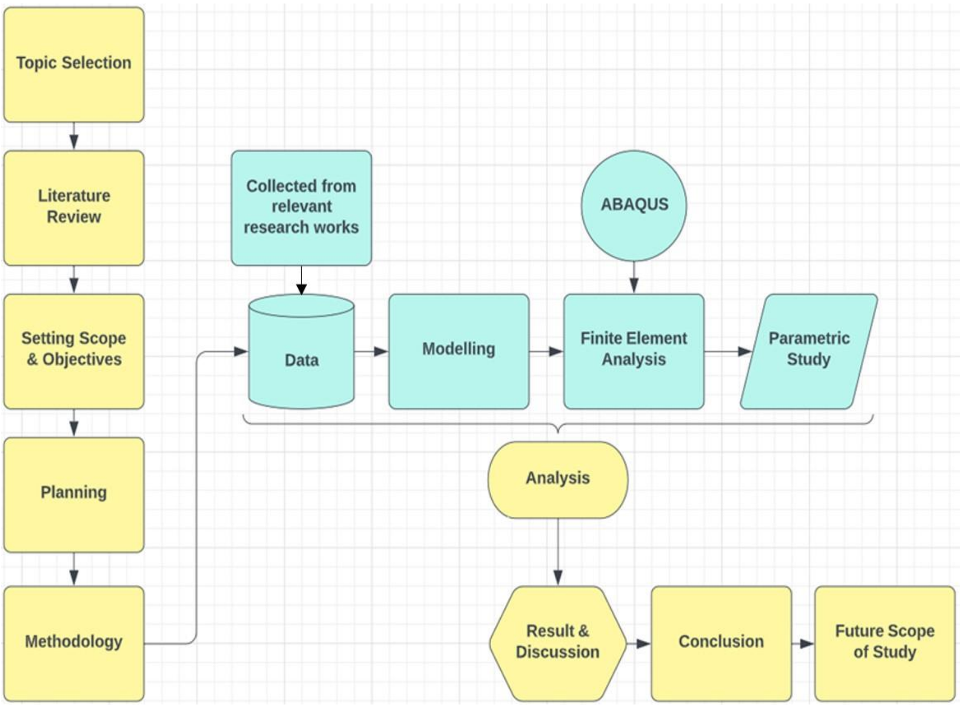

Figure 1: Research flow diagram.

1.6 LAYOUT OF THE THESIS

The rest of the thesis has been organized as follows:

Chapter 1:

Introduction **-** The current chapter, that discusses about the theory, background, objectives, boundaries and work diagram.

Chapter 2:

Literature Review – This chapter reviews prior work on similar studies and offers advice on how to finish the work plan.

Chapter 3:

Methodology – The procedural steps of the research will be detailed in this chapter.

Chapter 4:

Results and Discussions - Analyzing and collecting results from the data obtained from the models

Chapter 5:

Conclusions and Recommendations - This chapter will address the research's efficacy, recommendations, and potential future research scopes.

CHAPTER 2
LITERATURE REVIEW

Anil, Ö., Durucan, C., Erdem, R. T., & Yorgancilar, M. A. (2016): The behaviors of reinforced concrete beams made from various concrete kinds are explored experimentally and numerically under dynamic impact loads in this work [7].

Zhang, Q., & Baral, K. (2018): This study [8] demonstrates that the ECC material may be customized by combining local elements in order to obtain impact resistance behavior. This research's ECC combination demonstrated good damage tolerance and energy dissipation capability, making it ideal for the intended application.

Singh, M., Saini, B., & Chalak, H. D. (2019): This paper [9] presents a review of existing research investigations on the characteristics of ECC with the addition of different mineral admixtures and fibers. Various researches have reported on the effects of water-cement ratio, fiber form and length, mixing processes, temperature, and high-volume usage of fly ash on ECC characteristics.

Nehdi, M., Sciences, M. A.-A. (2019): In this investigation [10] , shock loads applied to an engineered cementitious composite (ECC) with deformation recovery and microfibers of polyvinyl alcohol (PVA) and shape memory alloy (SMA). The impact behavior of the composite was numerically simulated, and the simulation results matched the experimental results well. Because of the hybrid composite, it's a good competitor for protective constructions, with the ability to improve the safety of key infrastructure against impact actions and blasts. The introduction of SMA fibers improved the tensile and impact adsorption efficiency of the ECC composite and lowered its permeability, according to the results of the experiment and the various models used in it. The PVA fibers melted again as a result of the heat treatment procedure, causing a loss of mechanical properties. The heating rate, on the other hand, enthused the SMA fibers to locally pre-stress the composite-matrix because to its shape memory influence. This increased the heated HECC - SMAF hybrid composite's energy absorption capacities beyond its non-heated equivalent. Furthermore, the hybrid composite and comparable composites' better impact performance makes them ideal competitors for building protective structures, with the potential to improve the safety of vital infrastructure assets against explosions and impact occurrences. This study demonstrates how computational domain may be utilized to precisely predict how a hybrid composite produced in this study would behave when subjected to impact loads. The model could be modified to include more information about fiber type, dosage, strain rate, and other important variables not included in this work. Experimentation takes a significant amount of time, effort, and money. Time, effort, and money may be saved by developing a more thorough and resilient model.

Tambusay, A., Suprobo, P., Faimun, F., & Amiruddin, A. (2017): The actions of slab and column connectors in a flat slab construction under combination gravity-CLS (cyclic lateral stress) was investigated using a 3D finite element analysis. The structural approaches were then generated using the same approach after establishing a close likeness to the prior study. Due to its strain capacity of 3-5 percent under stress compared to 0.01 percent for traditional concrete, a cementitious composite material containing polyvinyl alcohol fibres (PVA-ECC) was also used. In this investigation, three distinct types of materials were used: a flat slab with complete Portland cement, a flat slab with PVA-ECC material just at the drop panel, and a flat slab with full PVA-ECC material. After conducting the experiment, it was discovered that among all the concrete panels, the flat slab using a drop panel with the entire PVA-ECC material is significantly better due to its remarkable behavior in terms of toughness, rigidity, lateral capacity, and dynamic response when subjected to combined lateral loading and cyclic lateral load, and thus symbolizes the most eligible model to be used in the construction site. Because

PVA-ECC has a greater beginning rigidity and a lower stiffness degradation ratio, it not only improves stiffness but also suffers from severe stiffness decline. Furthermore, PVA-ECC material shows no degradation in resilience at a drift ratio of 3.5 percent, whereas flat slabs using drop panel with whole normal concrete and flat slabs using PVA-ECC material only at drop panel show such degeneration up to this drift cycle, indicating that they meet the ACI minimum requirement. We may infer that PVA-ECC material is superior than the other two due to its adequacy. Finally, while the research was carried out with the aid of FE software, the evaluation process must be carried out as part of the research [11] to guarantee its accuracy.

Hemmati, Kheyroddin, A., &Hem Sharbatdar, M. K. (2015): In this study [12] , we look at High-Performance Fiber Reinforced Cementitious Composites (HPFRCC), which are cement matrices that have a strain hardening reaction when loaded under tension. The cement mortar with fine aggregates is reinforced by continuous or randomly dispersed fibers in these composites, which might be utilized for structural fusing and retrofitting of reinforced concrete components, among other things. A reinforced concrete beam is also chosen after a quick analysis of the mechanical parameters of HPFRCC materials. HPFR CC layers are used to substitute lower, higher, or both sections of that beam in various examples. With varied thicknesses, tensile strengths, and tensile stresses, different thicknesses of these specimens are studied. When compared to RC specimens, analytical findings obtained through nonlinear finite studies reveal that increasing loading capacity and ultimate displacement of these beams. High-Performance Hard Fiber Carbon (HPFRCC) can be utilized in key areas of reinforced concrete beams and frames to boost the capacity and longevity of the structures, according to the conclusions of this article.

Guan, Y., Yuan, H., Ge, Z., Huang, Y., Li, S., & Sun, R. (2018): The bound composite beam exhibited a stronger load bearing capacity and better subsequent fracturing energy absorption than the fiber reinforced composite beam in this research, according to a team of researchers that researched the flexural of ECC-concrete composite-beams. The topic of rebar corrosion-induced bridge durability is discussed here, as bridges are subject to wear and tear. The strain-hardening behavior of ECC, the bonded composite beam's higher loading capacity, but the unbounded beam's improved post-crack energy absorption, and the strain was dispersed across the beam by the unbounded ECC layer are among the findings reported in this study [13]. As a result, the unbounded composite beam might be used to construct bridges in abrasive environments to increase their service life. However, further study is needed to assess the program's effectiveness interacting on the performance of the beams and the longevity of composite beam.

Xiao, Y., Chen, Z., Zhou, J., Leng, Y., & Xia, R. (2017): Following are the conclusions obtained after researching this topic [14] : The tendency of the plastic-damage factor strain curves produced using both approaches is the same, while the impact factor founded on the assumption of released soon develops faster; the uniaxial modelling approach was reduced, and piece - wise component curves of the concrete functionalization in formulae, which corresponded to the CDP model, were generated. When the CDP model is merged with the measured idyllic yield model of rebar in the nonlinear FE model, the P-D curve built on the EEP agrees better with the experiment measured result, demonstrating the reasonableness of the energy equivalent approach to calculate the plastic-damage factor of concrete, as well as the accuracy of simplifying the ideal elastic-plastic model of rebar.

CHAPTER 3
METHODOLOGY

3.1 GENERAL

Using C40 concrete as a base model, different types of ECC-concrete models has been made for parametric studies. To determine displacement over time, an impact force has been applied in the mid portion of the surface of the models. By implementing this method shock absorption capacity is determined to fulfill the objective of this study. This chapter describes the configuration of experimental models and material properties thoroughly. All of the configuration and analysis was done using Abaqus FEA 2017 software.

3.2 WORK SEQUENCE IN ABAQUS

A flow chart is presented below to provide an idea of the complete work done with Abaqus FEA 2017 software.

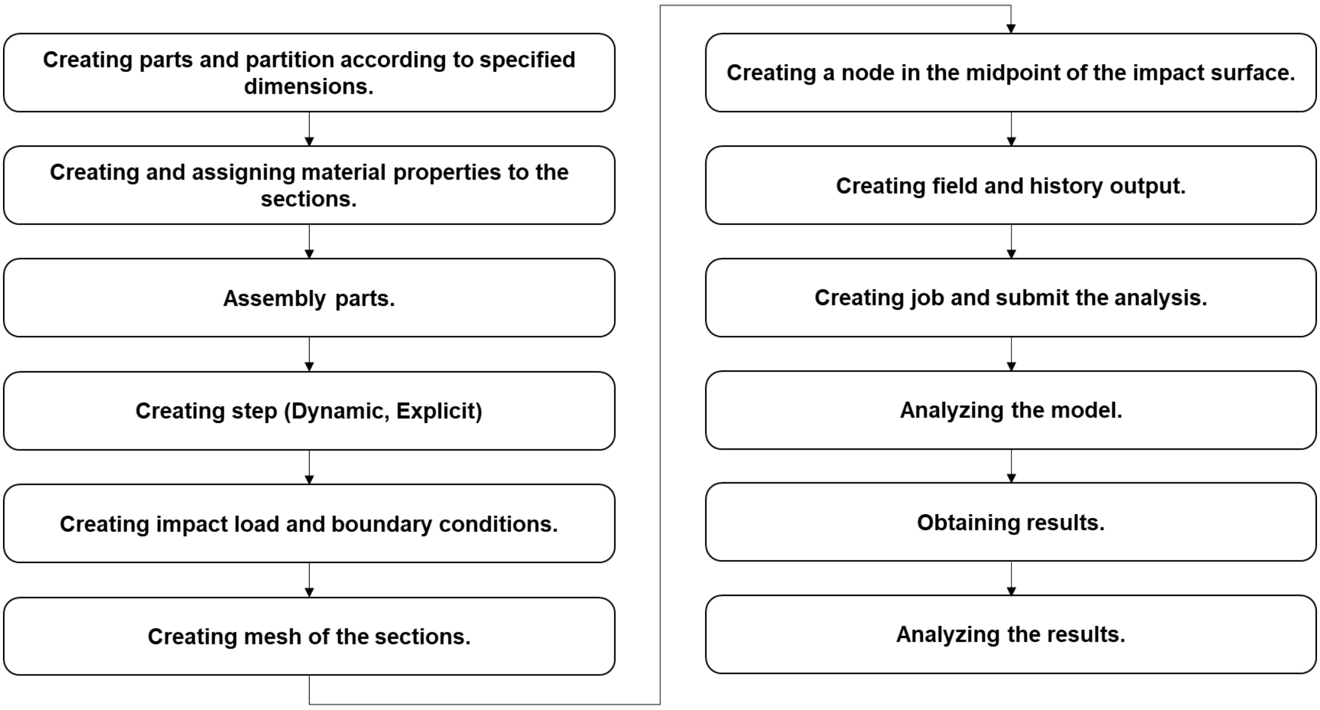

Figure 2: Work Sequence in Abaqus.

3.3 CONFIGURATION OF MODELS

Figures below depict some configurations (Here S.V means Side view and F.V means Front View). The 1m*1m*150mm concrete model is placed in the Concrete section; there is no ECC layer and this is the base model. In the second figure, the wall thickness was lowered to 100mm, and in the third figure, the wall thickness was dropped to 90mm.

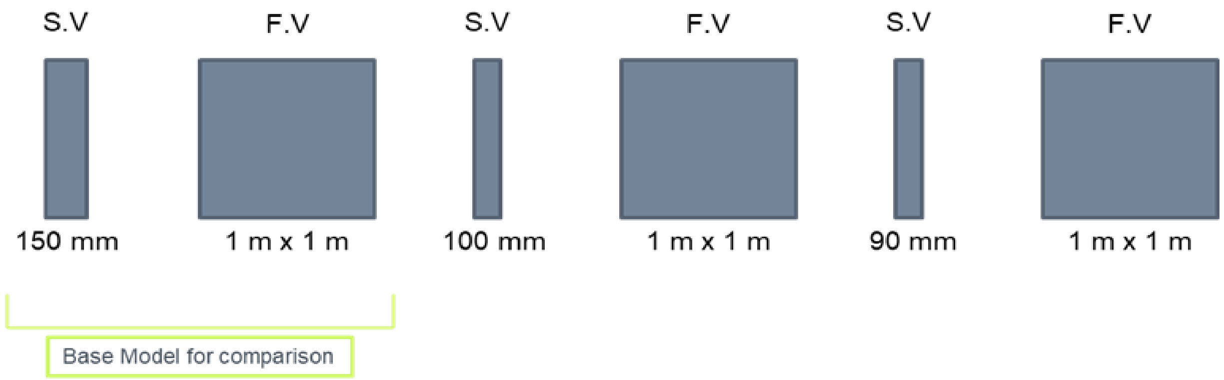

Figure 3: Configuration of Concrete.

