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Deanship of Graduate Studies and Scientific Research

Master of Civil Engineering

Strengthening reinforced concrete beam with Ultra High Performance Concrete

Done By
Abdelrahman Amer Mosllam Salahat

Supervisor
Ph.D. Abdulsamee Halahla

Thesis submitted in partial fulfillment of requirements of the degree

Master of Civil Engineering

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The undersigned hereby certify that they have read, examined and recommended to the Deanship of Graduate Studies and Scientific Research at Palestine Polytechnic University:

[Strengthening reinforced concrete beam with Ultra High Performance Concrete]

[Abdelrahman Amer Mosllam Salahat]

in partial fulfillment of the requirements for the degree of Master in Renewable Energy & Sustainability.

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Thesis Approved by:

Name:

Dean of Graduate Studies & Scientific Research

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[Strengthening reinforced concrete beam with Ultra High Performance Concrete]

(**Abdelrahman Amer Mosllam Salahat**)

Abstract

Many researchers studied and used different materials to strengthen and rehabilitate the concrete beam, we know that the concrete beam is a structure element that can be deformed from applying loads to it and there are two types of deformations to the concrete beam shear failure and flexure failure.

Examples of such materials include carbon polymer fiber concrete (CFRP), glass polymer fiber concrete (GFPR), shape memory alloy (SMA) and ultra high performance concrete (UHPC)... etc.

In this thesis, analysis and investigation to strengthen concrete beam sample using UHPC from practical experience, comparing results with finite element method.

The study of parameters in this research is the thickness of the ultra-performance concrete layer where different thicknesses will be used 20,40,50mm, the length of the ultra-performance concrete layer where the length will be changed to 370mm at the beginning and end of the sample and 370mm in the middle and the shear reinforcement ratio. The results of tested beams showed the beneficial effects of strengthening the RC beams using UHPC, as evident from enhancement of the shear capacity and shifting of the failure mode from brittle to ductile with more stiff behavior.

تقوية جسر خرساني باستخدام الخرسانة فائقة الأداء

عبد الرحمن عامر مسلم صلاحات

المستخلص

درس العديد من الباحثين واستخدموا مواد مختلفة لتقوية وإعادة تأهيل الشعاع الخرساني، ونعلم أن الشعاع الخرساني هو عنصر هيكلي يمكن تشويهه من تطبيق الأحمال عليه وهناك نوعان من التشوهات لفشل قص الحزمة الخرسانية وفشل الثني.

ومن الأمثلة على هذه المواد خرسانة ألياف البوليمر الكربونية (CFRP)، وخرسانة ألياف البوليمر الزجاجية (GFPR)، وسبيكة ذاكرة الشكل (SMA) والخرسانة عالية الأداء (UHPC)... وما إلى ذلك.

في هذه الأطروحة، يستخدم التحليل والتحقيق لتقوية عينة الحزمة الخرسانية باستخدام الخرسانة فائقة الاداء من تجربة عملية، تم تحليلها ومقارنتها مع طريقة العناصر المحدودة النتائج. دراسة المعلمات في هذا البحث هي سمك الطبقة الخرسانية فائقة الأداء حيث سيتم استخدام سمك مختلف 20,40,50 مم، وطول الطبقة الخرسانية فائقة الأداء حيث سيتم تغيير الطول إلى 370 مم في بداية ونهاية العينة و 370 مم في المنتصف ونسبة تعزيز القص. أظهرت نتائج الحزم المختبرة الآثار المفيدة لتقوية حزم RC باستخدام UHPC، كما يتضح من تعزيز سعة القص وتحويل وضع الفشل من هش إلى مطاطي بسلوك أكثر صلابة

Declaration

I declare that the Master Thesis entitled” Numerical investigation of flexural and shear behavior of reinforced concrete beam strengthening with Ultra High Performance Concrete” is my own original work, and herby certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

Student Name :Abdelrahman Amer Mosllam Salaha**t**

Signature:———————————— Date:————————

Dedication

Thanks be to God Who is always helping us to success

To my loving parents that are a great support in the life

To my brothers and sister

To all friends and colleagues

To my teachers

To my precious persons

To all of them

Acknowledgement

I would like to thank my supervisor Ph.D. Abdulsamee Halahla for his continuous support and motivation while preparing this work. Ph.D. Belal Almassri the head of the Civil Engineering Department who worked hard to establish the plan for the Master's Degree in Civil Engineering. Ph.D. Haitham Ayyad and Ph.D. Naser Abboushi who I learned so much from their knowledge.

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Chapter 1 : Introduction

1-1 Background

Nowadays most buildings are concrete structures consisting of reinforced concrete . These buildings are designed based on different loads depending on the nature of use and based on global codes, but sometimes there is a shortage of construction or the durability of these structural elements resulting in an unexpected increase in loads, changes in conditions of service or the eating of steel rods as a result of chemical or other conditions. Where there are many ways of strengthening such as concrete jacket, carbon polymer fiber concrete (CFRP), glass polymer fiber concrete (GFPR), shape memory alloy (SMA) and ultra high performance concrete (UHPC).

Normal concrete is a combination of well-known ingredients such as cement, sand, aggregate and water where they are mixed in certain proportions to form according to the required strength where their compression strength ranges from (20 - 40) MPa and tensile strength is less than 5Mpa, Also Flexural strength less than 6MPA with Durability and ductility weak, as science and studies on concrete evolve, researchers and laboratories are able to develop a new type of concrete called ultra-high performance concrete where it attracted a lot of attention due to its excellent mechanical properties and high durability, Its compression strength reaches more than 150 MPa, tensile strength of more than 8 MPa and negligible permeability. UHPC was developed in the context of vertical urban centres, which demand improved concrete property to comply with higher building loads.

The UHPC matrix features high cement contents, up to more than 800 kg/m 3, accurate totals smaller than 0.6 ml, Metal additives such as volatile ash, silica fumes, or granulated blast furnace slag, water/cement ratios under the contents of 0.2 and high plasticizers , This combination of high quantities of link and very precise combinations greatly reduces the porosity of the matrix and ensures the low water/link ratio of high-strength cement paste, while superplasticizers ensure good working for the mixture. The low water content combined with the high quantities of the link tends to decrease hydration scores, making it possible for the remaining link to interact with water once the matrix is cracked, giving the material a regenerative property and reducing its permeability. Adding fiber to the matrix is necessary to increase the rigidity and flexibility of UHPFRC after cracking. Improving the tensile properties of UHPC is important in several aspects, such as improving shear resistance, increasing durability, improving overall structural performance UHPC fitness is improved by adding fiber to the matrix, and creating UHPFRC.

1-2 Problem :

There are two types of failure of concrete beams, shear failure and flexure failure where the failure resulting from shearing is usually a diagonal cracks and flexure failure is a vertical main cracks. In this research we will study the effect of UHPC addition on these two types of failure and the figure below show an example of the two types of failure:

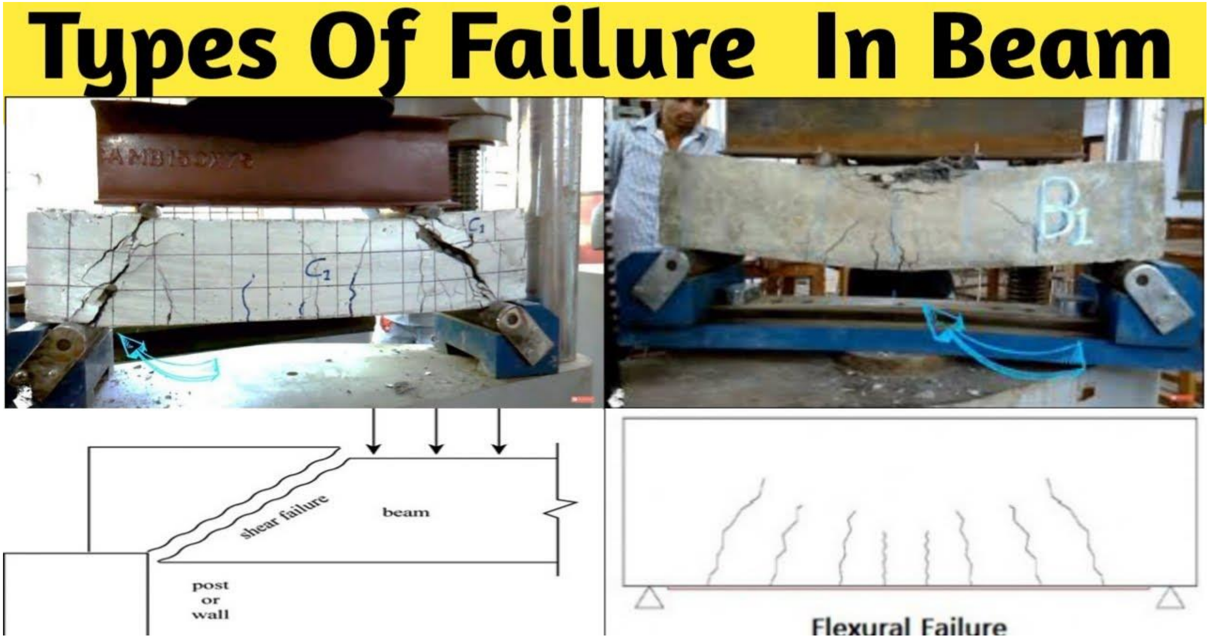


Figure 1 : Types of failure in beam

1-3 Research Significance and objectives:

The work done in the thesis is to investigate the use of ultra-high performance concrete for flexure and shear strengthening for reinforced concrete beams (RC) using two layers of UHPC and study their impact on concrete beam and identify an effective approach to strengthen it. UHPC has been used for its high effectiveness and excellent properties that make it suitable for use

1-4 Methodology

In this study the analysis and numerical investigation of a concrete beam. ABAQUS software will be hired to model a beam subjected to loads cause some deformation, this deformation will be treated and analyzed by Finite Element Method (FEM), compared and verified with laboratory work done by Bahraq, Ashraf Awadh et al (2019) and then will be some upgrades and different parameters to be studied.

Chapter 2 : Literature Review

This chapter will contain a summary of previous experiences and studies exploring the use of reinforcement strategies for construction elements in general and addressing reinforcement of construction elements and concrete beam using UHPC.

There are many methods that have been developed to rehabilitate concrete beams over the decades. (B. Täljsten et al 2003). There are many techniques to strengthen structural elements, and these techniques include mineral fibers, FRP, which is used to strengthen various elements such as columns, beams, etc. These fibers have different types that are strips, wires, rods.

Carbon fiber FRP consists of a mixture of two or three materials to form a matrix of reinforced polymer fibres. There are different types of mineral fibers, such as AFRP, CFRP and GFRP.(B. Benmokrane et al 2000) . (N. Attari et al 2012) . (T. Uomoto et al 1995) .(G. Tumialan et al 2000).

The best types mentioned are CFRP, which offers the best performance among them due to their attic endurance compared to the other two. WFP has also been used largely to strengthen and reform various structural elements. There are many advantages, including its high endurance and increases hardness, durability and maximum load capacity. (A. Nanni et al 2003). (M. Samaan et al 1998). (M. Ameli et al 2007). (F. Bencardino et al 2002) . (F. Katsuki et al2000)

Strengthening the Near Surface Structural Element (NSM) which also works with composite materials such as FRP is being studied and used in scientific research. **(**Bilotta A el al 2011) .(De Lorenzis L et al2007). (Al-Mahmoud F et al2010).

Where in this way, grooves are made in the concrete cover, and then improved materials such as FRP are introduced. After that, the grooves are filled with adhesive materials such as epoxy. (Kreit A et al2011)

Researchers have done numerous studies on the forms and types of failure of reinforced concrete beam with NSM-CFRP and the patterns of failure varied between each research and another according to previous studies. Failure is either a deformation of CFRP or a crash of concrete. There are kinds of early failures that occur such as separation in the concrete cover or epoxy adhesive. (J. Teng et al2006). (L. De Lorenzis et al2007)

A study was conducted to predict the conduct of NSM-CFRP reinforced concrete beams failures. The results of his study showed that the amount of increase in the length of NSM CFRP in the concrete beam increases its resistance to failure. (Teng JG et al2016).

(Almassri, B. and Halahla2020), They did a study on a corrosive concrete beam that was reinforced by a bar of NSM-CFRP with an external steel plate where the results showed an increase in capacity yield and capacity moment and showed results close to the non-corroded sample.

(Obaidat et al 2020) , They studied the behaviour of the reinforced concrete beam with NSM-CFRP with a steel plate at the end where the results showed that the reinforced samples increase the maximum load capacity and increase the behavior of the stiffness and hardness.

Researchers used many materials for rehabilitee and strengthening such as fiber reinforced polymer FRP , carbon fiber reinforced polymer CFRP , shape memory allow for strengthening and rehabilitate concrete member (Chen and Teng 2003) . The researchers found that CFRP and FRP have some shortcoming as low fire resistance , fading bonding ... etc.

Researchers used Ultra High Performance Concrete (UHPC) , this new material have high fire resistance , bonding and jacketing, it fixed a lot of problem and solved the shortage in other materials (Li 2004) . Ultra High Performance Concrete , is a new material that used to strengthening R.C. is an element that consist of cementitious materials , high tensile fiber , and little amount of water (Al-osta 2018) . Or defined as cementitious materials have compressive strength more than 150 Mpa and high durability (B.A. Graybeal 2009)

Many researcher study high strength concrete in last decade they found that shear and flexure behavior change and increase when they used High Performance Fiber Reinforced concrete (HPFRC) which studied by Alaee (Alaee et al. (2003)) . This study found that HPFRC increase fluxed and shear strength of RC member . Farahat (Farhat et al. (2007)) studied behavior of collapsed beam and rehabilitation of beam using High Performance Fiber Reinforced Cementitious Composite (HPFRCC) . Conclusion showed if we strengthening beam from tension and compression side of HPFRCC ultimate failure load up to 86% . (Hussein and Amleh (2015)) studied shear and flexure of R.C beam normal concrete composite with UHPC , without stirrups . it concluded that composite technique increase shear and flexural strength of beam . Martinola et al (2010) (Martinola et al (2010)) study experimentally and numerically of high performance fiber reinforced concrete (HPFRC) by strengthening of 40 mm layer .