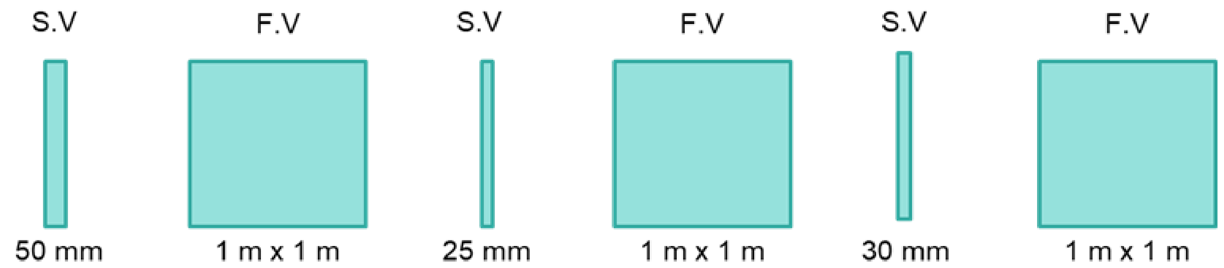

Figure 4: Configuration of ECC.

In the ECC portion, the first 50mm of ECC layer is implemented with a concrete wall thickness of 100mm. In the second figure, two ECC layers of 25mm thickness were utilized. The thickness of the ECC layer was extended from 25mm to 30mm in the third figure.

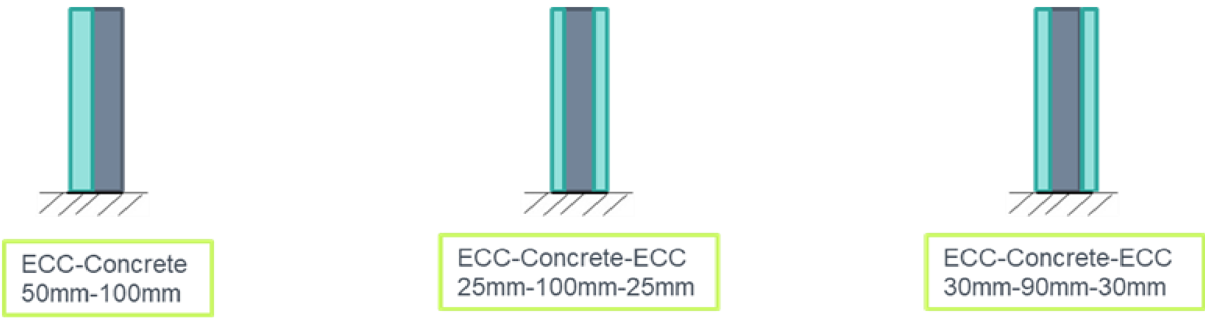

Figure 5: Configuration of ECC-Concrete Composites.

ECC-Concrete Composites is displayed here. The configuration is represented here. In the first figure, we can see a 50mm ECC layer applied to one side of a 100mm concrete wall. In the second figure, two ECC layers of 25mm thickness are used on both sides of a 100mm concrete wall, and in the third figure, two ECC layers of 30mm thickness are used on both sides of a 90mm concrete wall.

3.4 ABAQUS UNITS USED

Table 1: Abaqus Units.

Measurement	**SI Unit**
Force	Newton
Length	meter
Time	second
Mass	Kilogram
Stress	Pascal ($N.m^{-2}$)
Density	$Kg.m^{-3}$
Energy	Joule

3.5 MATERIAL PROPERTIES

In this section materials properties used in Abaqus finite element analysis is given in tabular and graphical formation. Since the lack of experimental data, C40 concrete [14] and ECC mix [10] material properties are noted from different studies. In addition, for different types of ECC, the compressive Stress vs inelastic Strain data were generated using Carreira and Chu (1985) model [15].

In case of assigning material properties in Abaqus FEA 2017 software strain-rate effect of concrete were considered. So, compressive stress was multiplied with a factor of 1.1 and inelastic strain was multiplied with 10 to achieve accurate results.

3.5.1 C40 CONCRETE PROPERTIES

Table 2: C40 Concrete Properties.

Property of Concrete		
Mass Density	**Young's Modulus (Pa)**	**Poisson's Ratio**
2300	27000000000	0.2

Table 3: C40 Concrete Damage Plasticity Properties.

Concrete Damage plasticity				
Dialation Angle	**Eccentricity**	**fb0/fc0**	**k**	**Viscosity parameter**
35	0.1	1.16	0.666666667	0.001

Table 4: C40 Concrete Compressive-Tensile Behavior.

Compressive Behavior		Tensile Behavior	
Yield Stress (Pa)	**Inelastic Strain**	**Yield Stress (Pa)**	**Cracking Strain**
6420000	0	2390000	0
9330000	0.0001	2320000	0.00001
10690000	0.00015	2190000	0.00002
17050000	0.00042	1840000	0.000045
19700000	0.00056	1610000	0.000064
25100000	0.00098	1450000	0.00008
26800000	0.00139	1290000	0.0001
25050000	0.00183	820000	0.000206
20510000	0.00244	570000	0.000346
11220000	0.00431	500000	0.000413
7100000	0.00637	440000	0.0005
4570000	0.00933	380000	0.000608
2550000	0.01578	260000	0.001031
390000	0.09532	70000	0.006258

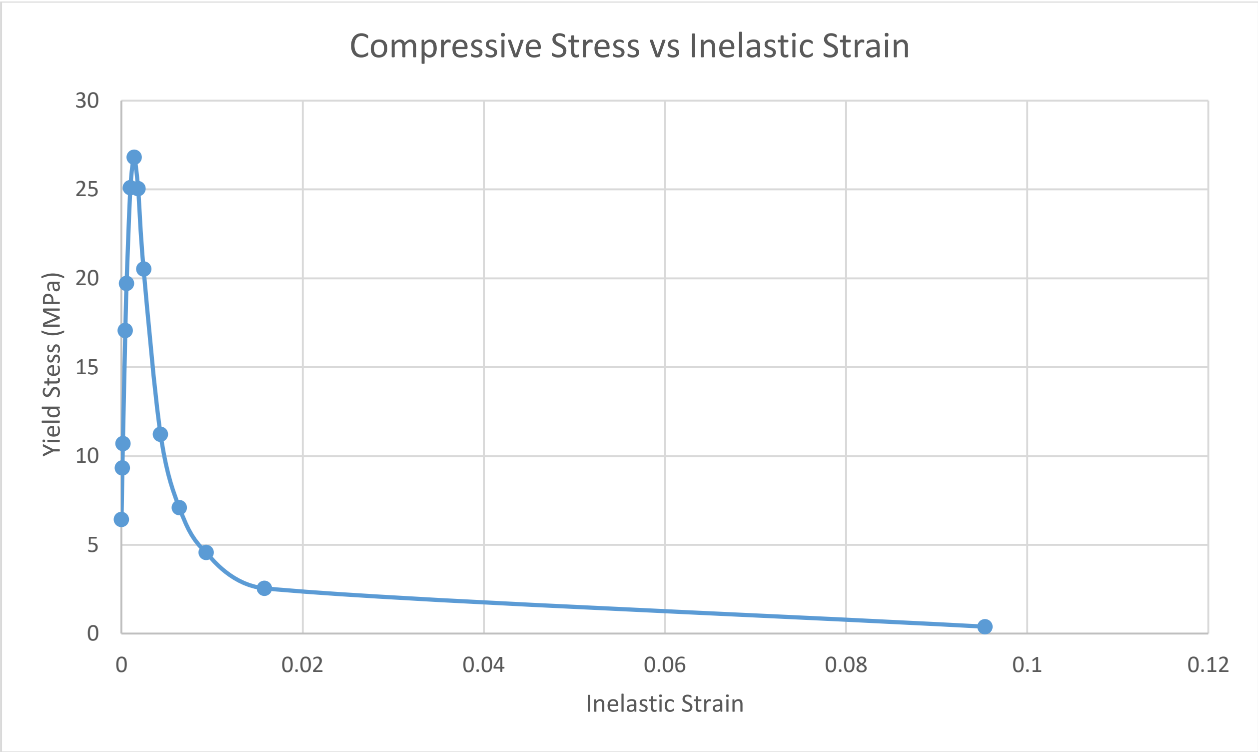

Figure 6: C40 Concrete Compressive Stress vs Inelastic Strain.

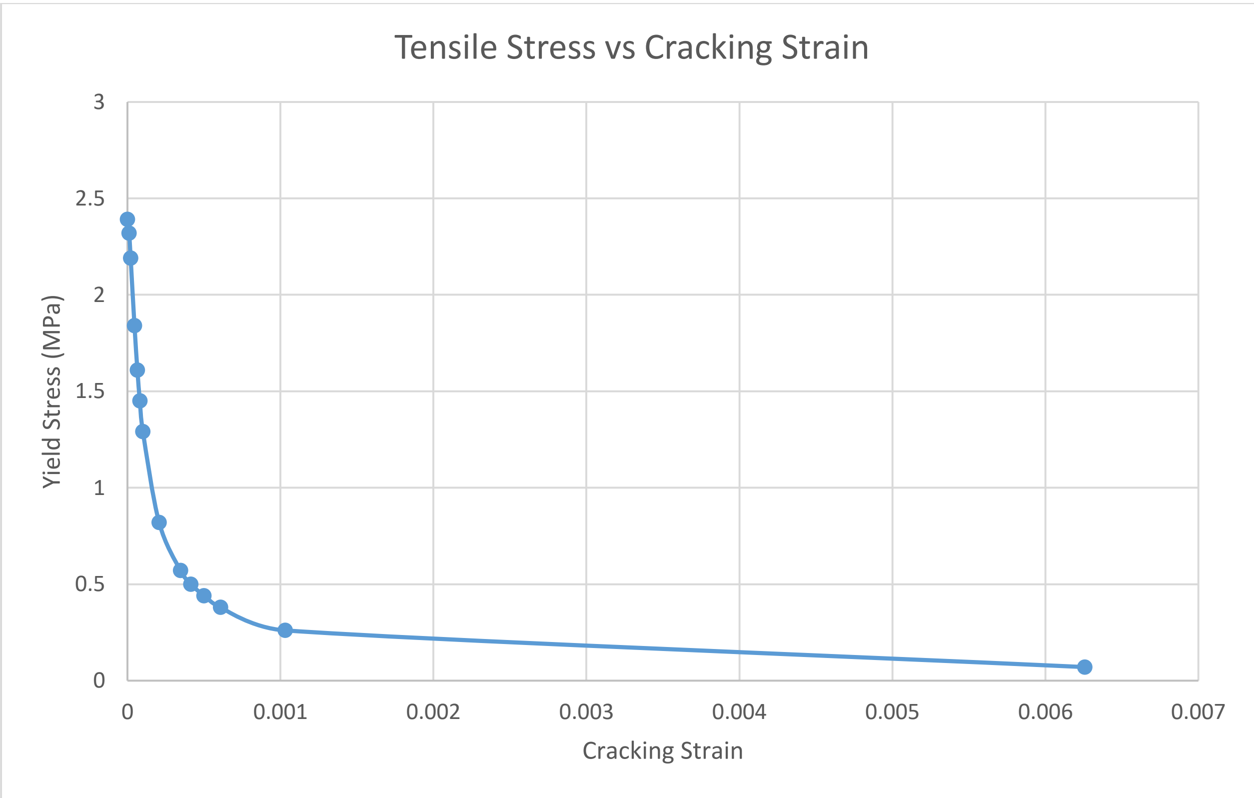

Figure 7: C40 Concrete Tensile Stress vs Cracking Strain.

3.5.2 ECC MIXTURE MATERIALS

Table 5: ECC Mixture Materials.

Mixture Materials	Accordance with code
Type-I OPC (Ordinary Portland Cement)	ASTM C150
FA (Fly Ash)	ASTM C618
Micro silica sand (≤ 200 μm)	-
HRWRA (Polycarboxylate High Range Water Reducing Admixture)	ASTM C494
0.8 cm long PVA (Polyvinyl Alcohol) fibers	-
1.6 cm long Nickel Titanium SMA (Shape Memory Alloy) fibers	ASTM F2063

Table 6: Properties of fibers.

Properties of fibers	PVA	SMA
Ultimate Tensile Strength	1620000000 Pa	869000000 Pa
Young's Modulus	43000 MPa	41000 MPa
Length	0.8 cm	1.6 cm
Diameter	0.0039 cm	0.0635 cm
Elongation	6%	38%
Density	1300 kgm^{-3}	6450 kgm^{-3}

ECC 2-1 means ECC containing 2% PVA fiber in volume fraction and 1% SMA fiber in volume fraction.

3.5.3 ECC 2-0 PROPERTIES

By proportion ECC 2-0 contains, Cement: Fly Ash: Silica Sand: Water/Cement: HRWRA = 1: 1.2: 0.8: 0.26: 0.012 and 2% PVA fiber in volume fraction and 0% SMA fiber in volume fraction.

Table 7: ECC 2-0 Properties.

Properties	ECC 2-0
Compressive Strength (Pa)	70100000
Tensile Strength (Pa)	4800000
Elastic Modulus (MPa)	19860
Poisson's ratio	0.185
Density (kgm^{-3})	1808
Dilation angle Y (Range: 36◦ - 40◦)	38
Eccentricity, e	0.1
fb0/fc0	1.16
shape - loading surface, Kc	0.666666667
Viscosity parameter	0.001

Table 8: ECC 2-0 Compressive-Tensile Behavior.

Compressive Behavior		**Tensile Behavior**	
Yield Stress (Pa)	**Inelastic Strain**	**Yield Stress (Pa)**	**Cracking Strain**
21030000	0	4693440	0
22999488.34	0.00E+00	4257110	8.8142E-05
26832726.45	0.00E+00	3641530	0.000150903
30665921.97	0.00E+00	3004730	0.000201725
34498946.91	0.00E+00	2547170	0.000252528
38331387.72	1.72E-08	2089610	0.000301841
42162063.79	1.43E-07	1832530	0.000554274
45987928.25	5.10938E-07	1594320	0.000805206
49801750.72	1.48524E-06	1257050	0.001145773
53587556.49	3.87017E-06	1157990	0.001434048
57312198.52	9.3347E-06	1096670	0.001811931
60910758.29	2.11475E-05	1018840	0.002113645
64263155.43	4.53545E-05	957520	0.002515428
67160751.24	9.24607E-05	858460	0.002905263
69267980.73	0.000179362	778270	0.003396667
70100000	0.00033047	759400	0.003798448
69834504.58	0.000443837	700440	0.004201731
34068898.72	0.003282633	660340	0.004591563
		639110	0.004981404
		580150	0.005471307
		540050	0.005874589
		499960	0.006276371
		441000	0.006779724
		422130	0.007069485
		400900	0.007283066

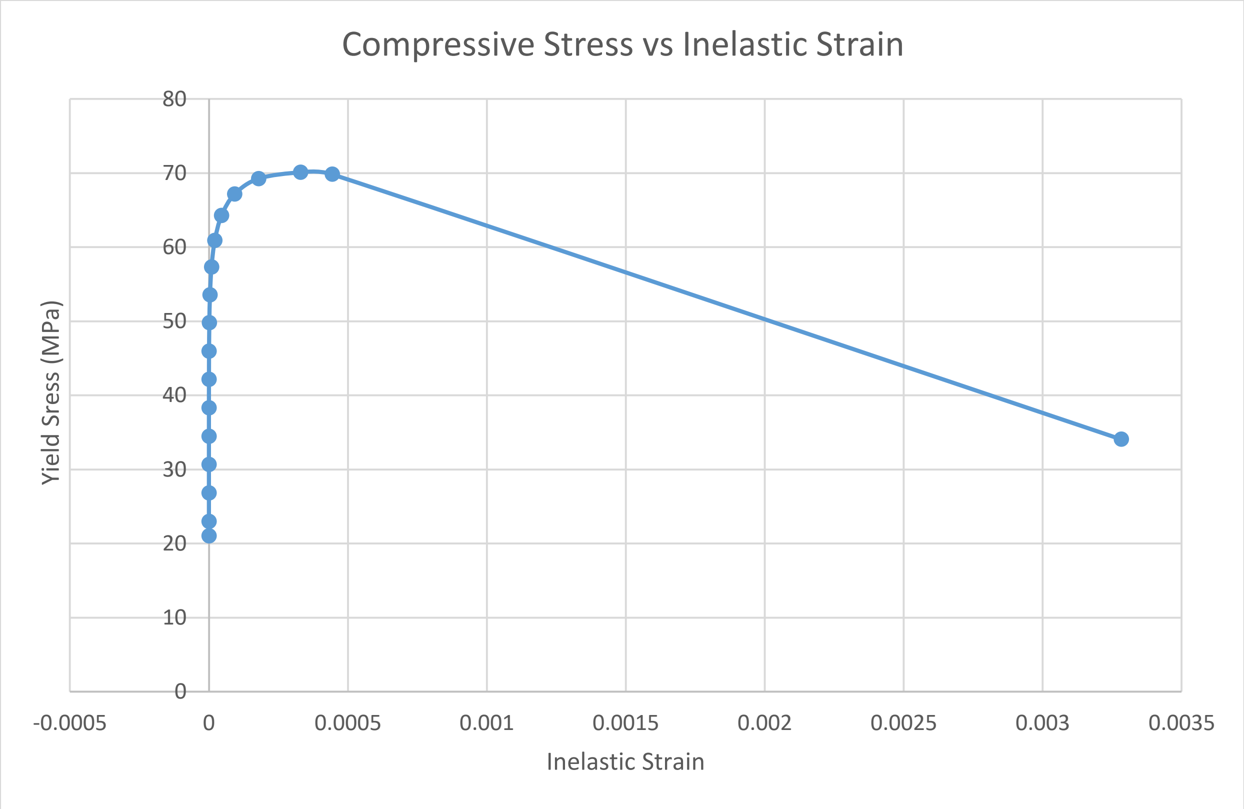

Figure 8: ECC 2-0 Compressive Stress vs Inelastic Strain.

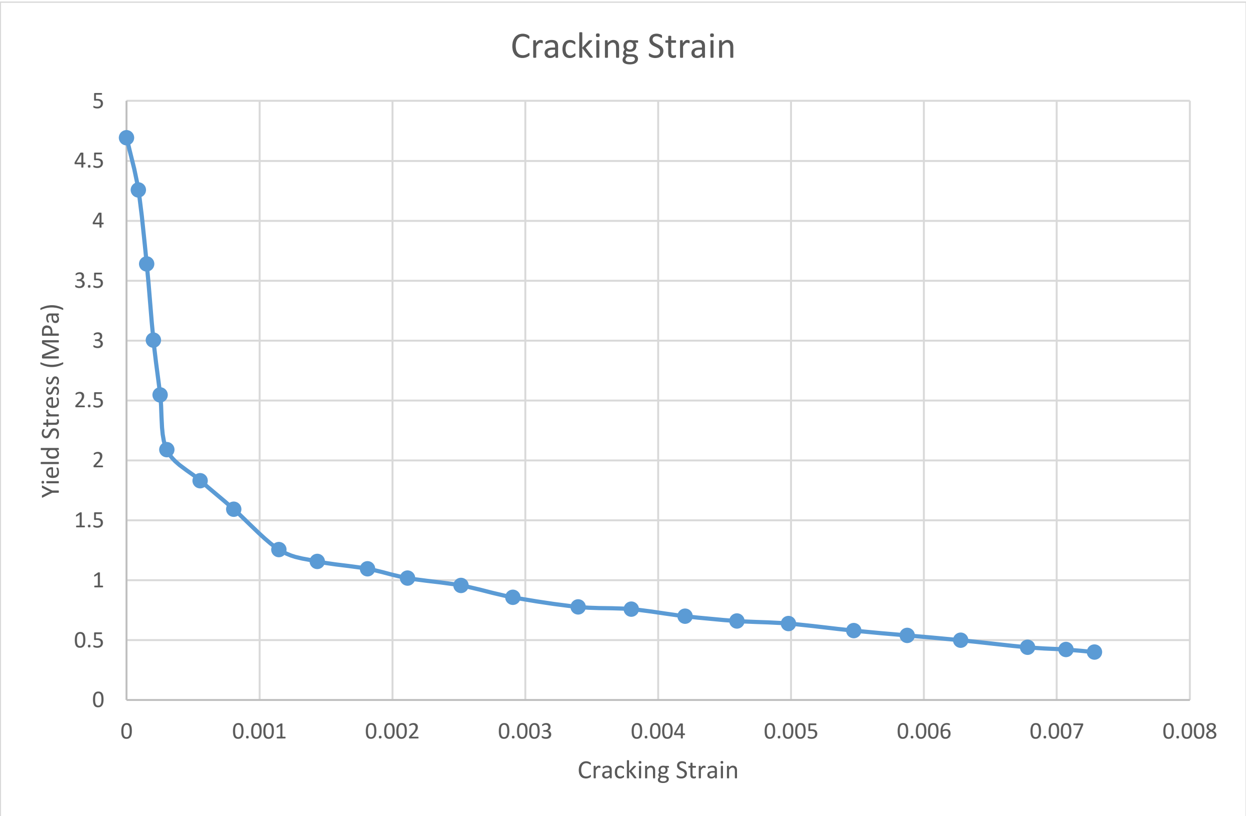

Figure 9: ECC 2-0 Tensile Stress vs Cracking Strain.

3.5.4 ECC 2-0.5 PROPERTIES

By proportion ECC 2-0 contains, Cement: Fly Ash: Silica Sand: Water/Cement: HRWRA = 1: 1.2: 0.8: 0.26: 0.012 and 2% PVA fiber in volume fraction and 0.5% SMA fiber in volume fraction.

Table 9: ECC 2-0.5 Properties.

Properties	ECC 2-0.5
Compressive Strength (Pa)	69600000
Tensile Strength (Pa)	5900000
Elastic Modulus (MPa)	19080
Poisson's ratio	0.183
Density (kgm^-3)	1736
Dilation angle Y (Range: 36◦ - 40◦)	38
Eccentricity, e	0.1
fb0/fc0	1.16
shape - loading surface, Kc	0.666666667
Viscosity parameter	0.001

Table 10: ECC 2-0.5 Compressive-Tensile Behavior.

Compressive Behavior		Tensile Behavior	
Yield Stress (Pa)	**Inelastic Strain**	**Yield Stress (Pa)**	**Cracking Strain**
20880000	0	5926954.532	0
22875655.4	9.39E-11	5488266.564	0.000327124
26688252.07	7.69E-10	5290149.418	0.000477989
30500796.8	4.17E-09	4992973.698	0.000678149
34313139.14	1.82E-08	4594380.867	0.00097988
38124804.98	6.77E-08	4297205.147	0.001156142
41934471.37	2.22E-07	3997670.89	0.001320455
45738793.89	6.56795E-07	3620304.896	0.001534061
49529985.56	1.78033E-06	3301902.339	0.001696882
53291143.2	4.47937E-06	2964631.482	0.00191198
56987771.67	1.05635E-05	2726419.199	0.002024013
60553378.11	2.35207E-05	2587265.488	0.002401904
63866860.97	4.97037E-05	2507075.215	0.002666278
66721016.08	9.99819E-05	2429243.479	0.0029426
68787687.71	0.00019157	2349053.205	0.003181583
69600000	0.000348958	2268862.931	0.003445956
69360346.95	0.00046153	2129709.221	0.003949311
36676890.98	0.00320936	2011782.348	0.004351099
8022541.408	0.005745832	1891496.938	0.004703598
		1792438.364	0.005042653
		1752343.227	0.005471322
		1712248.091	0.005935838
		1674511.491	0.006363013
		1634416.354	0.006854414
		1613189.517	0.007030661

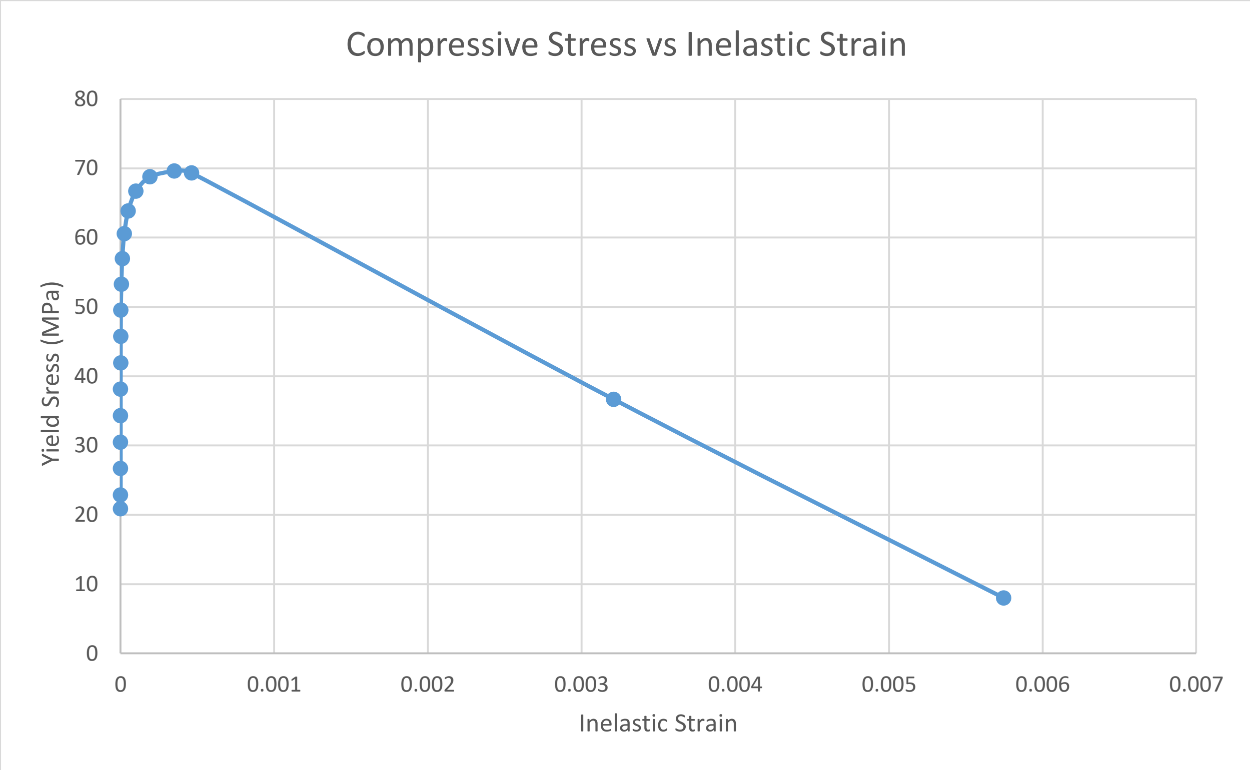

Figure 10: ECC 2-0.5 Compressive Stress vs Inelastic Strain.