The result showed jacketing of UHPC increase load capacity up to 2.15 . (Noshiravani and Burhwiler (2013)) studied experimentally of R.C. section composite with UHPC at tensile face . It concluded that UHPC is an effective shear strength . (Bastiien – Masse and Bruhwiler (2014)) studied R.C. beam and slab strengthening by 50 mm layer of UHPC under different load . The result showed that layer of UHPC increase load capacity effectively . (Lampropoulos et al (2016)) used jacketing UHPC in compression side , tensile side and three side jacketeing . They found that three side jacketing increase moment capacity of the element .

UHPC have attractive properties such as high strength, high flow ability, high ductility, service ability and high corrosion resistant . (Ahmad et al.2015) .

The flexural behavior of UHPC-enhanced normal RC beams was studied experimentally by (Al-Osta et al (2017)) . It recommended that flexural and stiffness was increased when strengthening of this technique .

(Al-Osta et al (2017)) They used the concrete damage plasticity theory to construct a finite element model of reinforced flexural beams, and they discovered that their suggested model predicted the load–deflection response and crack patterns in consistent with the experimental data.

Chapter 3: Finite element model Program

3-1 General

A previous laboratory experiment was done by Bahraq, Ashraf Awadh et al (2019). Now we will do a simulation of the concrete beam on the ABAQUS program used in finite element method, and verify the results of this simulation with the result of the laboratory so that we can study new parameters for development from the concrete beam

3-2 Geometry of Beam

The concrete beam used in the Apaqus verification program obtained from paper (Bahraq, Ashraf Awadh et al (2019) is a rectangular concrete beam with a length of 1120 mm, a width of 140 mm and a height of 230 mm, strengthened by a layer of 30 mm UHPC and the attached figure shows the shape and dimension of the sample

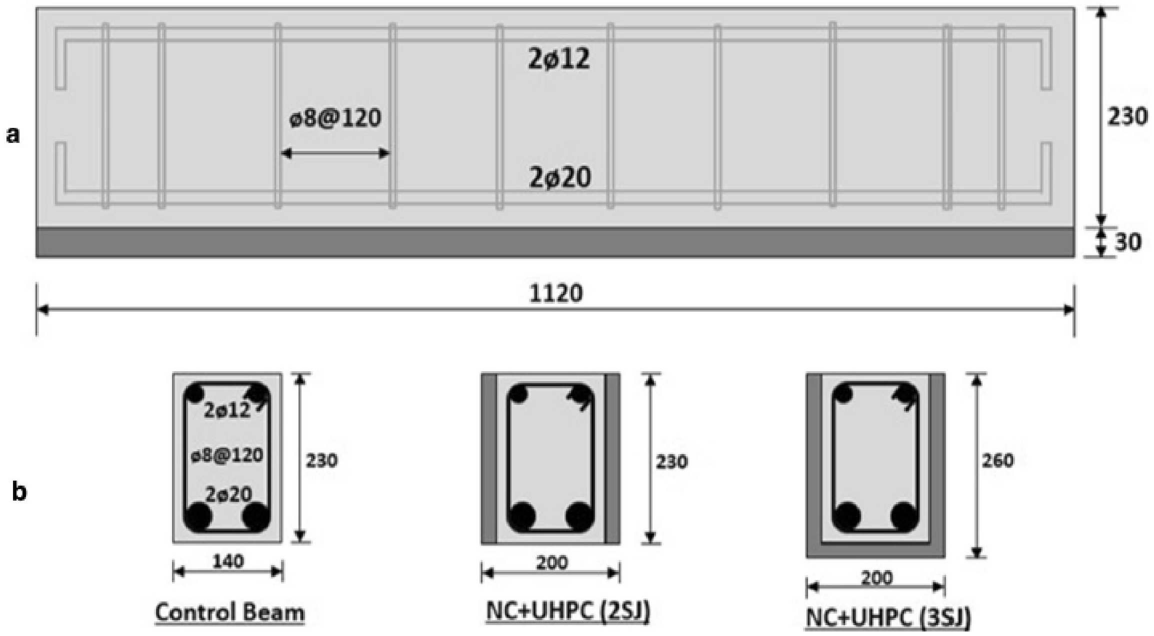


Figure 2: : a RC beam details, b strengthening configurations (all dimensions in mm)

3-3 Specifications of material

The concrete damage-plasticity (CDP) model used to represent the plastic behavior of concrete in compression and tension. plasticity theory is only appropriate in compression zones . This model employs two basic failure criteria: compressive crushing and tensile cracking of concrete. Furthermore, the yield function used in the plasticity model founded by Lubliner et al. (1989) and modified by Lee and Fenves (1998) . The damage variables are dt and dc where indicate to tension and compression damage parameters respectively . Fig3.showed damage variables . Based on the formulae supplied by Birtel and Mark (Birtel 2007) , the compressive and tensile damage parameters are determined from the following equations :

- Compressive damage parameter (d_c):

$$d_c = 1 - \frac{\sigma_c E_c^{-1}}{\varepsilon_c^{pl}(1/b_c - 1) + \sigma_c E_c^{-1}}. \quad (1)$$

- Tensile damage parameter (d_t):

$$d_t = 1 - \frac{\sigma_t E_c^{-1}}{\varepsilon_t^{pl}(1/b_t - 1) + \sigma_t E_c^{-1}}. \quad (2)$$

where d_c and d_t are compressive and tensile damage parameters, σ_c and σ_t are compressive and tensile stresses of concrete, E_c is the modulus of elasticity of concrete, ε_c^{pl} and ε_t^{pl} are plastic strains corresponding to compressive and tensile strengths of concrete. b_c and b_t are constant parameters, $0 < b_{c,t} \leq 1$.

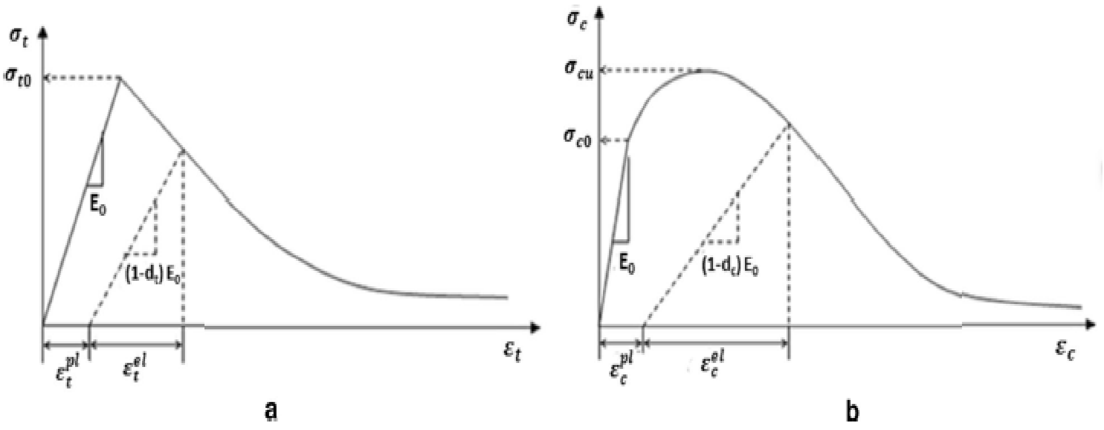


Figure 3 Damage variables: a in tension, b in compression (Bahraq, Ashraf Awadh et al (2019)

The mechanical properties of normal concrete , steel reinforcemenr , UHPC mixture proprortions and UHPC , are shown in Table 1 , Table 2 , Table 3 , Table 5 , respectively.

And Fig. 4 showed stress strain behavior for normal concrete and shear reinforcement & Fig. 5 for UHPC in compression and tension

Table 1: Mechanical properties of normal high grade concrete.

Property	**Min. value**	**Max. value**	**Average value**	**Standard deviation**
Compressive Strength (MPa)	59	71	65	4.6
Modulus of elasticity (GPa)	26	34	31	2.9

Table 2: Mechanical properties of steel reinforcement.

Material	**Property**	**Average value**
Steel rebar used as stirrups	Yield strength (MPa)	610
	Modulus of elasticity (GPa)	200.6
	Ultimate strength (MPa)	710.1

Table 3: Mixture proportions of UHPC for 1 m3 (Bahraq, Ashraf Awadh et al (2019)

Ingredients	**Cement**	**Micro-silica**	**Fine quartz sand**	**Water**	**Superplasticizer**	**Steel fibers**
Quantity (kg)	900	220	1005	163	40	157

Table 4: Mechanical properties of UHPC.

Property	Average value
Cubical compressive strength (MPa)	151.4
Direct tensile strength (MPa)	8.7
Modulus of elasticity (GPa)	41.0

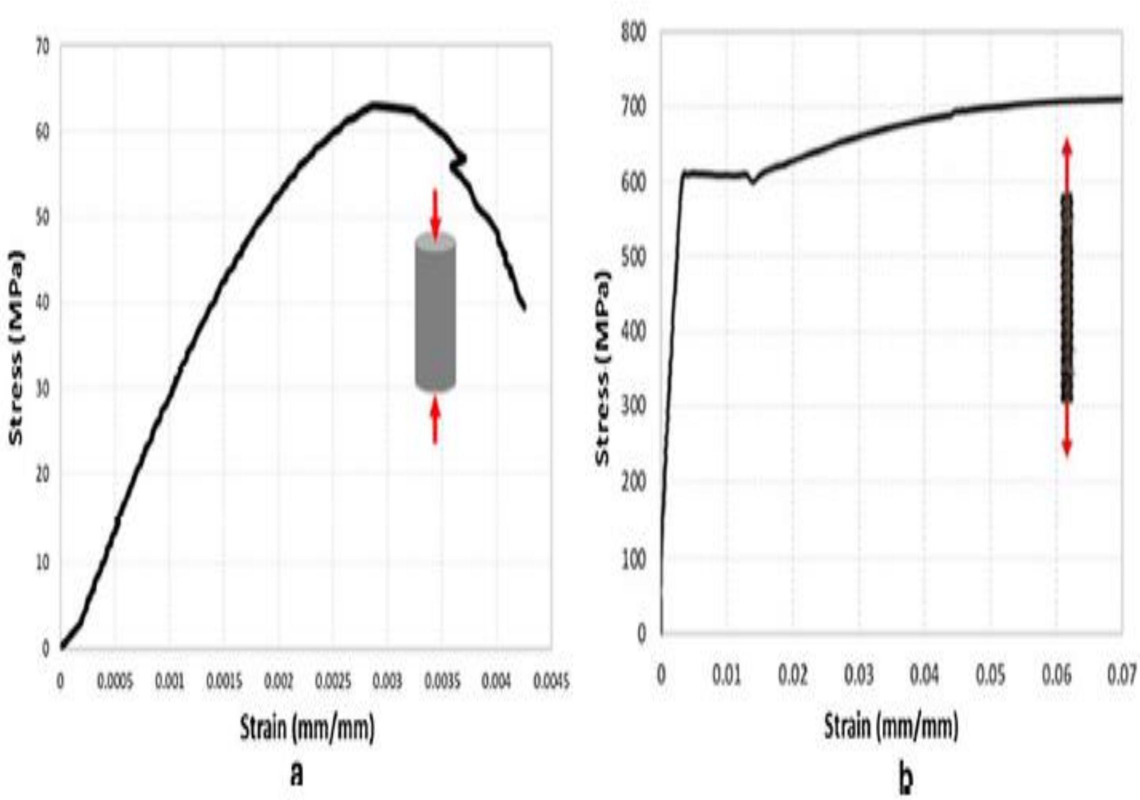


Figure 4 Stress-strain behavior a normal concrete, b shear reinforcement.

3-4 FE Modeling Considerations

All elements data modeled were taken from the experiment . Fig. 6 shown the nonlinear behavior for tension and compression of both the normal concrete and UHPC .

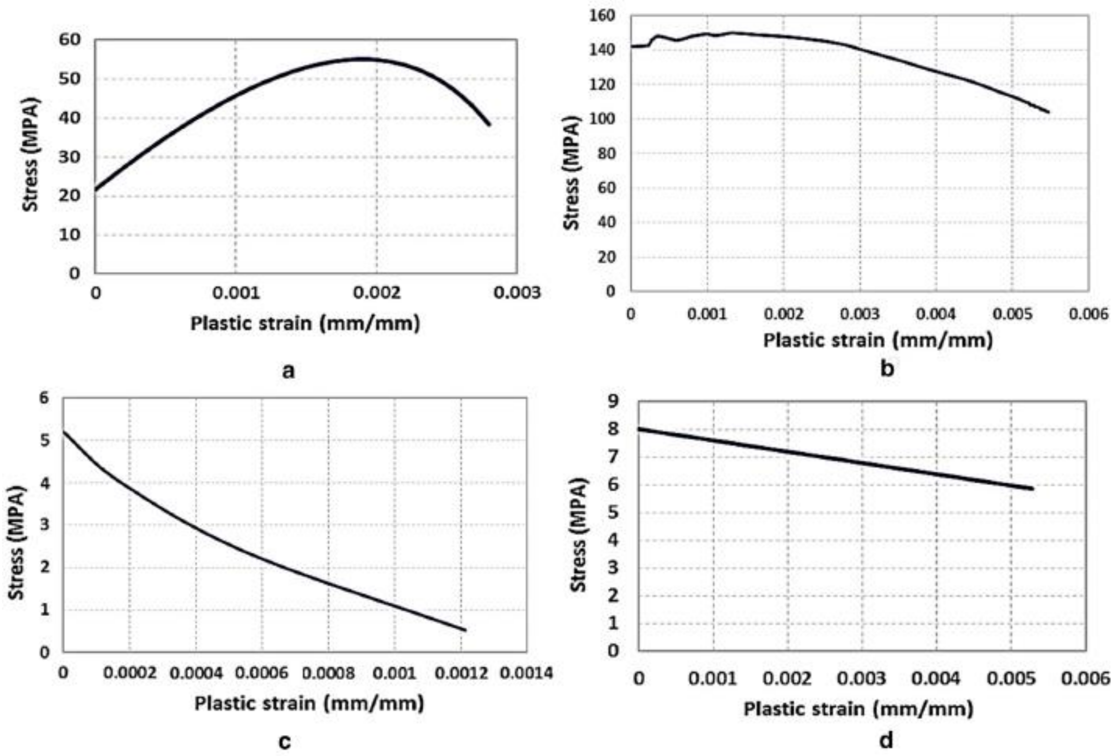


Figure 5: Nonlinear behavior of materials: a normal concrete in tension b normal concrete in compression c UHPC in tension d UHPC in compression.