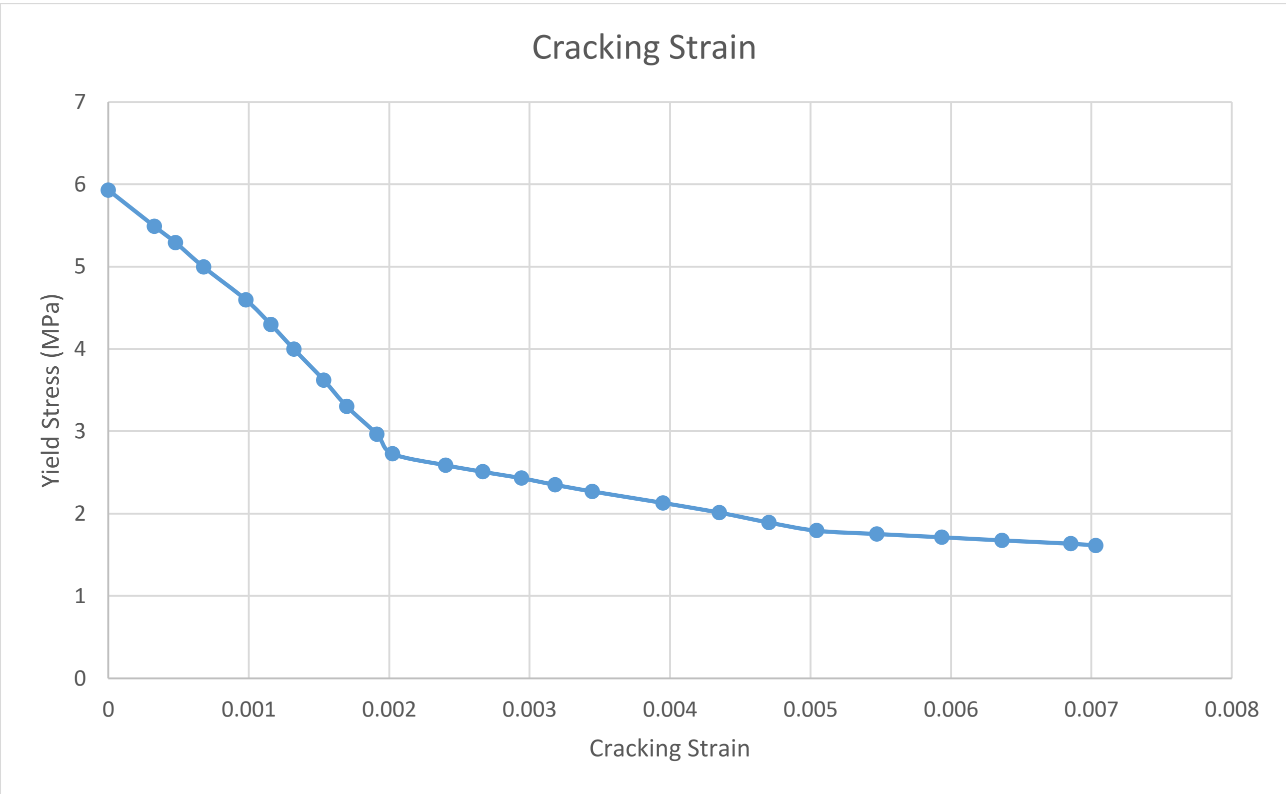

Figure 11: ECC 2-0.5 Tensile Stress vs Cracking Strain.

3.5.5 ECC 2-1 PROPERTIES

By proportion ECC 2-0 contains, Cement: Fly Ash: Silica Sand: Water/Cement: HRWRA = 1: 1.2: 0.8: 0.26: 0.012 and 2% PVA fiber in volume fraction and 1% SMA fiber in volume fraction.

Table 11: ECC 2-1 Properties.

Properties	**ECC 2-1**
Compressive Strength (Pa)	68700000
Tensile Strength (Pa)	8100000
Elastic Modulus (MPa)	18960
Poisson's ratio	0.17
Density (kgm^-3)	1758
Dilation angle Y (Range: 36◦ - 40◦)	38
Eccentricity, e	0.1
fb0/fc0	1.16
shape - loading surface, Kc	0.666666667
Viscosity parameter	0.001

Table 12: ECC 2-1 Compressive-Tensile Behavior.

Compressive Behavior		**Tensile Behavior**	
Yield Stress (Pa)	**Inelastic Strain**	**Yield Stress (Pa)**	**Cracking Strain**
20610000	0	8070865.083	0
22654006.05	2.64E-08	7575572.217	6.27579E-05
26429654.73	3.19E-08	6919898.803	0.000137473
30205229.77	4.12E-08	6224130.252	0.000225633
33980531.25	6.49E-08	5747705.685	0.000276441
37754956.81	1.35E-07	5686383.711	0.000364567
41526891.66	3.36E-07	5608551.975	0.000464643
45292400.29	8.76045E-07	5290149.418	0.000715587
49042622.33	2.2221E-06	4872688.287	0.001068102
52758916.61	5.35702E-06	4575512.567	0.001332487
56404346.13	1.22284E-05	4474095.457	0.001432564
59909693.83	2.64856E-05	4415132.02	0.001571473
63152324.84	5.45949E-05	4316073.447	0.001847797
65928082.5	0.00010732	4136824.6	0.002276473
67922420.12	0.000201247	4077861.163	0.002578186
68700000	0.000359329	3997670.89	0.003256291
68470584.92	0.000471425	3957575.753	0.003773083
37393927.33	0.003143917	3879744.017	0.004578144
8791686.488	0.005685943	3818422.043	0.005068052
		3780685.443	0.005432496
		3759458.606	0.005759598
		3740590.306	0.005998577
		3700495.17	0.006200217
		3700495.17	0.00628834
		3679268.332	0.006388413

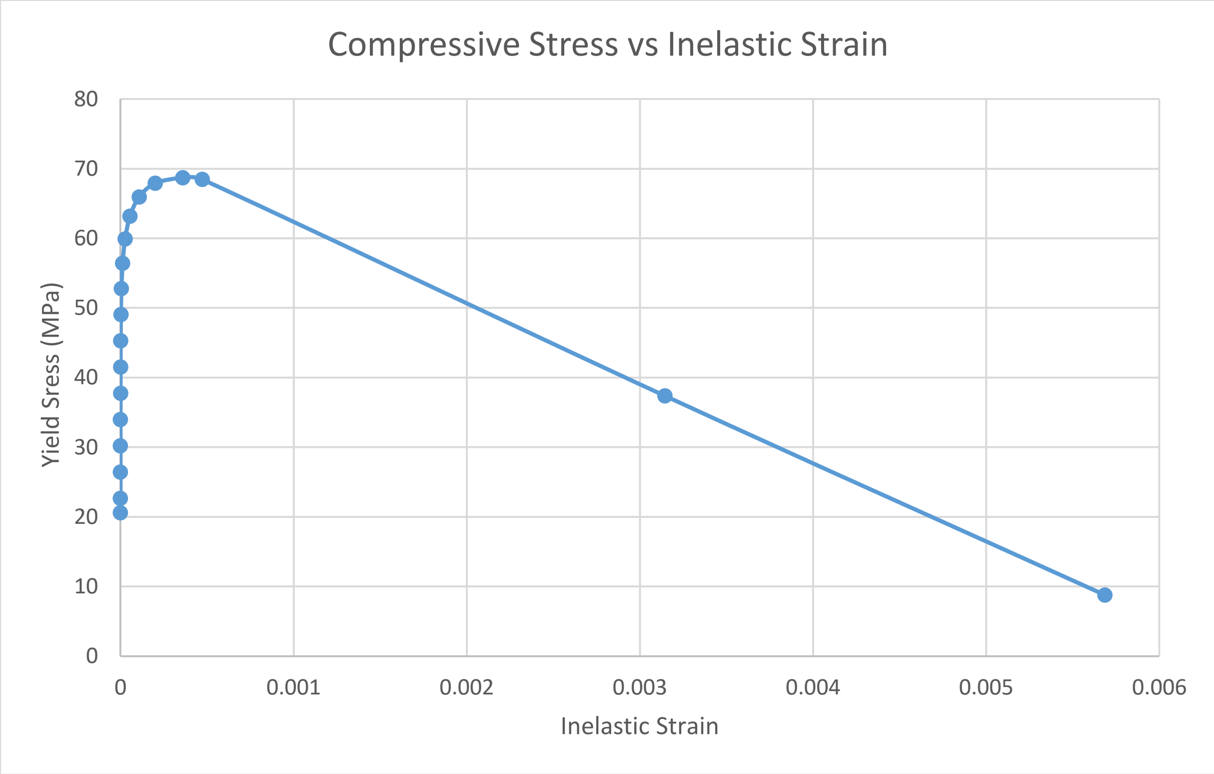

Figure 12: ECC 2-1 Compressive Stress vs Inelastic Strain.

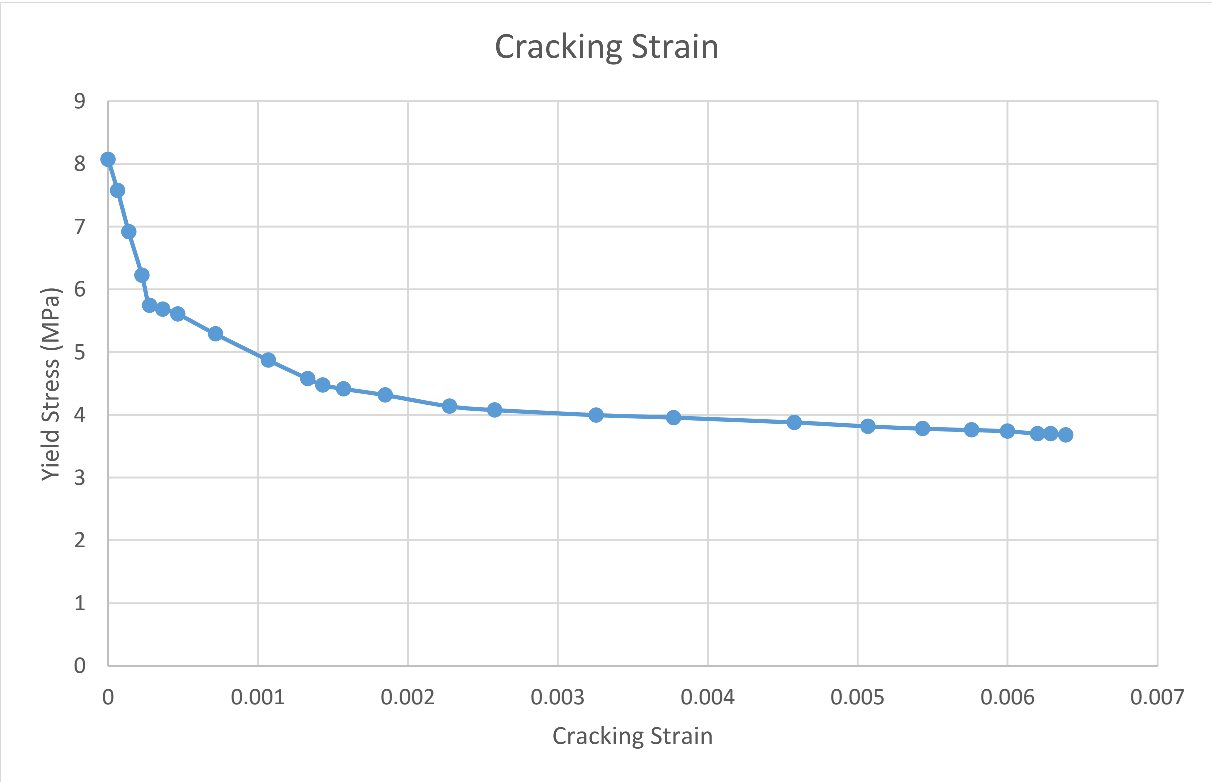

Figure 13: ECC 2-1 Tensile Stress vs Cracking Strain.

3.5.6 ECC 2-1.5 PROPERTIES

By proportion ECC 2-0 contains, Cement: Fly Ash: Silica Sand: Water/Cement: HRWRA = 1: 1.2: 0.8: 0.26: 0.012 and 2% PVA fiber in volume fraction and 1.5% SMA fiber in volume fraction.

Table 13: ECC 2-1.5 Properties.

Properties	**ECC 2-1.5**
Compressive Strength (Pa)	66000000
Tensile Strength (Pa)	6500000
Elastic Modulus (MPa)	18920
Poisson's ratio	0.14
Density (kgm^-3)	1790
Dilation angle Y (Range: 36◦ - 40◦)	38
Eccentricity, e	0.1
fb0/fc0	1.16
shape - loading surface, Kc	0.666666667
Viscosity parameter	0.001

Table 14: ECC 2-1.5 Compressive-Tensile Behavior.

Compressive Behavior		**Tensile Behavior**	
Yield Stress (Pa)	**Inelastic Strain**	**Yield Stress (Pa)**	**Cracking Strain**
19800000	0	6403379.099	0
21999319.54	0.00E+00	6242998.552	7.61827E-05
25665811.15	0.00E+00	6044881.405	0.000201657
29332104.44	0.00E+00	5528361.701	0.000301756
32997755.53	4.04E-08	5191090.844	0.000365999
36661587.21	1.82E-07	4891556.587	0.000428747
40320786.25	5.68E-07	4495322.294	0.000503448
43969177.34	1.52487E-06	4096729.463	0.000605035
47594134.39	3.72082E-06	3957575.753	0.000717063
51171376.6	8.43883E-06	3780685.443	0.00084403
54656716.12	1.80145E-05	3521246.323	0.00105763
57973865.13	3.64803E-05	3301902.339	0.001208497
60998111.21	7.04279E-05	3063690.055	0.001408653
63537866.51	0.000129984	2785382.635	0.001623748
65320919.59	0.000229538	2747646.036	0.001761163
66000000	0.000387444	2667455.762	0.001937413
65793981.17	0.000498333	2507075.215	0.002352646
38603686.74	0.002972995	2408016.641	0.002603578
10839002.54	0.005478017	2228767.794	0.003459428
		2129709.221	0.00392544
		2051877.485	0.004364566
		1971687.211	0.005120339
		1952818.912	0.005610245
		1912723.775	0.006113594
		1891496.938	0.0066035

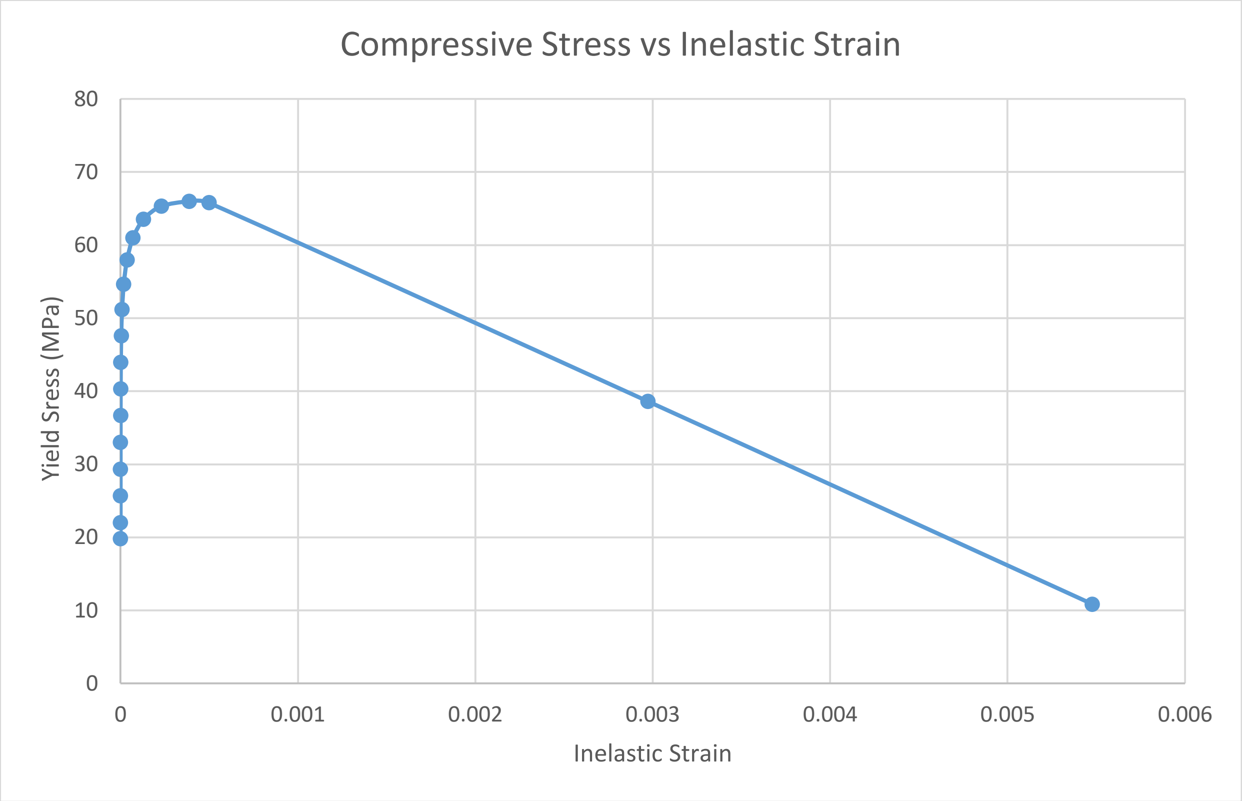

Figure 14: ECC 2-1.5 Compressive Stress vs Inelastic Strain.

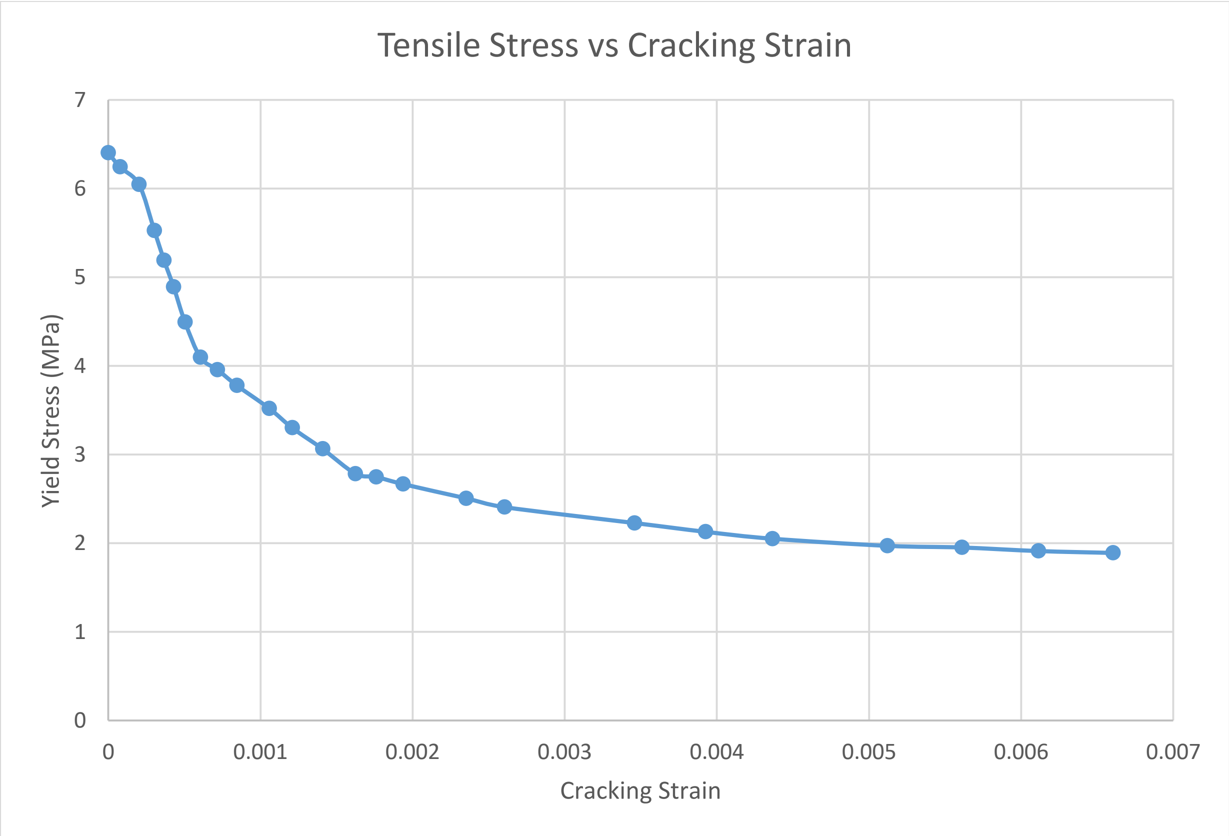

Figure 15: ECC 2-1.5 Tensile Stress vs Cracking Strain

3.6 METHOD OF ANALYSIS

3.6.1 FINITE ELEMENT ANALYSIS (FEA)

Finite Element Analysis is a mathematical approach for solving mathematical physics and engineering problems. In this study, FEA has been used for simulation. The FEA in this study, covers the whole range of physical behaviors and interactions of the created models. As well as, it portrays mechanics as the interaction of a set of components with simplified physical behavior.

3.6.2 CONCRETE DAMAGE PLASTICITY (CDP) MODEL

In this study, CDP model is considered while designing concrete and ECC models. The concrete damage plasticity (CDP) model was created for scenarios when the concrete is exposed to variable loading circumstances, involving cyclic loading, and when isotropic damage is assumed. The model accounts for the reduction of elastic stiffness caused by plastic straining in tension and compression. Likewise, it takes into account the impacts of stiffness recovery during cyclic loading [16].

3.6.3 SPATIAL DISPLACEMENT CALCULATION

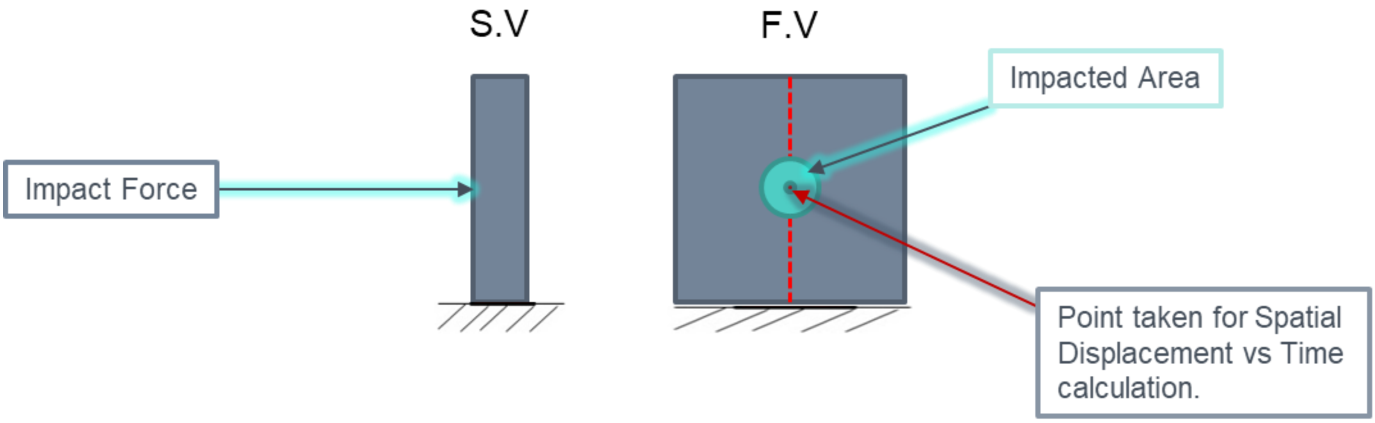

Figure 16: Method of Spatial Displacement Calculation.

In this figure, it can be seen that where the impact force will be applied and where the center point of the impacted region will be chosen for the displacement vs time estimate. Different levels of dynamic loads will be applied to each of these formations, and the displacement will be measured.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 GENERAL

A variety of models have been developed in accordance with the aims of the experimental procedures indicated above. As a result, the data gathered from the models has been evaluated in order to make certain conclusions. Furthermore, this chapter offers a full analysis and explanation of all the parameters necessary to attain the desired outcomes.

4.2 DISPLACEMENT IN CASE OF DIFFERENT CONFIGURATION

Changing the depth of ECC layers, the displacement over time is determined using finite element analysis to determine the best possible configuration of ECC-C40 concrete composite.

4.2.1 C40 CONCRETE 150MM BASE MODEL DISPLACEMENT (100KPA IMPACT)

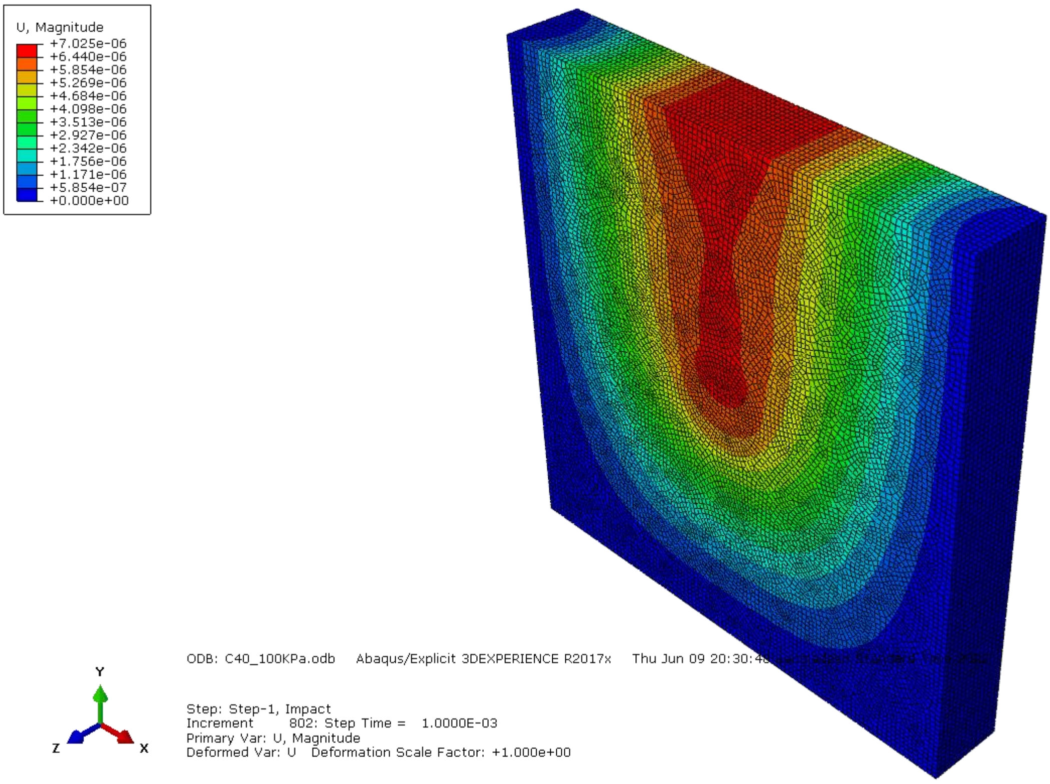

Figure 17: C40 Concrete 150mm Base Model Displacement (100KPa Impact).

4.2.2 ECC 2-0 – C40 50MM-100MM MODEL DISPLACEMENT (100KPA IMPACT)

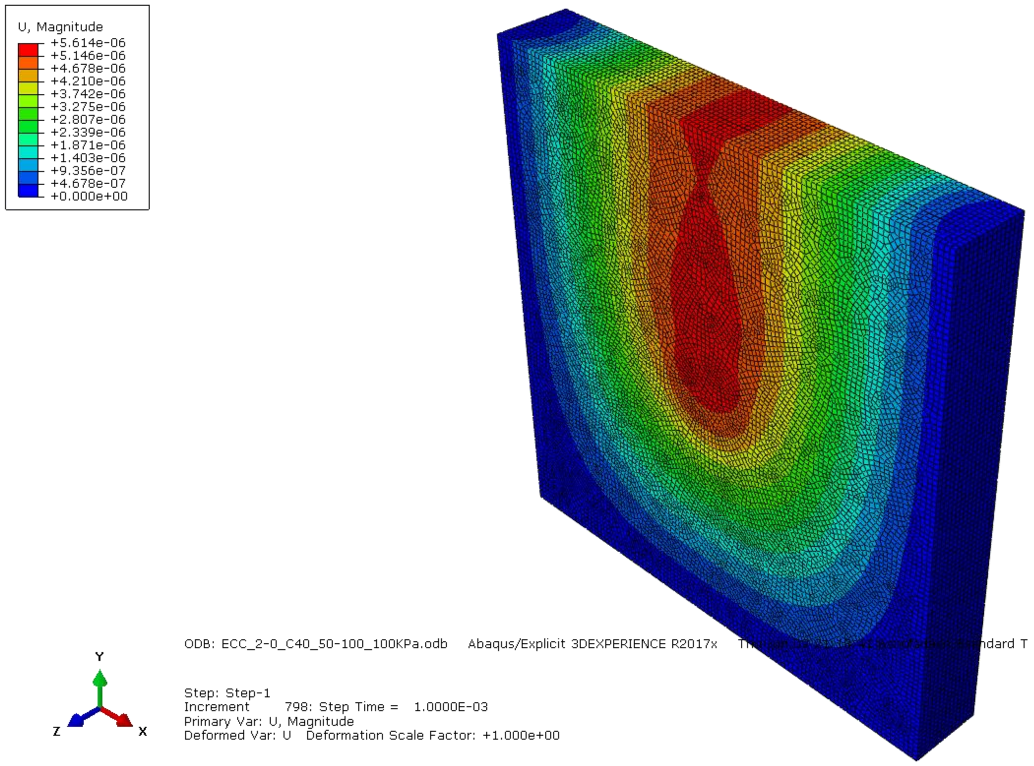

Figure 18:ECC 2-0 – C40 50mm-100mm Model Displacement (100KPa Impact).