Table 5 :Plasticity UHPC in ABAQUS

Dilation Angle, (ψ)	Viscosity, (μ)	Eccentricity	Stress ratio, (f_{b0}/f_{c0})	K
36˚	0.0001	0.1	1.16	0.667

Table 6 :Tension Nayal & Rasheeds Model In ABAQUS

Yield Tensile Stress, σt	εt ck Cracking Strain		dt damage Para.	εt ck Cracking Strain
0	0		0	0
3.814385927	0		0	0
2.937077164	3.16596E-05		0.23	3.16596E-05
1.716473667	0.000234149		0.55	0.000234149
0.1	0.000657845		0.97378346	0.000657845

The explicit dynamic technique is the most reliable way of applying the load in Abaqus. This approach is said to be successful for two reasons: first, it produces consistent findings with less convergence issues, and second, it is the most appropriate for materials like concrete in terms of capturing concrete fractures and general failure behavior (Mercan 2011). All data from F.E model compared with experimental data included load curve , ultimate failure load and cracks . this comparison showed that F.E model capturing most failure mode with good accuracy .

3-5 Modeling of UHPC

UHPC was modeled in Abaqus program such as normal concrete a solid material with 3D dimensional with a compressive strength (fc' = 151 Mpa) and thickness 30 mm along the beam (1120 mm length) Fig.7 , note that Abaqus can't identify the small fiber wire in UHPC

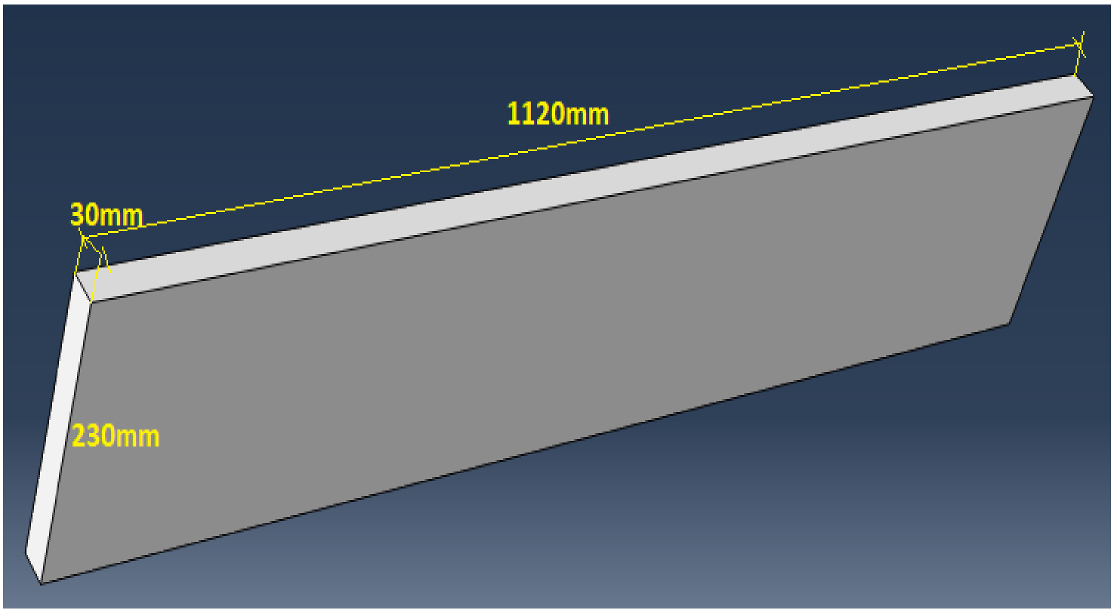


Figure6 : UHPC dimensions

3-6-Numerical modelling

In addition to the experimental examination, the shear behavior of the reinforced beams was studied numerically using the finite element approach. The primary goal of the numerical modeling in this work was to confirm the adequacy of the experimental data for highlighting shear behavior, which included depicting load against deflection graphs, failure loads, and cracking pattern. Abaqus finite element analysis software was used to create the numerical models. All element are defined as 3D modeling , steel reinforcement (longitudinal and transverse) modeling as wire with two nodes 3D truss elements , normal concrete , UHPC and steel plate modeling as solid extrusion with three nodes . The concrete-reinforcement-steel bond was represented as an embedded region , with the concrete as the host element. Normal concrete and UHPC , and normal concrete and steel plate was bonded by tie-bond .

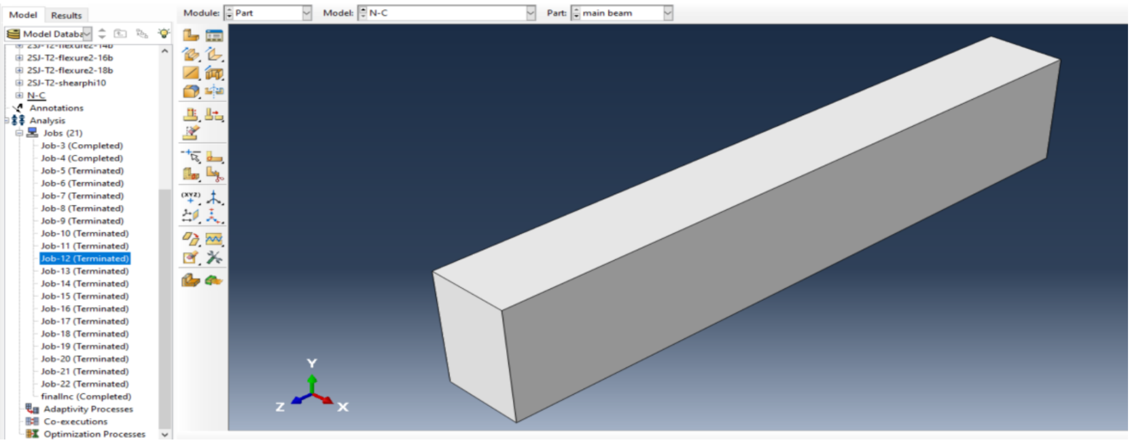


Figure 7 : Nc beam part

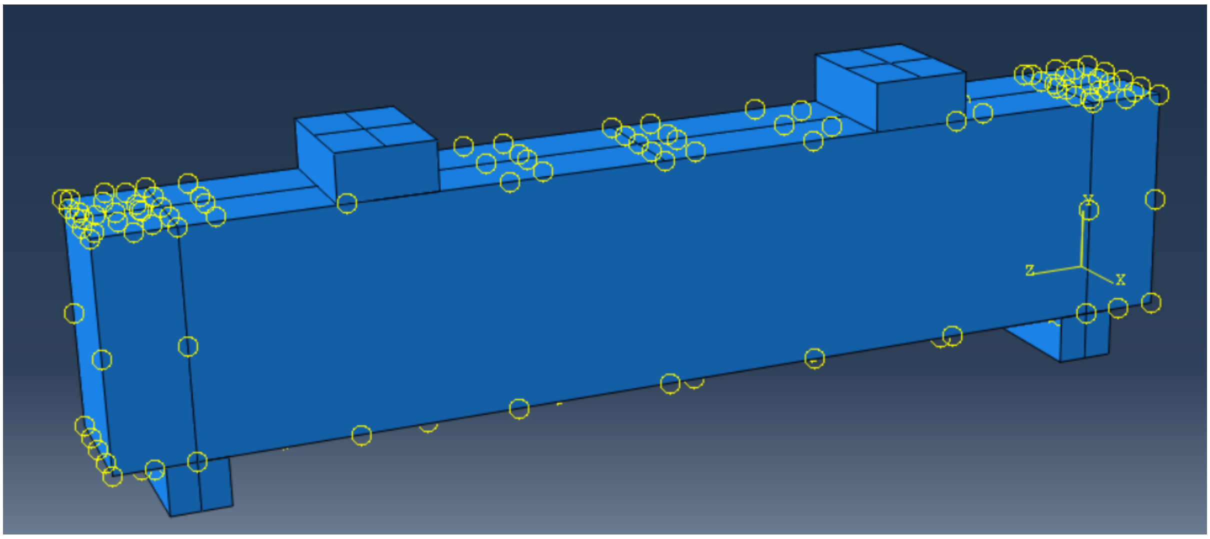


Figure 8: Tie constrain between beam and support plate , beam and load plate

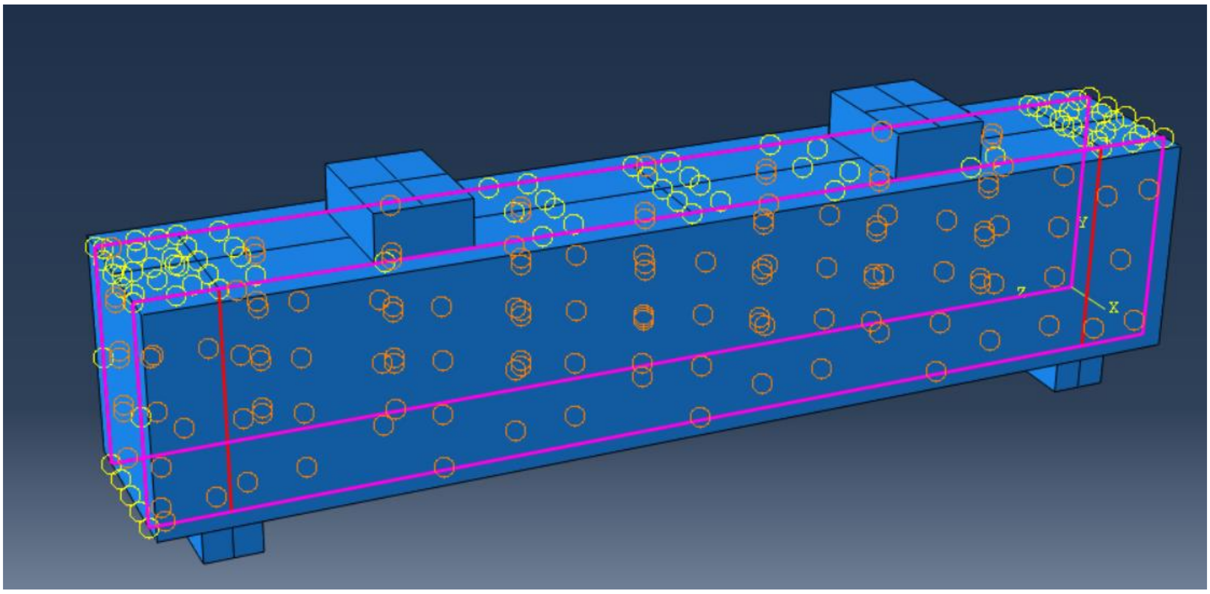


Figure 9 : Tie constrain between beam and UHPC

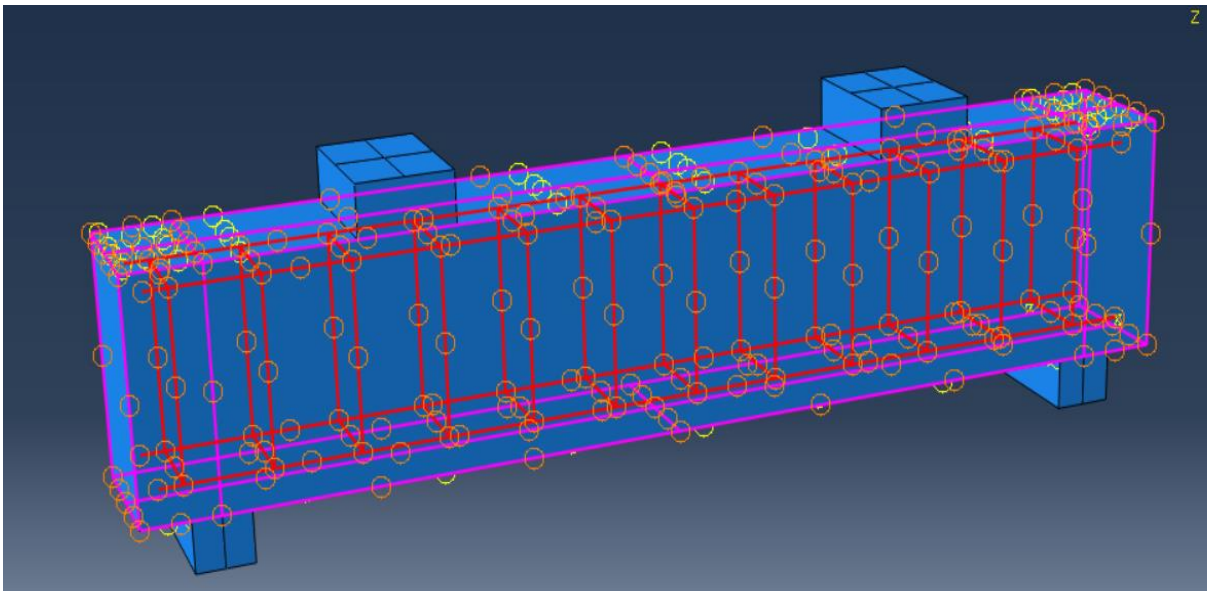


Figure 10: embedded constrain between beam and steel reinforced

3-7 loading and boundary conditions

The boundary conditions were utilized in modeling are the same ones that were used in experiments. Fig. 8 shows the arrangement of boundary conditions , the bottom of the beam have two supports , a pin support at right bottom to restrain translation of the point in the three orthogonal directions (X, Y, Z). At the opposite end, a roller is assigned to prevent translation along only (X and Z) directions. Two load plate are placed at top of the beam at distance 280 mm from each edge . the load applied as a displacement load (50 mm) .Three spotting points (LVDT) , one for displacement and the rest for load. Fig.8 show the experimental beam with load , Fig. 8 show abaqus detailing

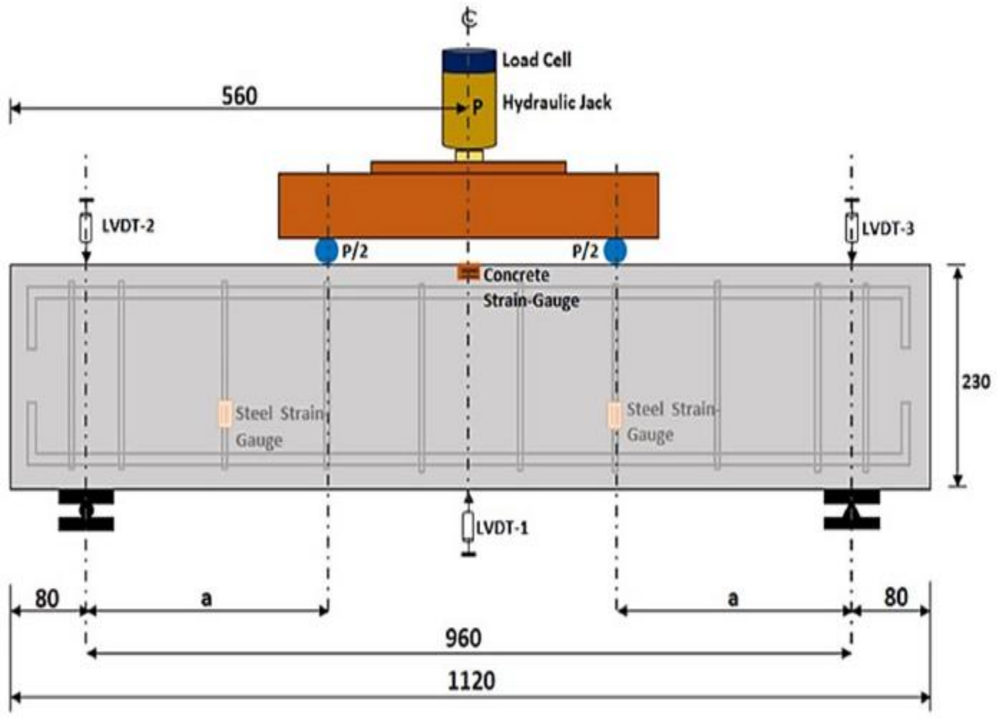


Figure 11: Schematic representation of beam testing setup (all dimensions in mm).

3-8 Verification of model data

3-8-1 Control beam (without UHPC)

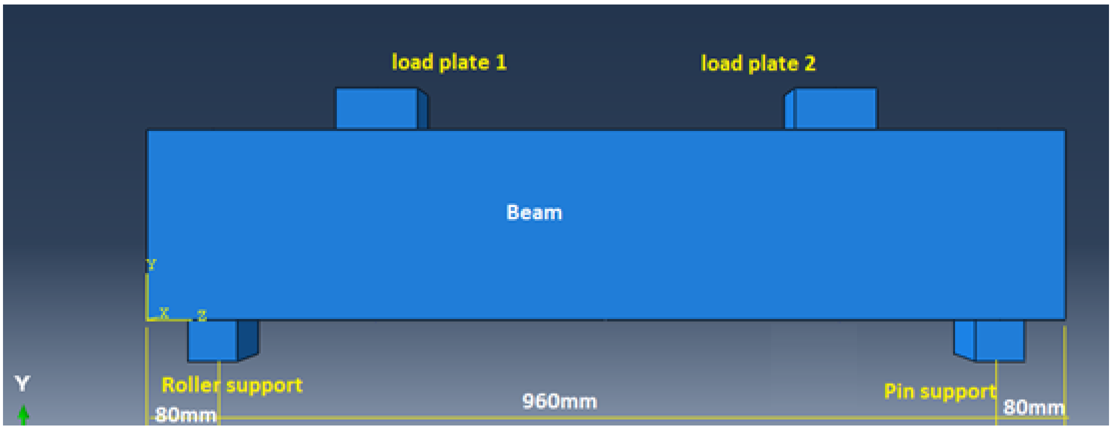


Figure 12: side-face control beam without UHPC

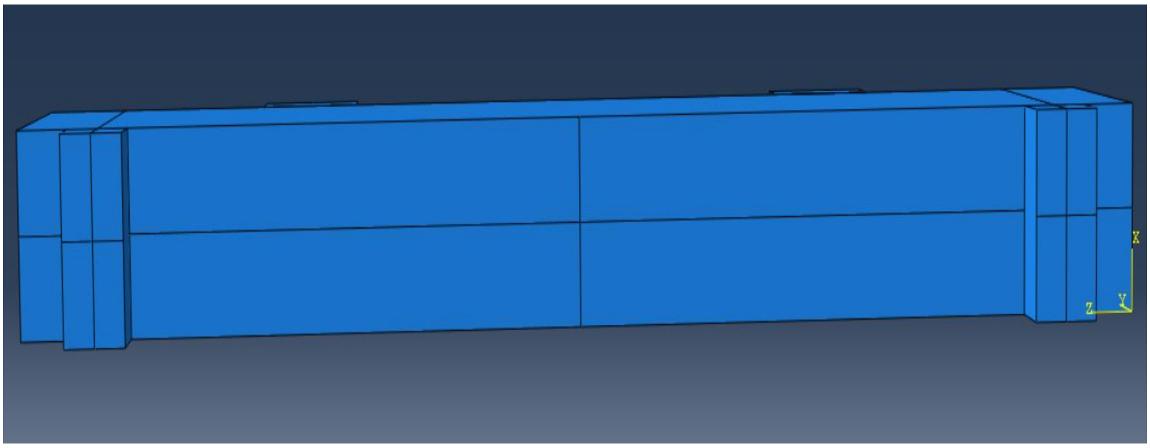


Figure 13: bottom-face control beam without UHPC

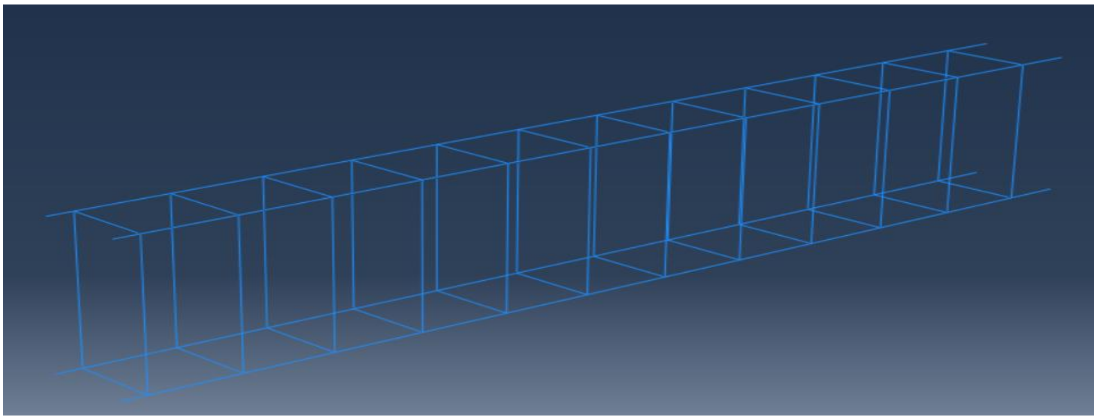


Figure 14: steel control beam without UHPC

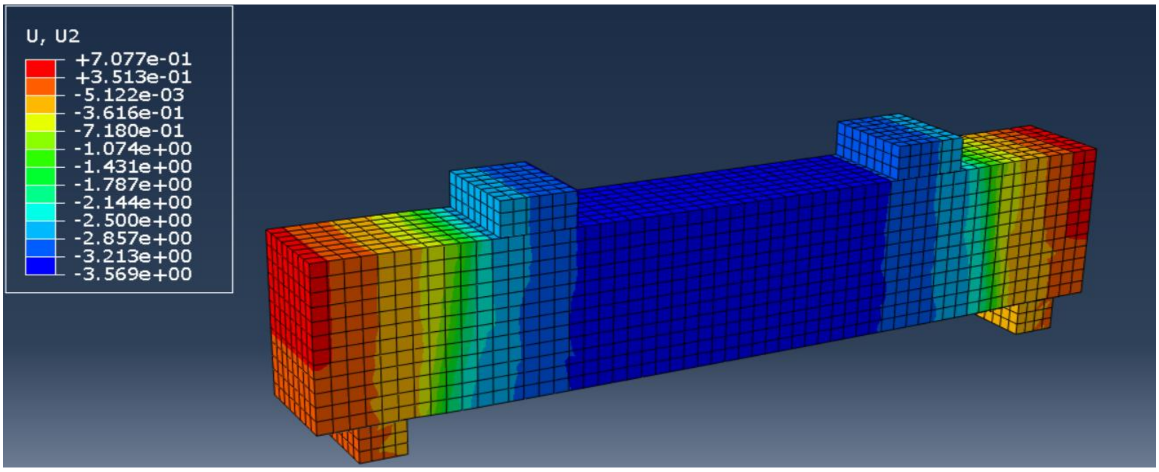


Figure 15: Without UHPC Model – U2 (Vertical Displacement)

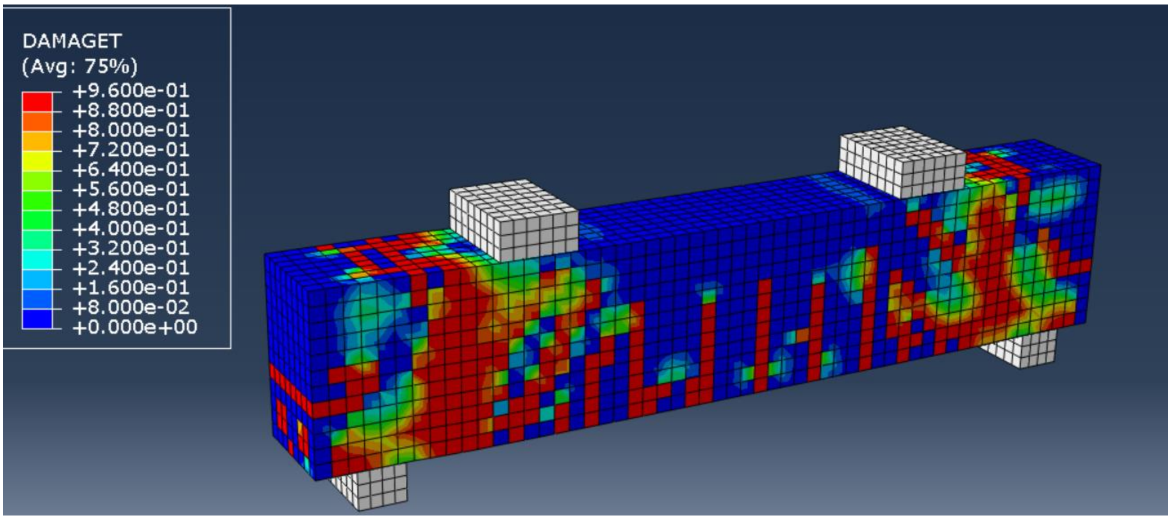


Figure 16: Without UHPC Model – Damage Tension

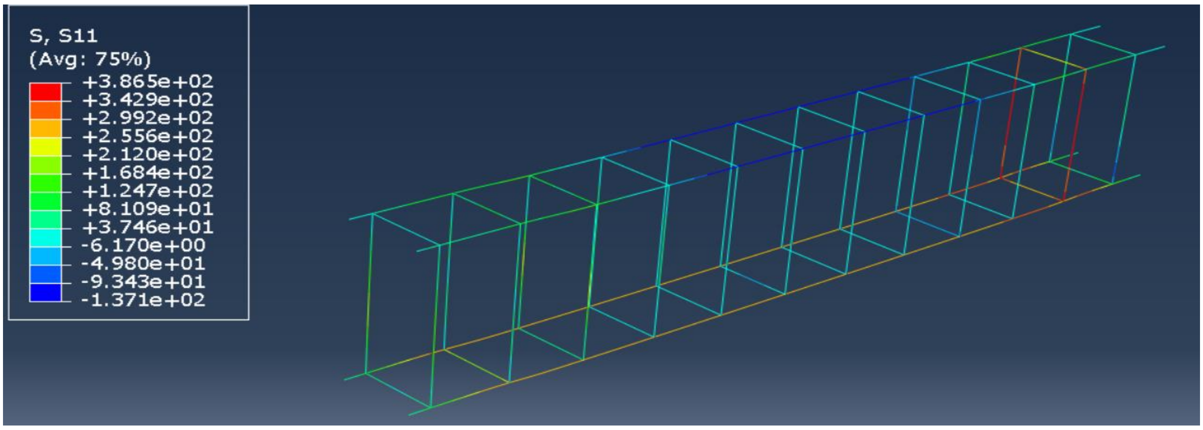
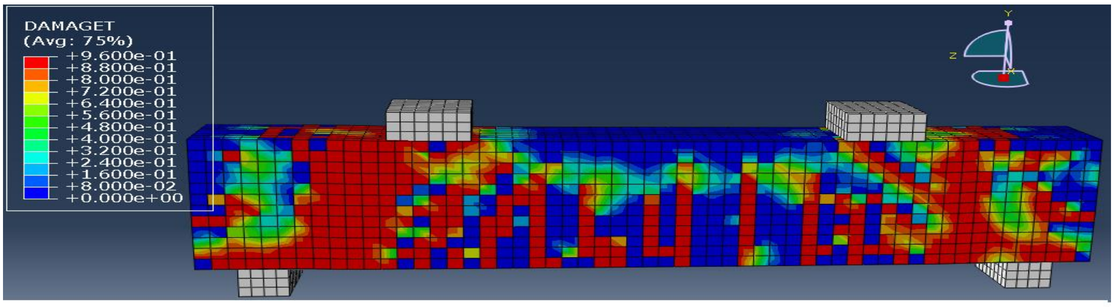


Figure 17 Without UHPC Model – Steel Normal Stress



The figure below shows the relation between load and displacement on the midspan of the beam (the converting point of the size of the beam) both given by the paper (Bahraq, Ashraf Awadh et al (2019) and obtained from the Abaqus software. Abaqus model showed a very similar behavior and reaction of the experimental beam. Maximum load capacities were approximately 383 kN and 369 kN in Abaqus model and experiment respectively at midspan displacement of 2.5mm. The difference of the maximum load capacity obtained from Abaqus is decrease about 3.8% which is acceptable percentage.