4.2.3 ECC 2-0 – C40 25MM-100MM-25MM MODEL DISPLACEMENT (100KPA IMPACT)

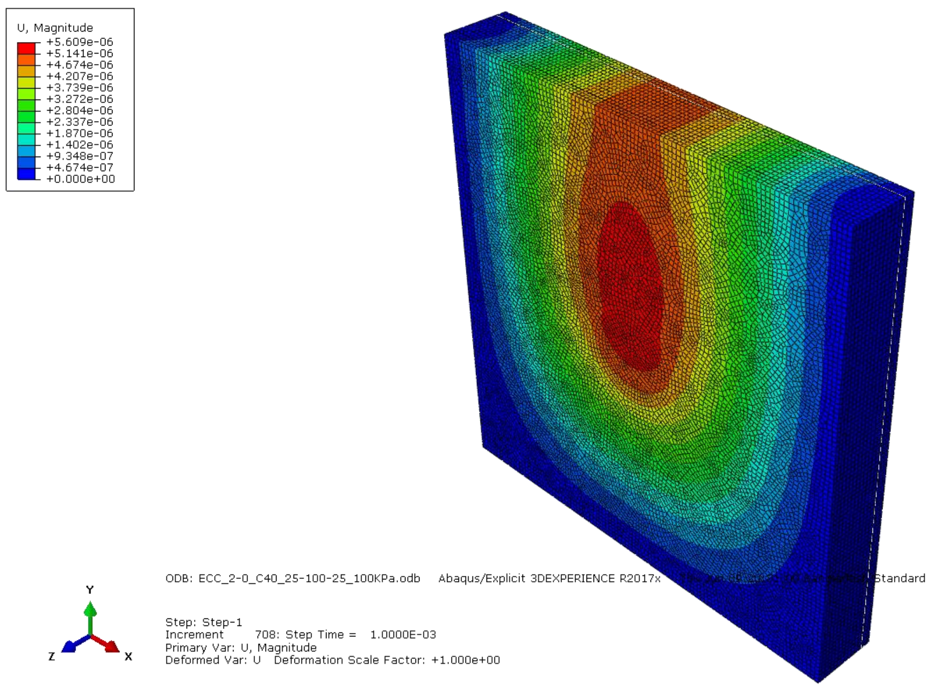

Figure 19: ECC 2-0 – C40 25mm-100mm-25mm Model Displacement (100KPa Impact).

4.2.4 ECC 2-0 – C40 30MM-90MM-30MM MODEL DISPLACEMENT (100KPA IMPACT)

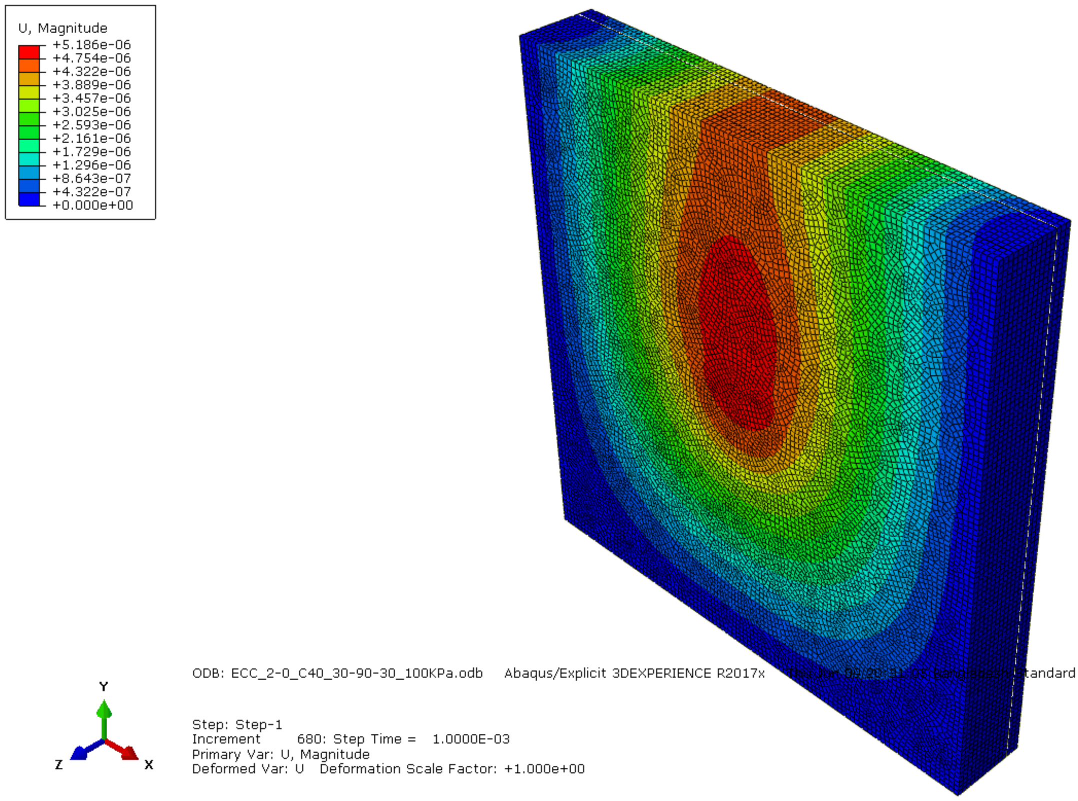

Figure 20: ECC 2-0 – C40 30mm-90mm-30mm Model Displacement (100KPa Impact).

4.2.5 COMPARISON OF ECC 2-0 – C40 MODELS DISPLACEMENT (100KPA IMPACT)

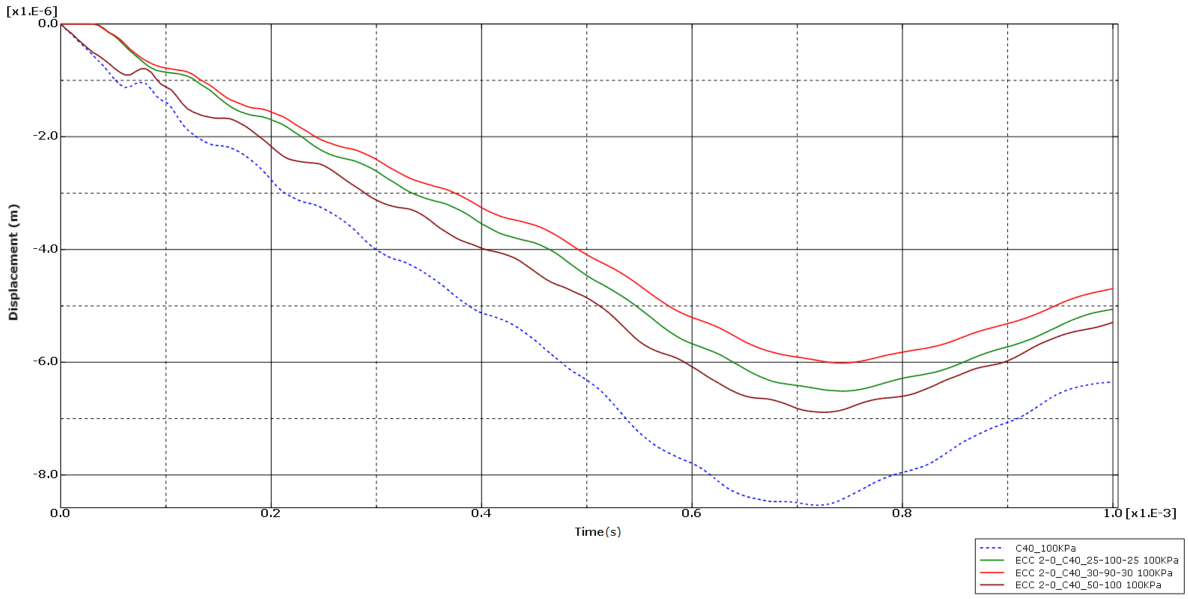

Figure 21: ECC 2-0 – C40 Models Displacement (m) vs Time (s) (100KPa Impact).

From the analysis it is visible that adding ECC 2-0 panel over concrete greatly reduces displacement over time. C40 concrete base model has the highest displacement over time than other models.

In case of ECC 2-0 – C40 50mm-100mm model and ECC 2-0 – C40 25mm-100mm-25mm model the difference between displacement are moderately close. But instead of using ECC 2-0 in one layer, adding the same amount of ECC in both sides of concrete marginally helps to reduce the displacement over time.

Again, in case of ECC 2-0 – C40 25mm-100mm-25mm model and ECC 2-0 – C40 30mm-90mm-30mm model, it has been observed that increasing the depth of ECC 2-0 in both side significantly helps to reduce the displacement over time. Thus, the ECC 2-0 – C40 30mm-90mm-30mm model has the least amount of displacement over time than the other models.

4.3 DISPLACEMENT IN DIFFERENT TYPES OF ECC MATERIALS

Since it has been observed that ECC 2-0 – C40 30mm-90mm-30mm model has the least amount of displacement which indicates higher shock absorption capacity. For the comparison of different types of ECC materials the ECC– C40 30mm-90mm-30mm model has been selected.

4.3.1 ECC 2-0.5 – C40 30MM-90MM-30MM MODEL DISPLACEMENT (100KPA IMPACT)

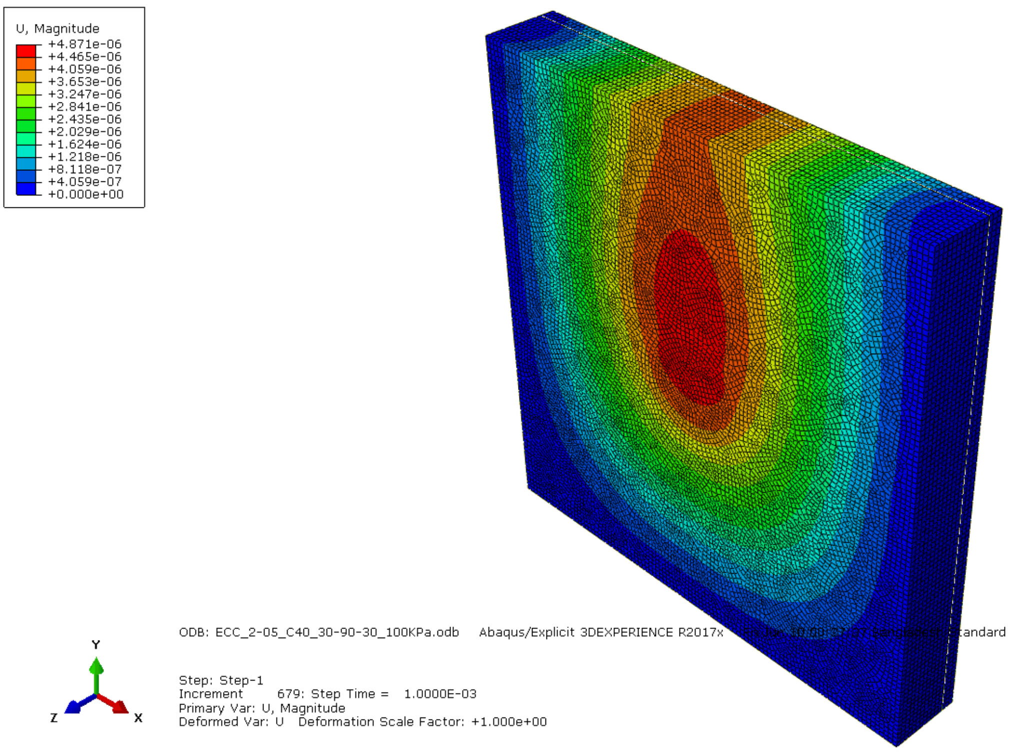

Figure 22: ECC 2-0.5 – C40 30mm-90mm-30mm Model Displacement (100KPa Impact).

4.3.2 ECC 2-1 – C40 30MM-90MM-30MM MODEL DISPLACEMENT (100KPA IMPACT)

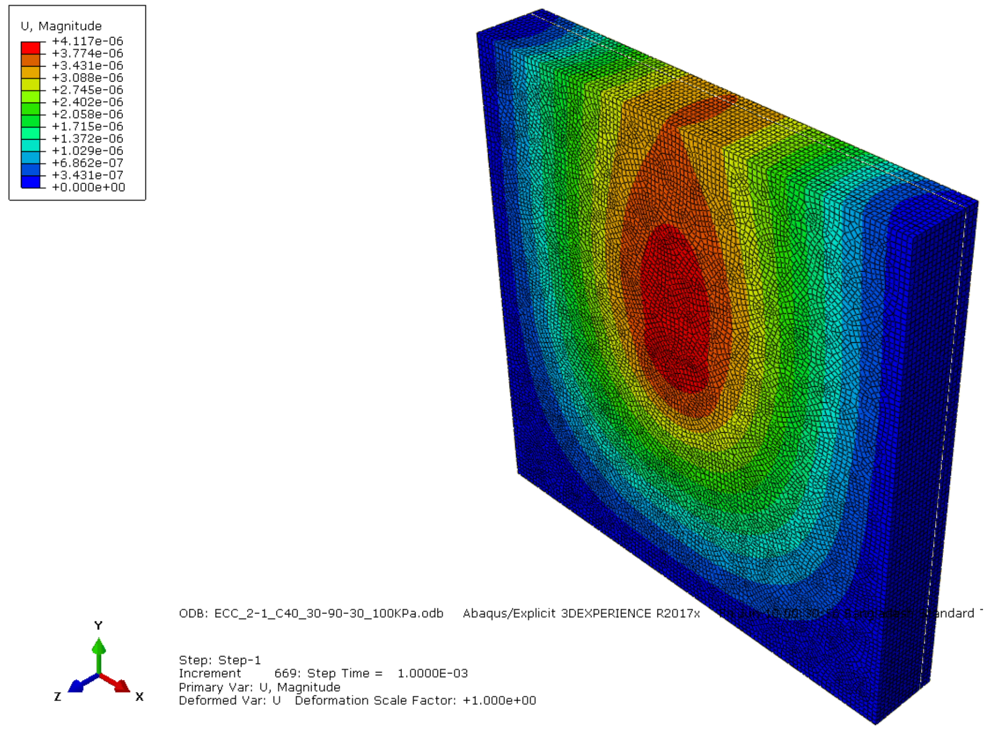

Figure 23: ECC 2-1 – C40 30mm-90mm-30mm Model Displacement (100KPa Impact).