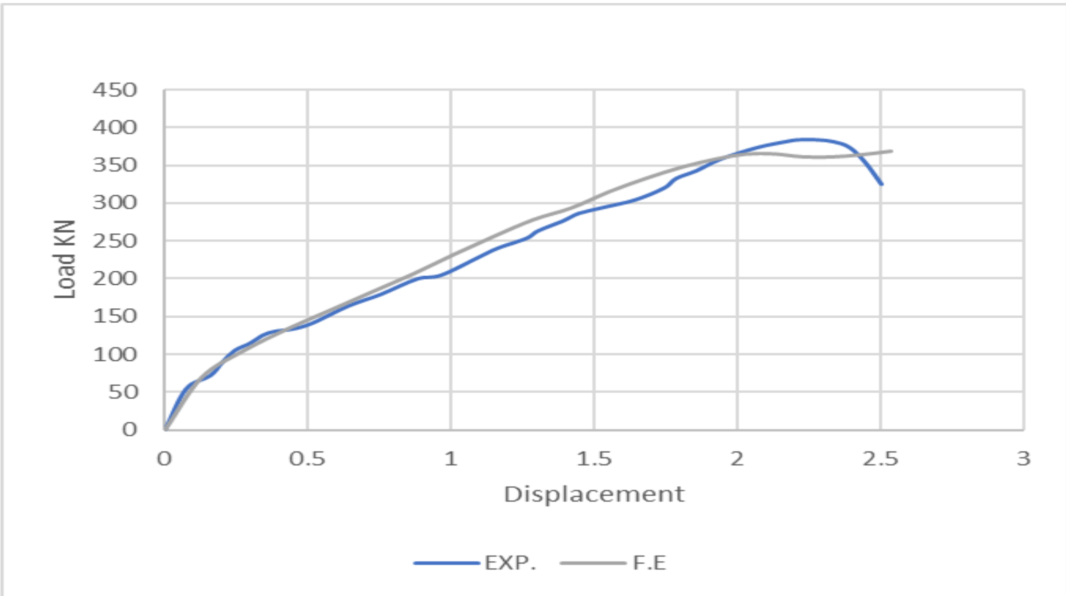


Figure 18: Load – Displacement Curve for original model

Figure 19: A failure mode (tension damage) of experimental and FE without UHPC

3-8-1-2: Meshing type and sensivity study

Solid components like concrete and UHPC are represented as eight-node linear brick elements . Steel reinforcement is provided by 2-node linear 3-D truss components. The best mesh sizes are chosen based on a sensitivity analysis in which a variety of global mesh sizes (20-50mm) is examined to ensure acceptable accuracy of the results. Fig. 17 shows that the best results were obtained through a 20-30 mm mesh. So the 20mm mesh is adopted .

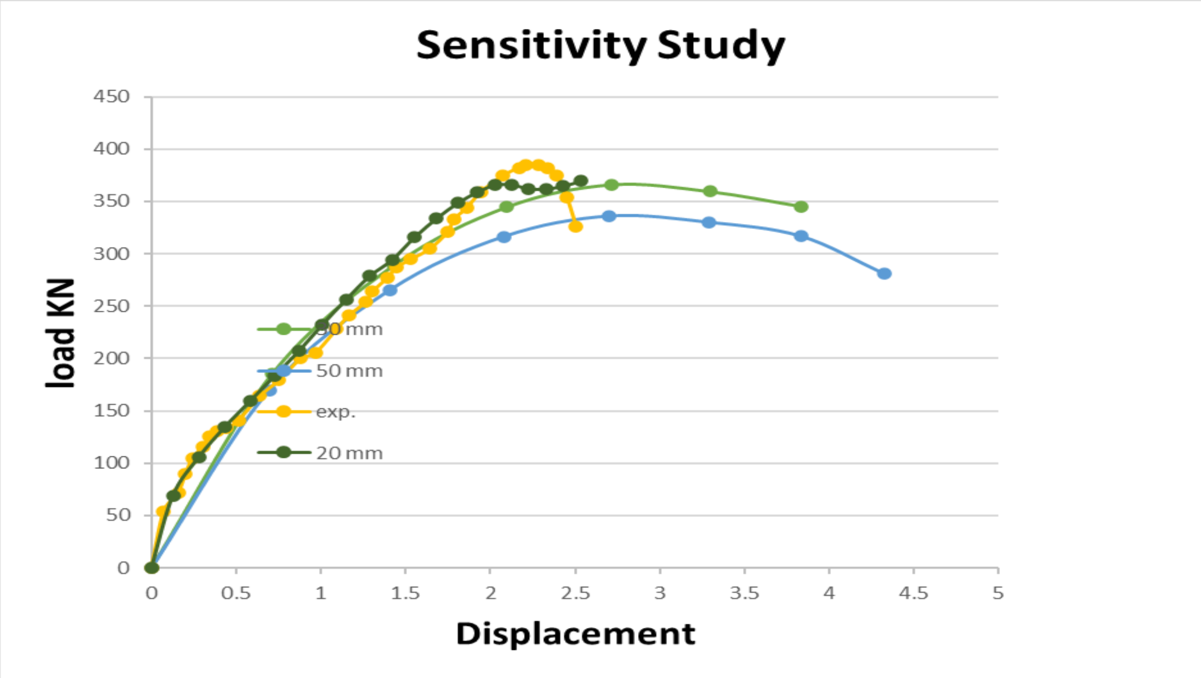


Figure 20: Effect of mesh size

3-8-2 beam with UHPC

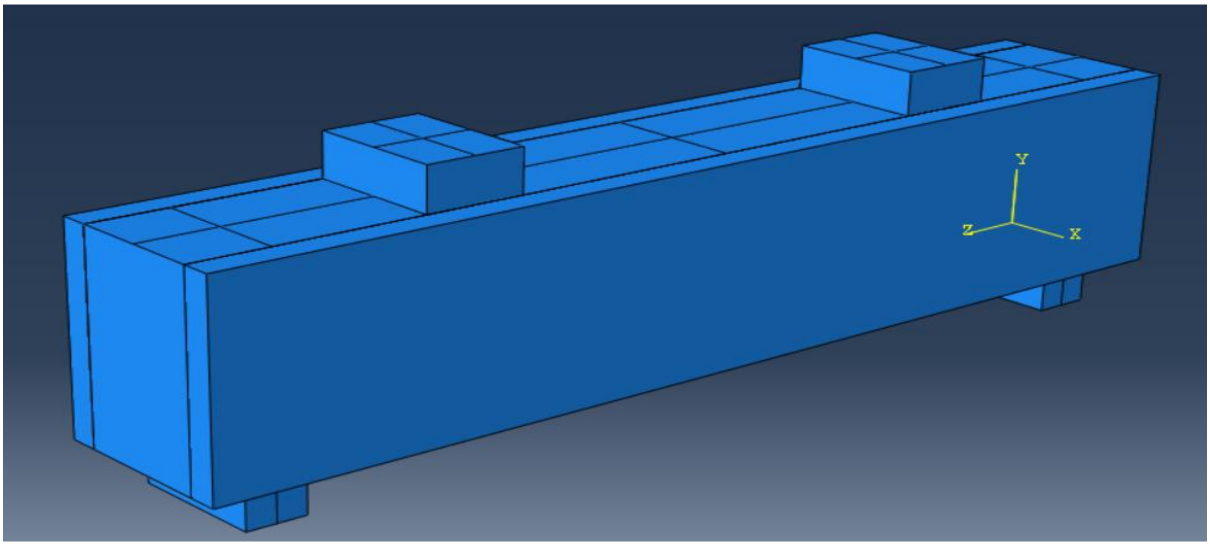


Figure21 : side-face beam with UHPC

Figure 22 : bottom-face beam without UHPC

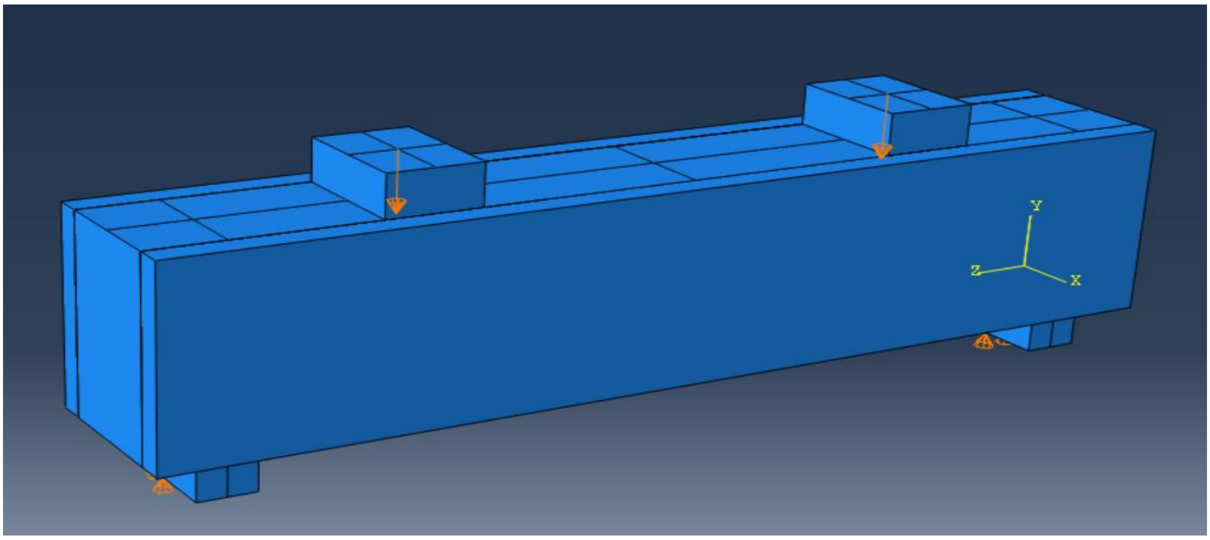


Figure 23: Load and supports' locations

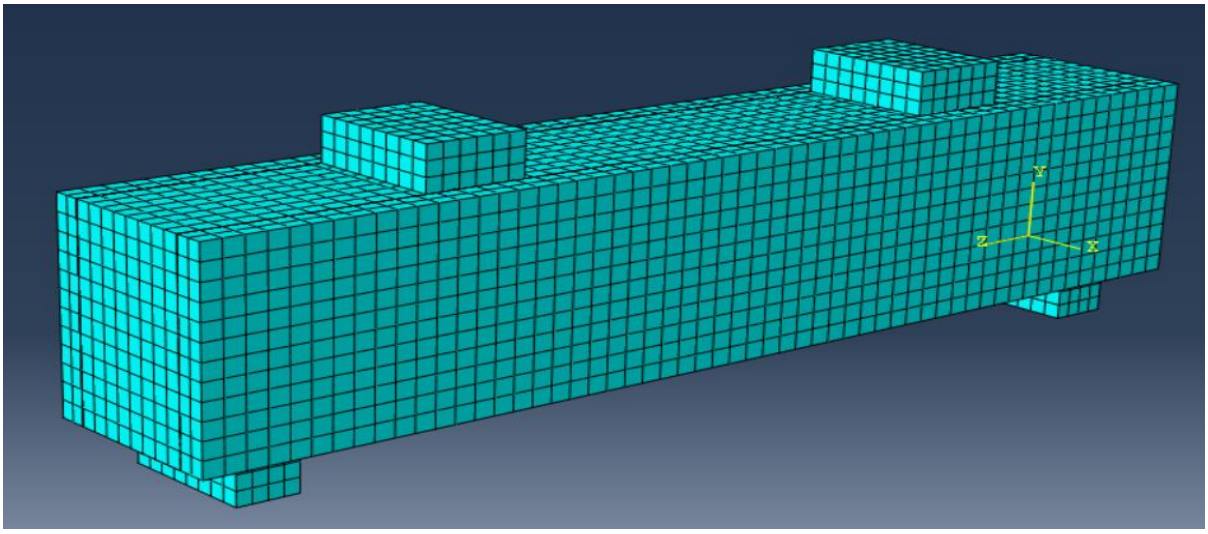
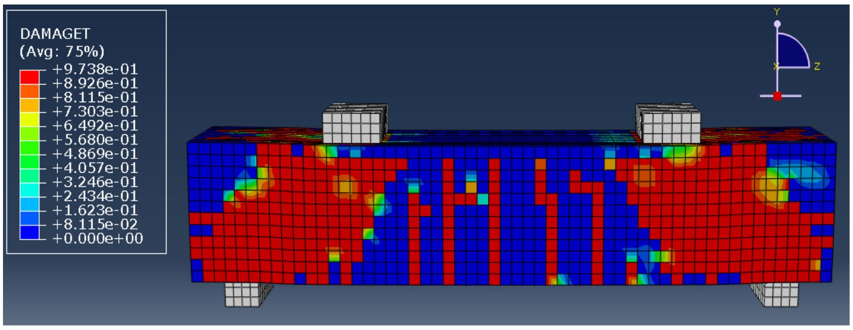
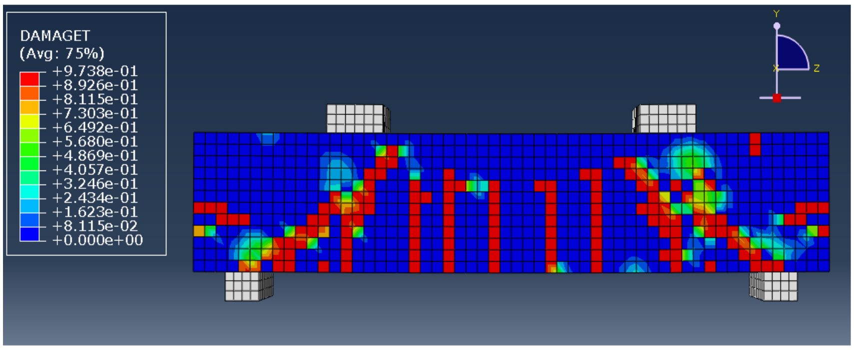


Figure 24: Meshing the whole model



c) Crack's @ ultimate load (FE)



b) Frist diagonal crack (FE)

a) Crack @ ultimate load (Exp.)

Figure 25: failure mode (tension damage) of experimental and FE with UHPC.