4.3.3 ECC 2-1.5 – C40 30MM-90MM-30MM MODEL DISPLACEMENT (100KPA IMPACT)

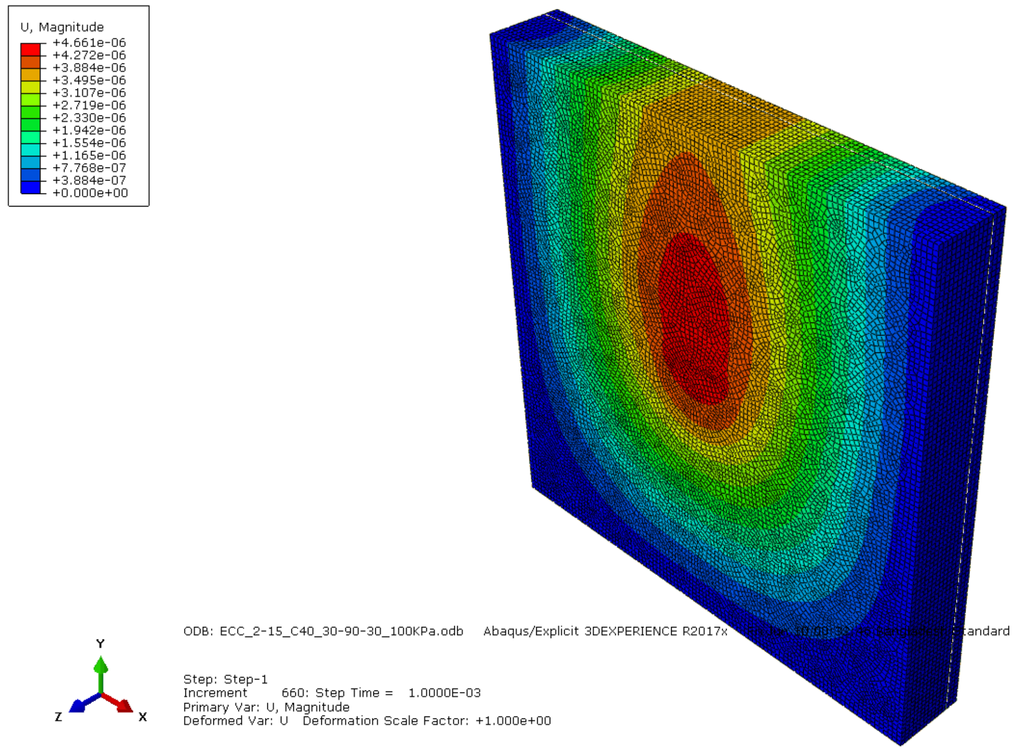

Figure 24: ECC 2-1.5 – C40 30mm-90mm-30mm Model Displacement (100KPa Impact).

4.3.4 COMPARISON OF DIFFERENT TYPES OF ECC FOR ECC – C40 30MM-90MM-30MM MODEL DISPLACEMENT (100KPA IMPACT)

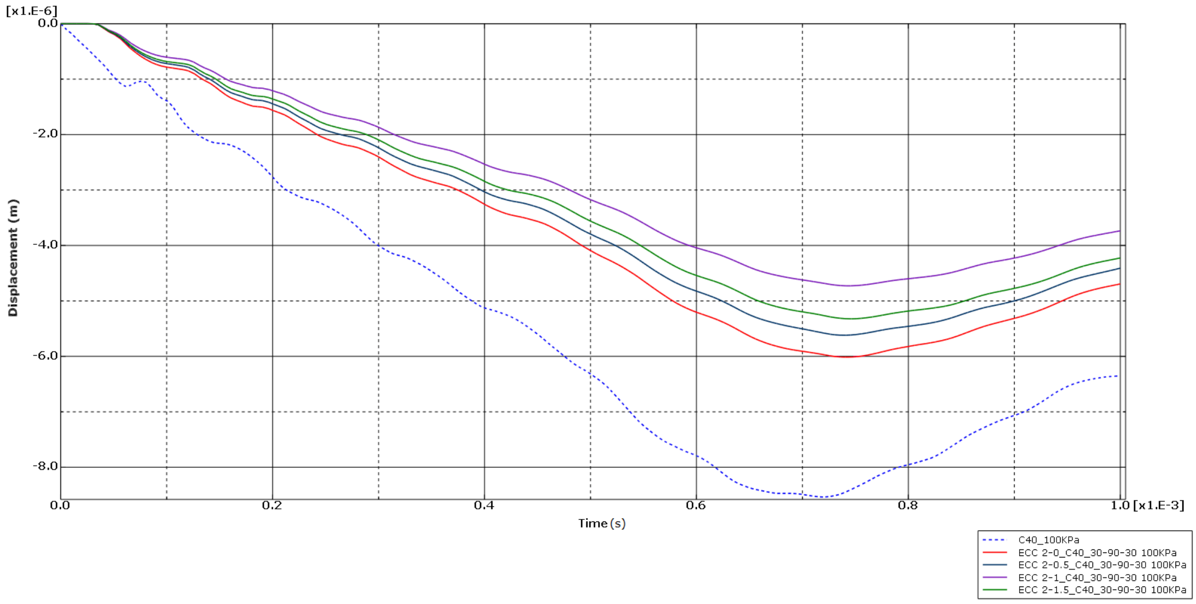

Figure 25: Different types of ECC for ECC – C40 30mm-90mm-30mm Model Displacement (m) vs Time (s) (100KPa Impact).

From the analysis it is noticeable that ECC 2-0 has the highest displacement over time than other ECC mixes. ECC 2-0 only has 2% PVA fiber in volume fraction and doesn't contain any SMA fiber.

Where ECC 2-0.5 contains 0.5% of SMA fiber in volume fraction, and it significantly reduces the displacement over time.

In case of ECC 2-1.5, it contains 1.5% of SMA fiber in volume fraction. It improves the shock absorption capacity by reducing displacement over time but comparing ECC 2-1 it has lower shock absorption capacity.

Therefore, ECC 2-1 reduces the displacement over time the most even though it has less SMA fiber in volume fraction than ECC 2-1.5. It is due to ECC 2-1 has the highest tensile strength than other ECC mixes.

4.4 DISPLACEMENT IN CASE OF VARIOUS IMPACT FORCES

In case of ECC types, ECC 2-1 shows the highest shock absorption capacity than other ECC mixes and ECC-C40 30mm-90mm-30mm configuration shows the best results. For the comparison of various impact forces ECC 2-1 – C40 30mm-90mm-30mm Model has been selected.

4.4.1 C40 CONCRETE 150MM BASE MODEL DISPLACEMENT (10KPA IMPACT)

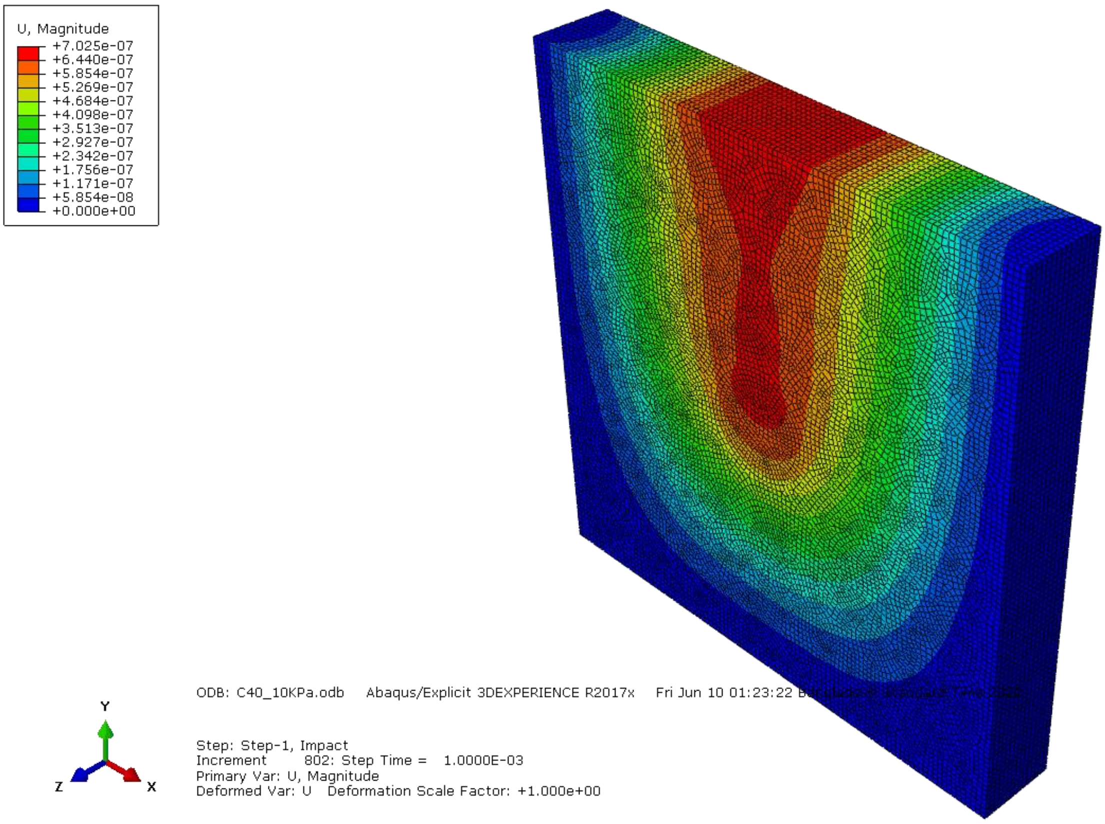

Figure 26: C40 Concrete 150mm Base Model Displacement (10KPa Impact).

4.4.2 ECC 2-1 – C40 30MM-90MM-30MM MODEL DISPLACEMENT (10KPA IMPACT)

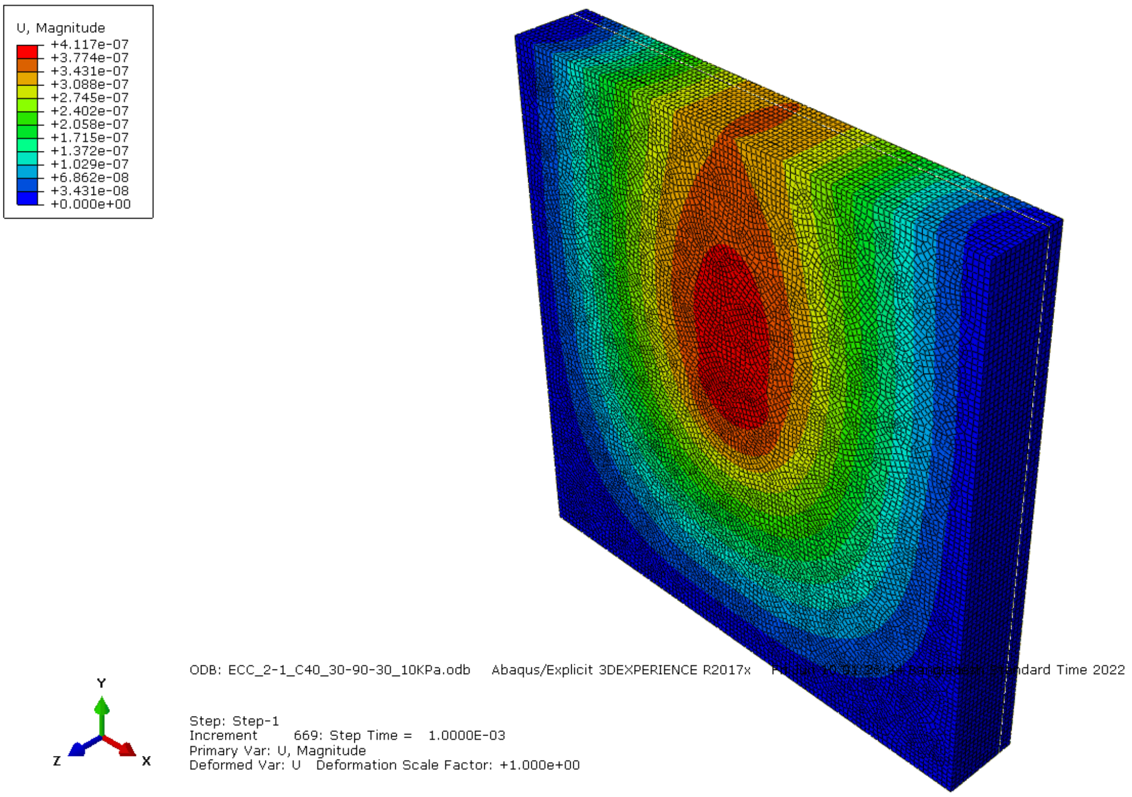

Figure 27: ECC 2-1 – C40 30mm-90mm-30mm Model Displacement (10KPa Impact).