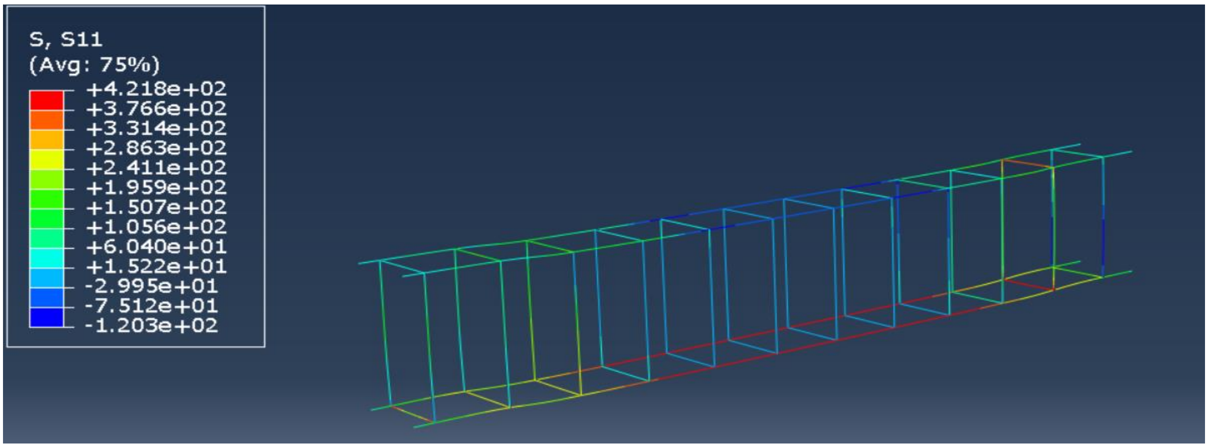


Figure 26: With UHPC Model – Steel Normal Stress

The figure below shows the relation between load and displacement on the midspan of the beam (the converting point of the size of the beam) both given by the paper (Bahraq, Ashraf Awadh et al (2019) and obtained from the Abaqus software. Abaqus model showed a very similar behavior and reaction of the experimental beam. Maximum load capacities were approximately 567 kN and 594 kN in Abaqus model and experiment respectively at midspan displacement of 3.47 mm. The difference of the maximum load capacity obtained from Abaqus is decrease about 4.5 % which is acceptable percentage. We can see that using ultra high performance concrete can increase the maximum moment capacity up to 594 kN and increase the displacement up to 5.3 as got by Abaqus, which means a development of more than 63%.

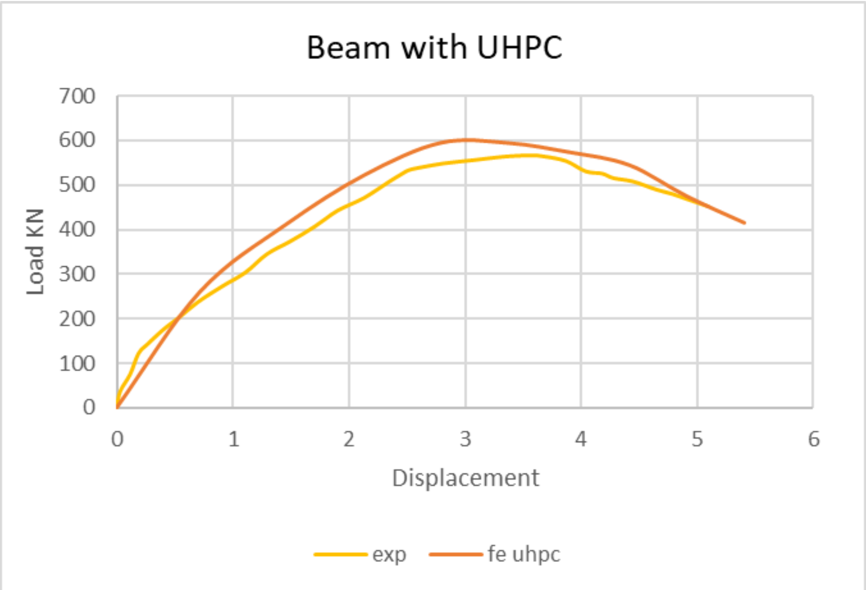


Figure 27: Load – Displacement Curve for UHPC model

3-9 Parametric study

Parametric study is conducted to investigate the behavior of R.C beam strengthened by UHPC in different cases (Bahraq, Ashraf Awadh et al (2019) studied two variables (shear span to the depth ratio and number of layer of UHPC). We will study the behavior affected by many parameters. These parameters are:

3-9-1 : Thickness of UHPC

In this parameter we will study decreasing and increasing the thickness of the UHPC layer. There are 3 models for this variable:

3-9-1-1: 20mm thickness of UHPC

In this parameter we will decrease thickness by 10 mm

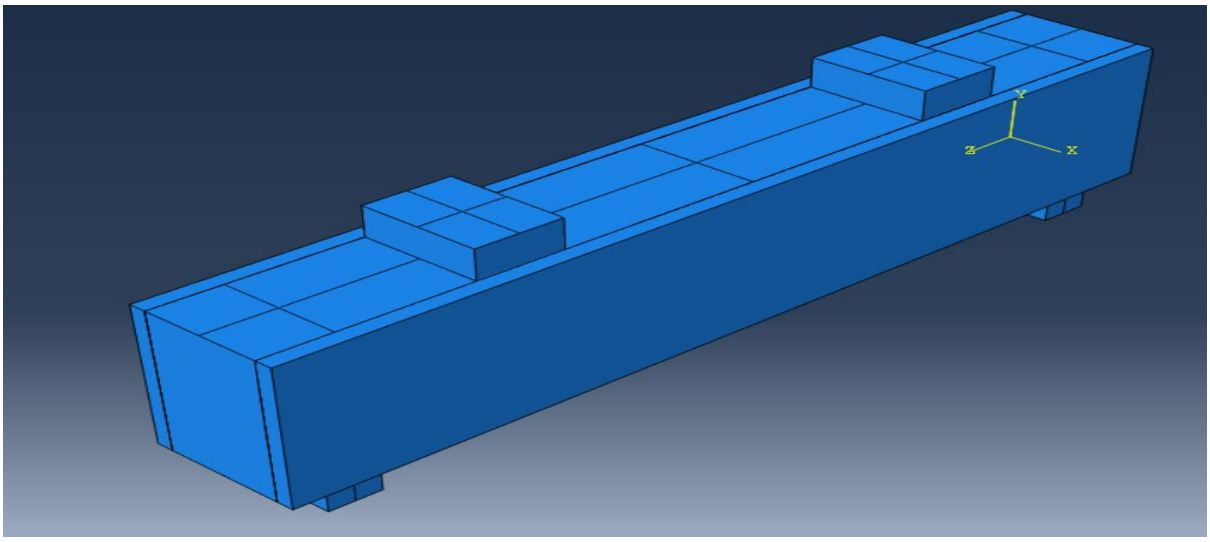


Figure 28: side-face control beam with 20mm UHPC

3-9-1-2: 40mm thickness of UHPC

In this parameter we will increase thickness by 10 mm

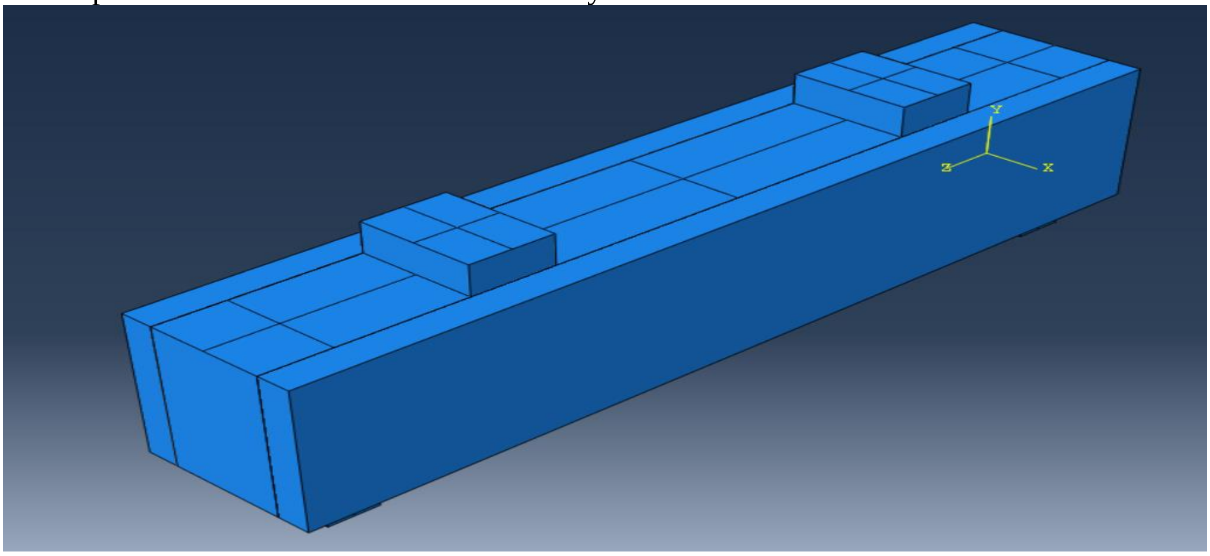


Figure 29: side-face control beam with 40mm UHPC

3-9-1-3: 50mm thickness of UHPC

In this parameter we will increase thickness by 20 mm

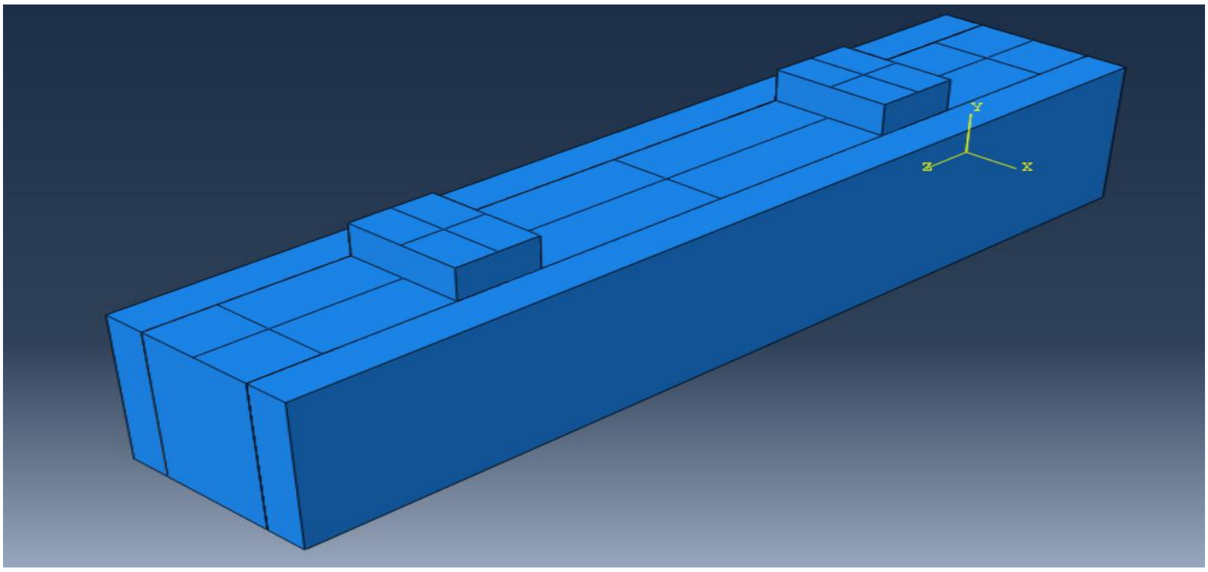


Figure 30: side-face control beam with 50mm UHPC

3-9-2 : Length of UHPC

In this parameter we will the decrease the length of UHPC

3-9-2-1 : UHPC length 370mm at start and end of beam

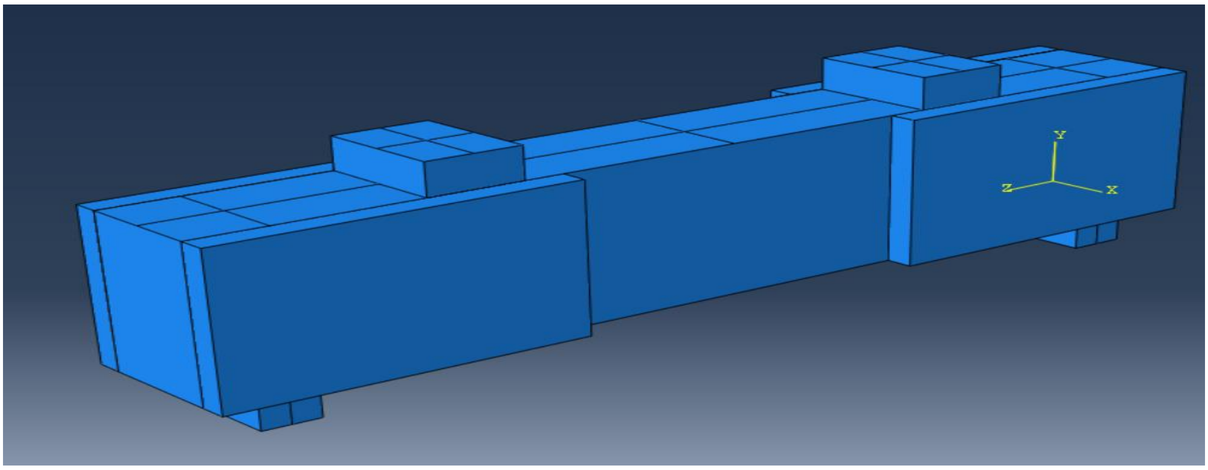


Figure 31: side UHPC length 370mm at start and end of beam

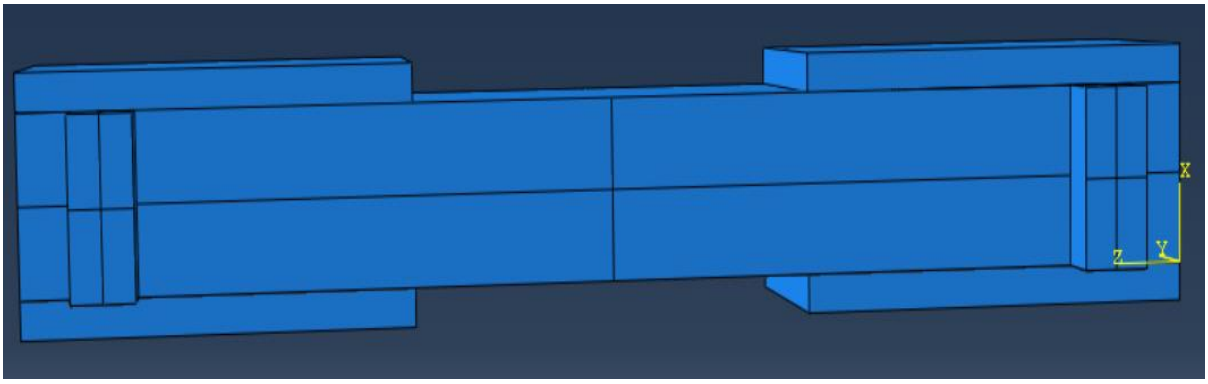


Figure 32: Bottom UHPC length 370mm at start and end of beam

3-9-2-2 : UHPC length 370mm at middle of beam

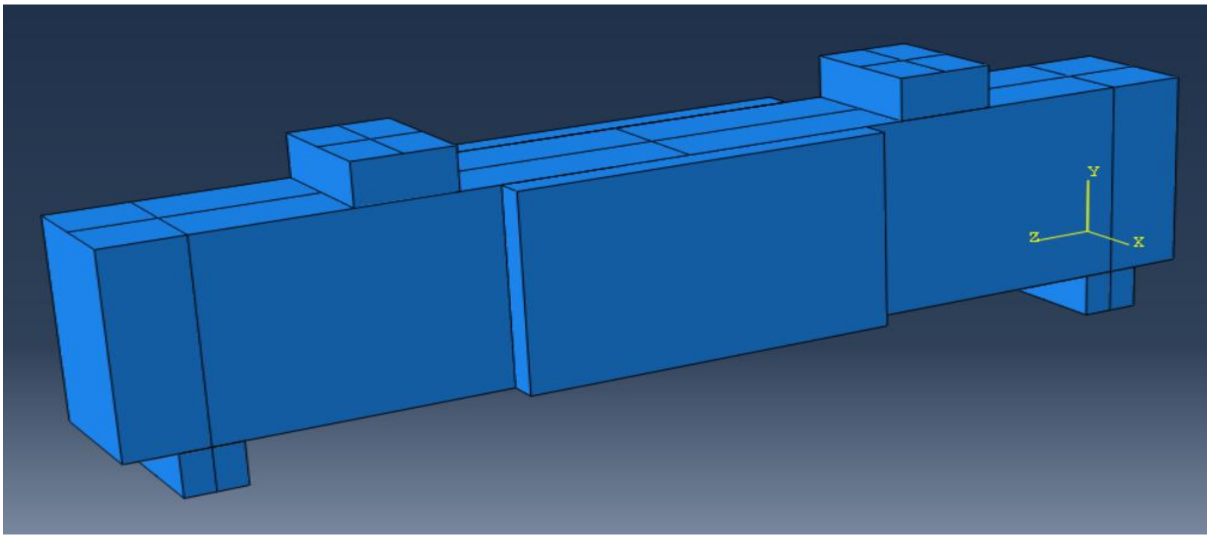


Figure 33: side UHPC length 370mm at middle of beam

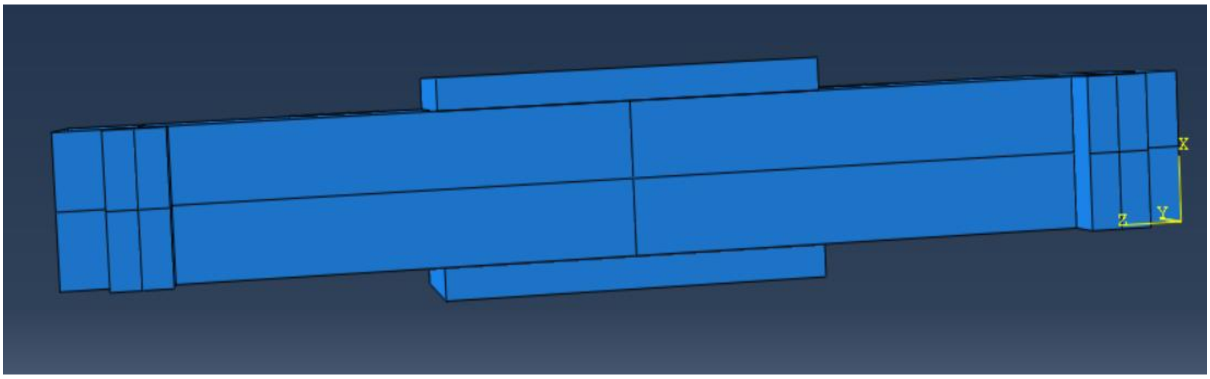


Figure 34: bottom UHPC length 370mm at middle of beam

3-9-3 : The ratio of shear reinforcement

In this parameter we will increase and decrease the ratio of shear (the shear reinforcement of original model is phi (8/12cm)

3-9-3-1 : Use phi8/20cm stirrups

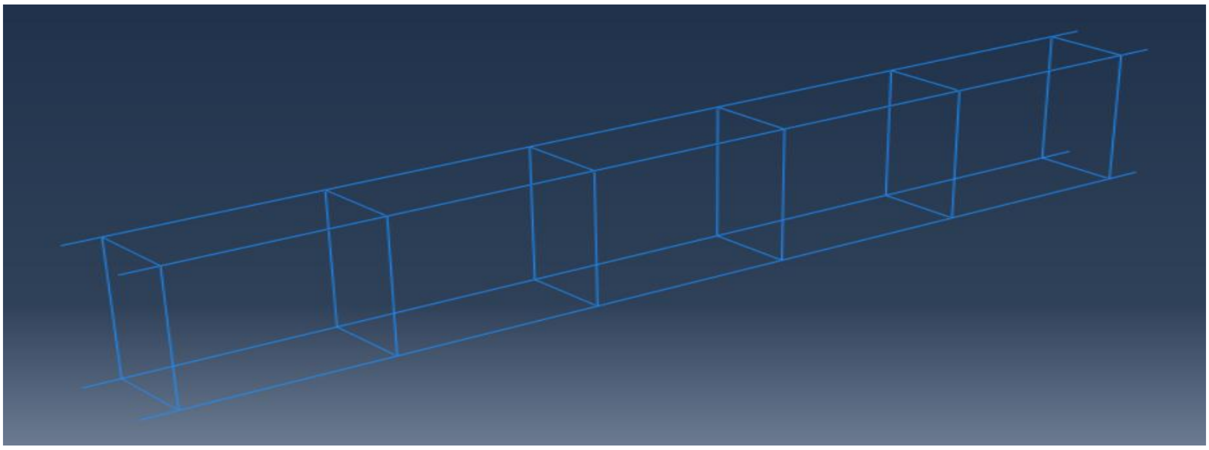


Figure 35 : reinforcement and stirups phi8/20cm

3-9-3-2 : Use phi8/12cm stirrups at start and end of beam

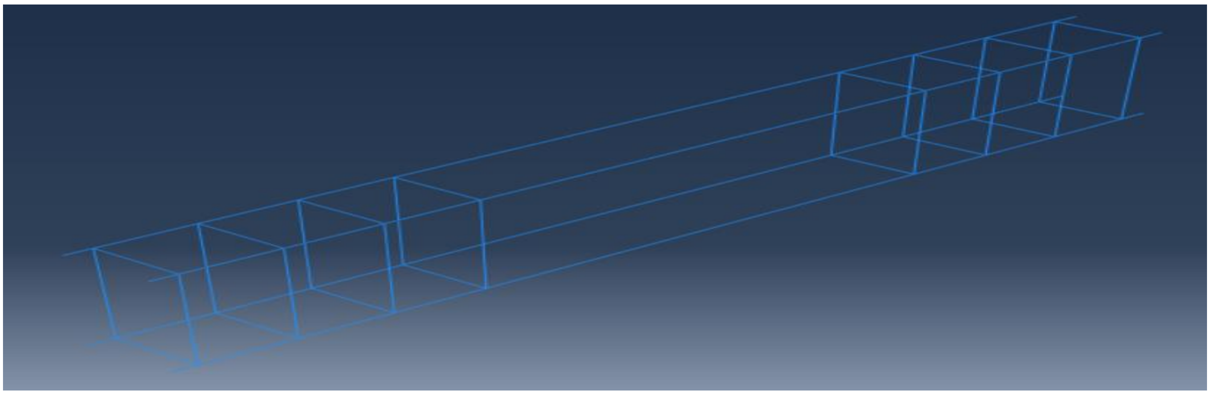


Figure 36 : reinforcement and stirrups phi8/12cm at start and end beam

3-9-3-3 : No shear reinforcement

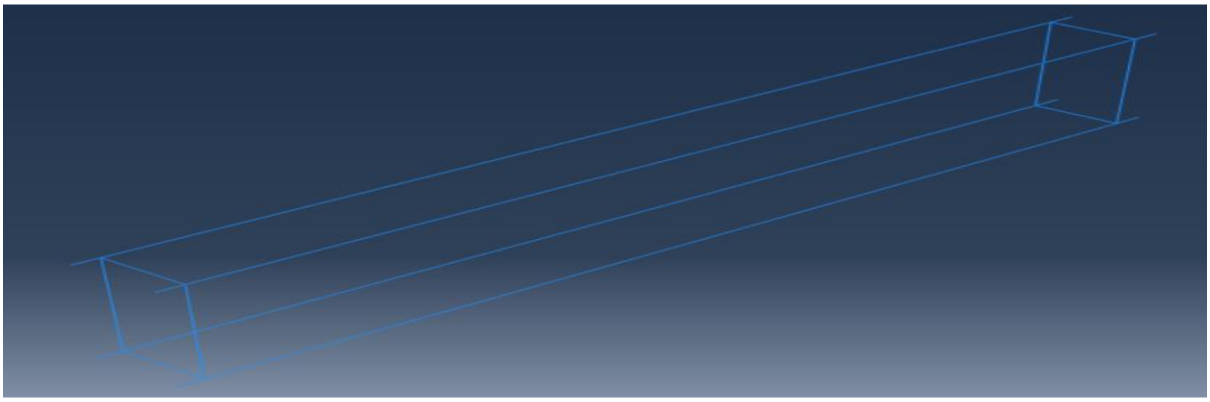


Figure 37: : reinforcement and no stirrups

Chapter 4 : Results and discussion

In this chapter we will present the main results of all parameters studied that were mentioned in Chapter 3 (3.9.1 to 3.9.3). load-deflection curves will be shown for all cases and will be discussed.

4-1 : Analysis :

BEAM #.	Specimen Designation	First Diagonal crack, (*kN*)	First diagonal crack, (%) (parameter /Control)	First Flexural crack, (*kN*)	First flexural crack, (%) (parameter /Control)	maximum load, (*kN*)	Maximum load crack, (%) (parameter /Control)	Failure load (kN)	Failure load, (%)(parameter /Control)
1	Control beam without UHPC	159	-	105	-	325	-	365	-
2	Control beam with UHPC	410	2.57	260	2.47	593	1.82	415	1.14
3	Beam with 20mm UHPC	400	2.51	250	2.4	574	1.76	403	1.1
4	Beam with 40mm UHPC	455	2.86	271	2.58	618	1.9	444	1.2
5	Beam with 50mm UHPC	463	2.9	280	2.66	644	1.98	423	1.15
6	**S-E 370mm**	419	2.6	246	2.34	630	1.93	380	1.04
7	**Middle 370mm**	343	2.15	222	2.11	497	1.47	329	0.9
8	**Phi8/20cm**	444	2.8	262	2.49	695	2.14	387	1.06
9	**Phi8/12cm at s-e**	422	2.65	262	2.49	594	1.82	390	1.07
10	**No shear**	423	2.65	262	2.49	595	1.82	477	1.3

BEAM #.	Specimen Designation	First Diagonal crack, (*kN*)	Def (mm)	First Flexural crack, (*kN*)	Def (mm)	maximum load, (*kN*)	Def (mm)	Failure load (kN)	Def (mm)
1	Control beam without UHPC	159	0.58	105	0.28	325	2.3	365	2.54
2	Control beam with UHPC	410	1.45	260	0.7	593	3.37	415	5.4
3	Beam with 20mm UHPC	400	1.44	250	0.7	574	3.3	403	5.3
4	Beam with 40mm UHPC	455	1.46	271	0.7	618	3.32	444	5.4
5	Beam with 50mm UHPC	463	1.46	280	0.7	644	2.8	423	5.48
6	S-E 370mm	419	1.36	246	0.7	630	3.12	380	5.11
7	Middle 370mm	343	1.37	222	0.7	497	3.12	329	5.11
8	Phi8/20cm	444	1.48	262	0.71	695	3.5	387	5.66
9	Phi8/12cm at s-e	422	1.45	262	0.71	594	3.37	390	5.41
10	No shear	423	21.46	262	0.71	595	3.53	477	5.44