4.4.3 COMPARISON OF C40 CONCRETE MODEL AND ECC 2-1 – C40 30MM-90MM-30MM MODEL DISPLACEMENT (10KPA IMPACT)

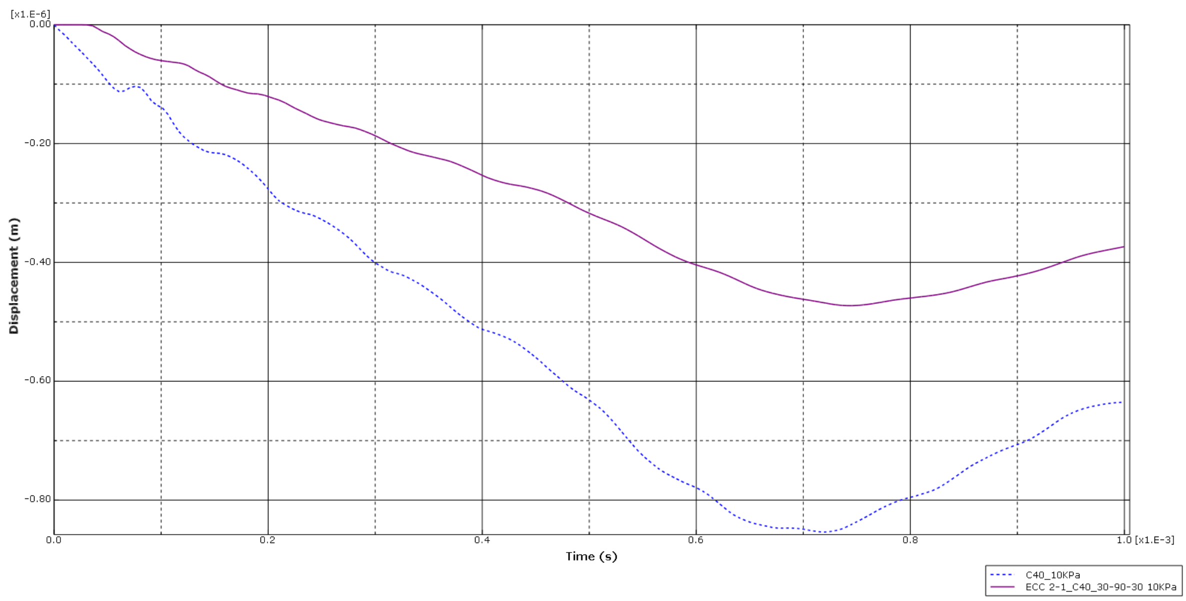

Figure 28: C40 Concrete Model and ECC 2-1 – C40 30mm-90mm-30mm Model Displacement (m) vs Time (s) (10KPa Impact).

From the analysis it is observed that by reducing the impact force from 100KPa to 10KPa doesn't change the fact that ECC-Concrete composite is still better in case of reducing the displacement over time than C40 concrete base model.

4.4.4 C40 CONCRETE 150MM BASE MODEL DISPLACEMENT (1MPA IMPACT)

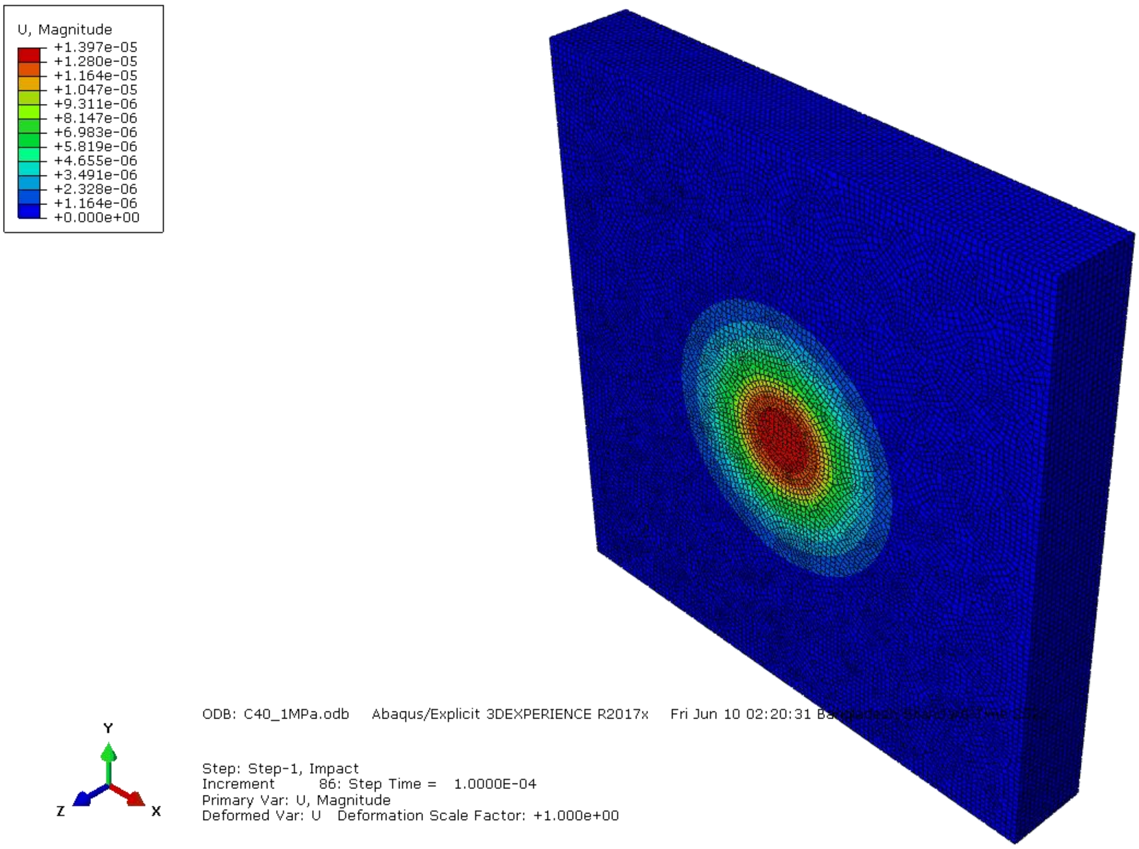

Figure 29: C40 Concrete 150mm Base Model Displacement (1MPa Impact).

4.4.5 ECC 2-1 – C40 30MM-90MM-30MM MODEL DISPLACEMENT (1MPA IMPACT)

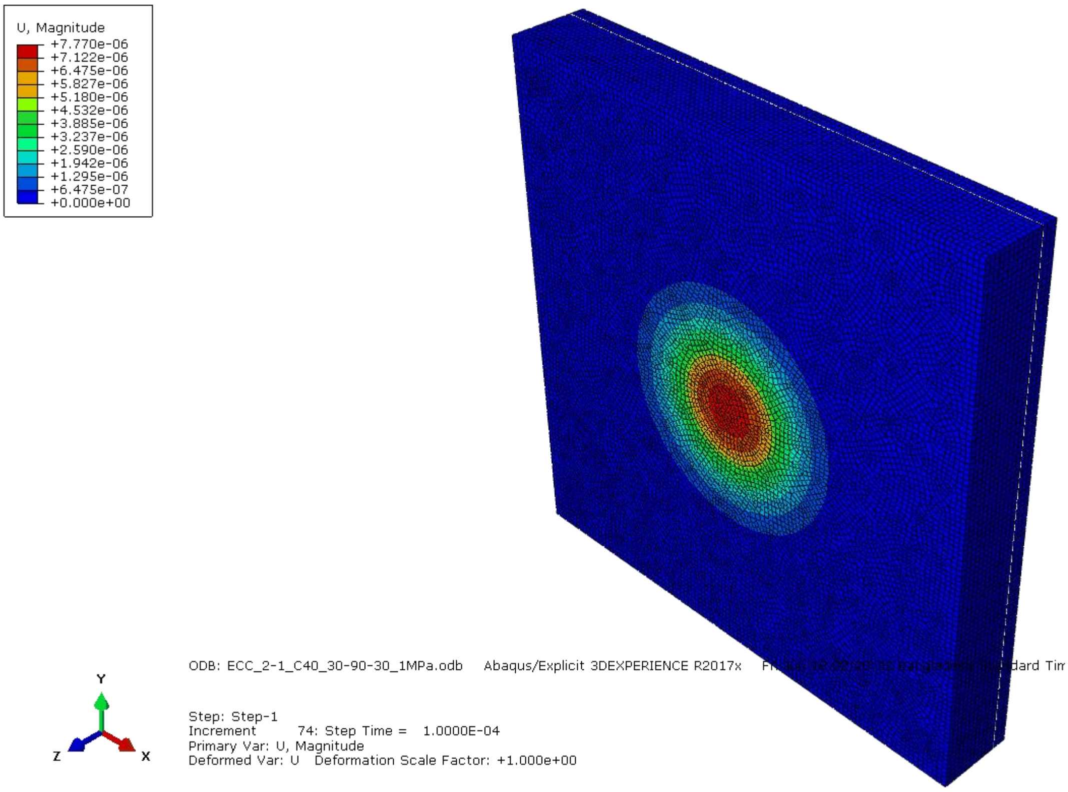

Figure 30: ECC 2-1 – C40 30mm-90mm-30mm Model Displacement (1MPa Impact).

4.4.5 COMPARISON OF C40 CONCRETE MODEL AND ECC 2-1 – C40 30MM-90MM-30MM MODEL DISPLACEMENT (1MPA IMPACT)

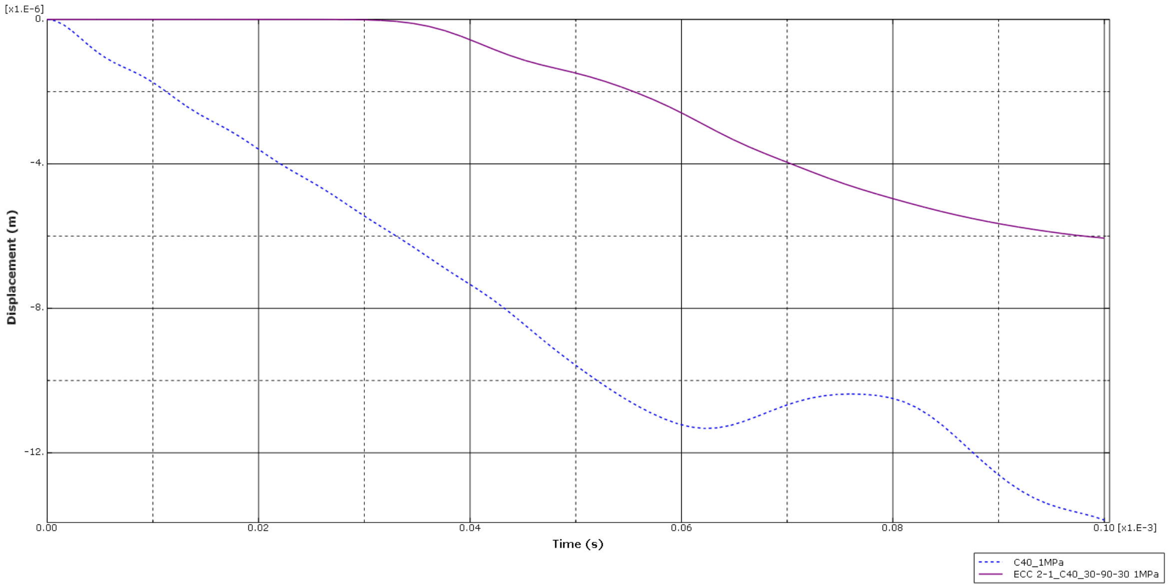

Figure 31: C40 Concrete Model and ECC 2-1 – C40 30mm-90mm-30mm Model Displacement (m) vs Time (s) (1MPa Impact).

For 1MPa impact it has been observed some changes in the analysis. In case of C40 concrete the displacement curve goes downward till a certain point. Then it goes upward again, then straight downward again. It is due to C40 losing its shock absorption capacity and creating damage on the model's impact surface.

But in case of ECC 2-1 – C40 30mm-90mm-30mm model the curve goes downward like C40 concrete but displacement over time, as expected is way less than C40 concrete base model.

Thus, in case of various impact forces the ECC-Concrete has higher shock absorption capacity than C40 concrete.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 General

As previously stated, three models were built which include four types of ECC in order to achieve the goal of this research. Some conclusions may be drawn after studying the findings of these models. This chapter contains all of the specifics necessary to get the desired result. The main purpose of this study was to find out what the best ECC-Concrete layer composition configuration and thickness were for withstanding impact forces. Based on the data and discussion in Chapter 4, this chapter summarizes the research findings. In addition, this chapter also includes suggestions for future research related to this experiment.

5.2 Conclusions

Analyzing all the data the following conclusions are made:

- The inclusion of an ECC layer to concrete greatly reduces distortion, indicating a greater shock absorption efficiency.
- When comparing the ECC-Concrete 50mm-100mm and ECC-Concrete-ECC 25mm-100mm-25mm model configurations, the ECC-Concrete 50mm-100mm model has a somewhat larger displacement than the ECC-Concrete-ECC 25mm-100mm-25mm model. Even though the same amount of ECC was utilized in the experiment, adding a second layer (front and rear) of ECC increases the experimental wall's shock absorption capability.
- In all sorts of impact situations, ECC-Concrete-ECC 30mm-90-30mm outperforms the alternatives.
- But the difference between displacement of ECC-Concrete-ECC 25mm-100mm-25mm and ECC-Concrete 50mm-100mm isn't much comparing ECC-Concrete 50mm-100mm and ECC-Concrete-ECC 30mm-90-30mm / ECC-Concrete-ECC 25mm-100mm-25mm and ECC-Concrete-ECC 30mm-90-30mm.
- As a result, increasing the depth of the double ECC layer enhances the shock absorbing capacity marginally.
- The addition of shape memory alloy (SMA) fibers with polyvinyl-alcohol (PVA) fibers in ECC mixes significantly enhances shock absorption capability of the composite, according to graphical data from the experiment.

- But adding more than 1% by volume fraction of SMA fiber in ECC mix can lower the tensile strength of ECC mix. Therefore, the perfect ECC mix ratio would be 2% PVA and 1% SMA fiber for gaining the highest tensile strength of the model.
- In case of different impact forces ECC-Concrete composite outperforms C40 concrete in every scenario.

5.3 Recommendations

Increasing the thickness of the ECC layers increases the shock absorption capacity, according to this study. Besides formation of ECC-Concrete layers and different types of ECC mixes also plays very important part. The displacement is varied since the same amounts of ECC is utilized but the layout is varied. Experimenting with different combinations will help determine the best layer size.

5.4 Future Scopes

- This study was performed by comparing C40 concrete as a base model due to lack of experimental laboratory data. But for better comparison, experimental laboratory data for compressive-tensile behavior of M60 or M70 concrete can be used to done similar type of study; since it has similar compressive strength as ECC mixes used in this study.
- Because this is a Finite Element Simulation (FEM) study, more research might be done utilizing other configurations, settings, impact force, ECC combinations, and other aspects, such as experimental lab studies.
- Similarly, road barriers can be studied. In the case of a traffic incident, increasing the shock absorption capacity of road barriers can help to decrease the vehicle damage.

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