4-1: : Thickness of UHPC

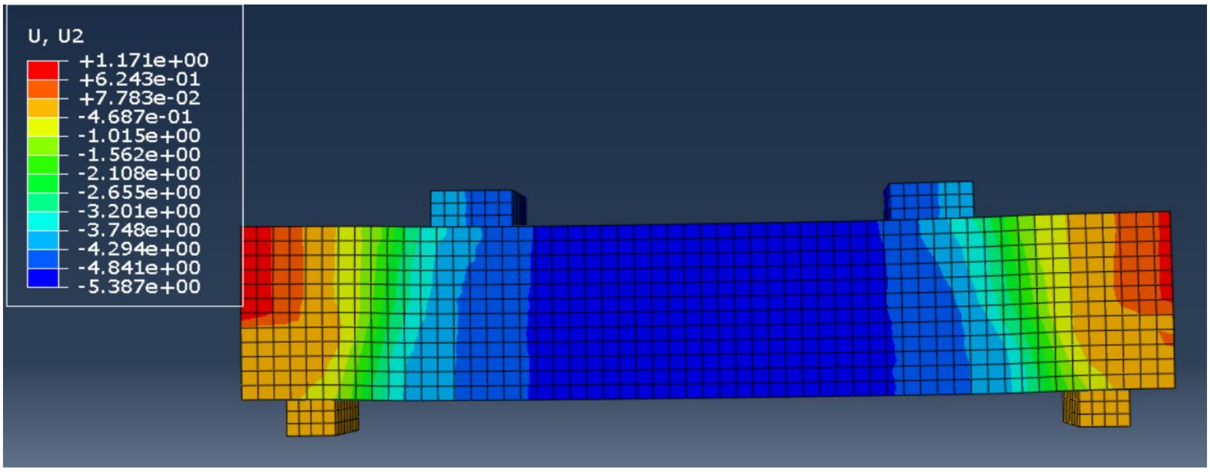


Figure 38: with 20mm thickness of UHPC – U2 (vertical displacement) at ultimate

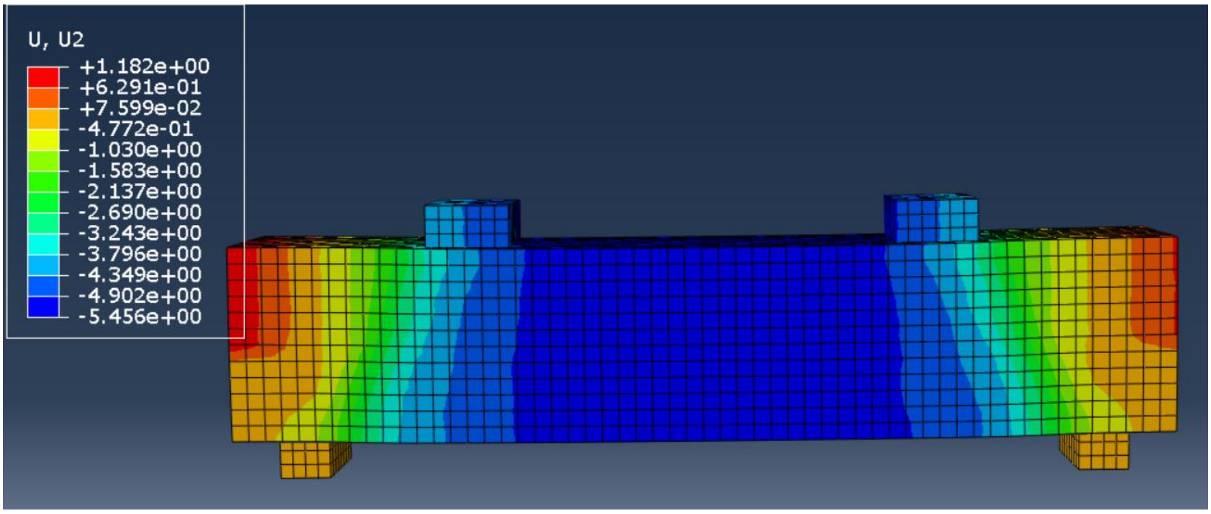


Figure 39: with 30mm thickness of UHPC – U2 (vertical displacement) at ultimate

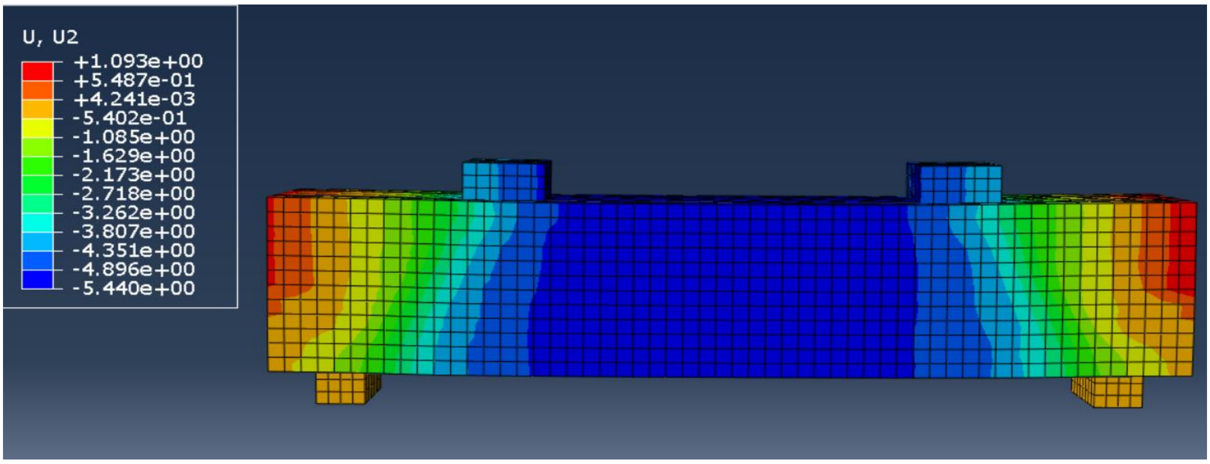


Figure 40: with 40mm thickness of UHPC – U2 (vertical displacement) at ultimate crack

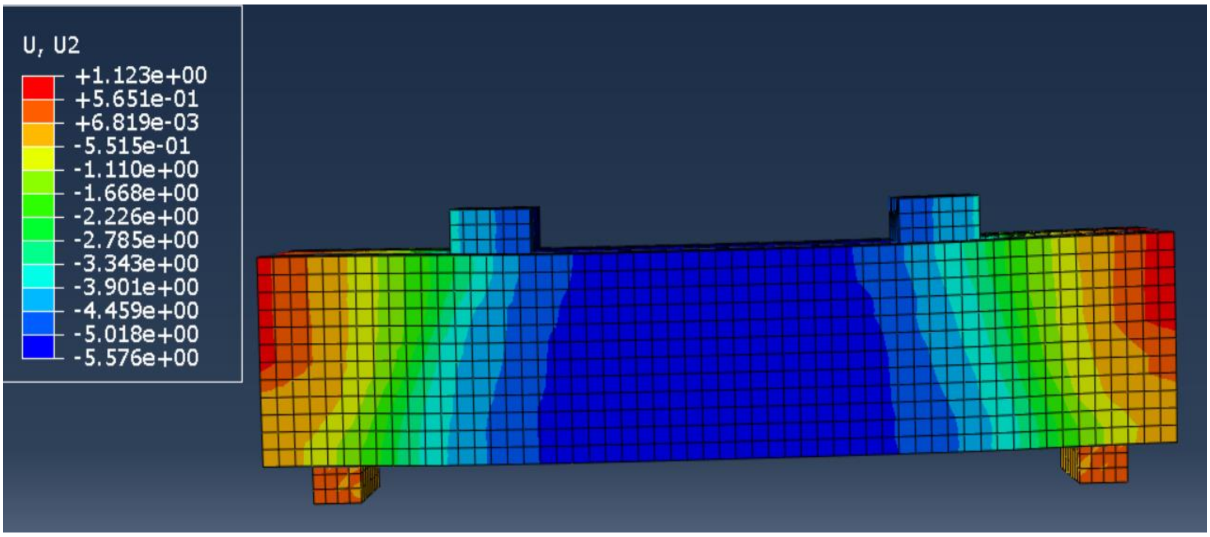


Figure 41: with 50mm thickness of UHPC – U2 (vertical displacement)

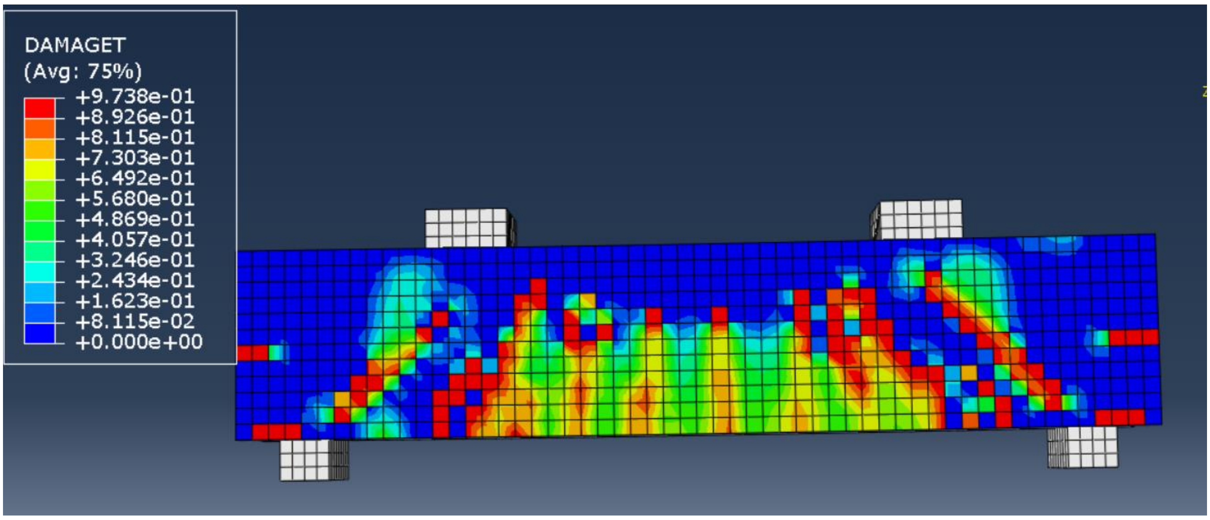


Figure 42: : with 20mm thickness of UHPC – first diagonal crack Damage tension

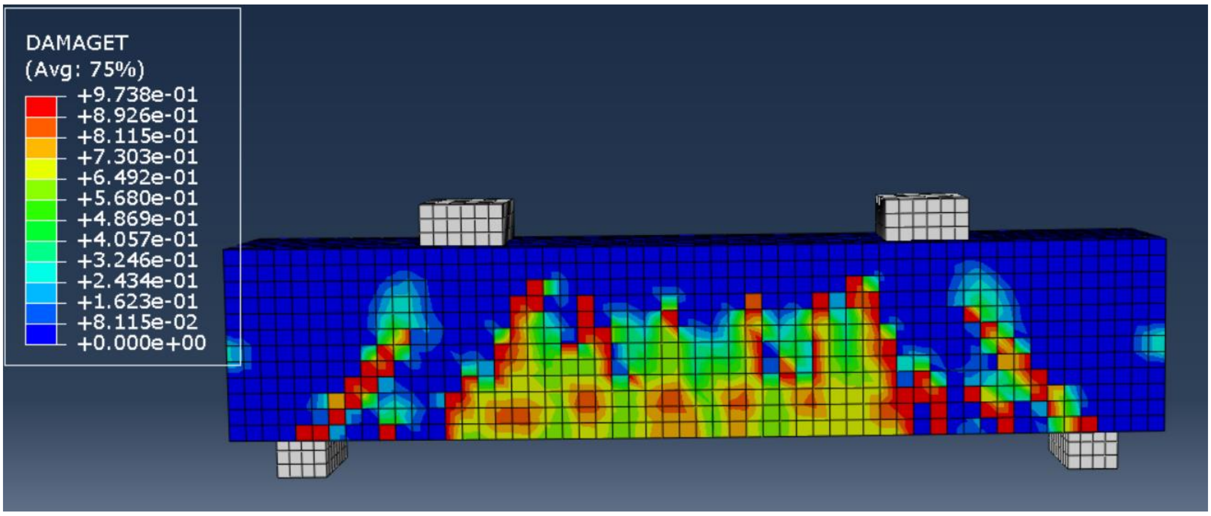


Figure 43 : with 30mm thickness of UHPC – first diagonal crack Damage tension

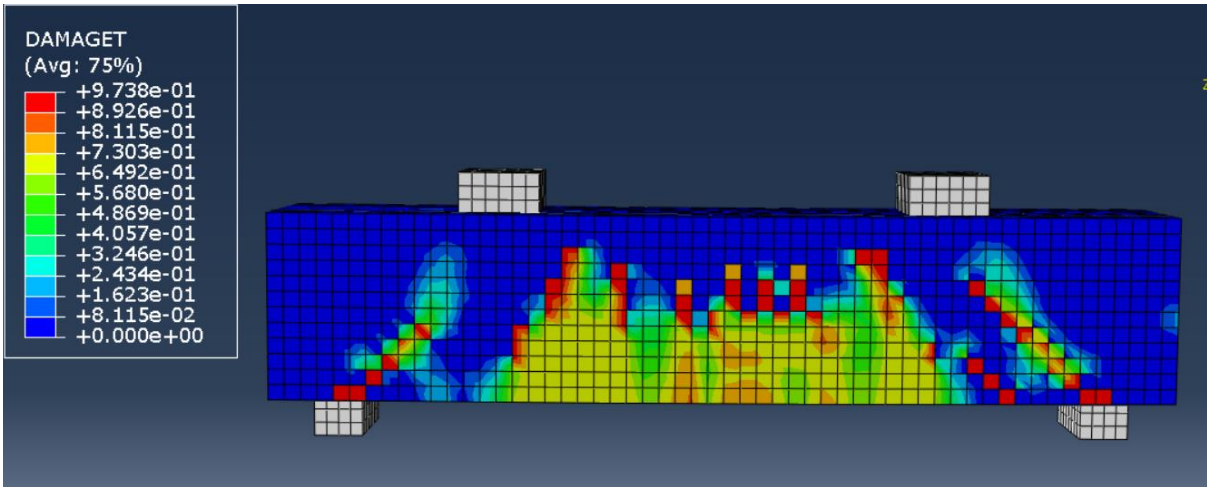


Figure 44: with 40mm thickness of UHPC – Damage tension first diagonal crack

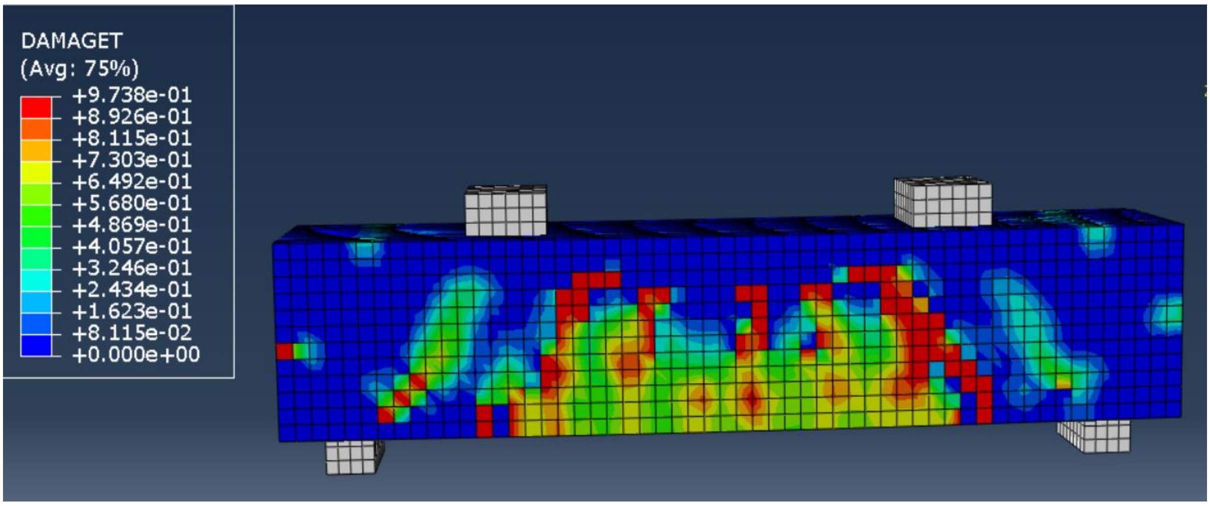


Figure 45: with 50mm thickness of UHPC – Damage tension at first diagonal crack

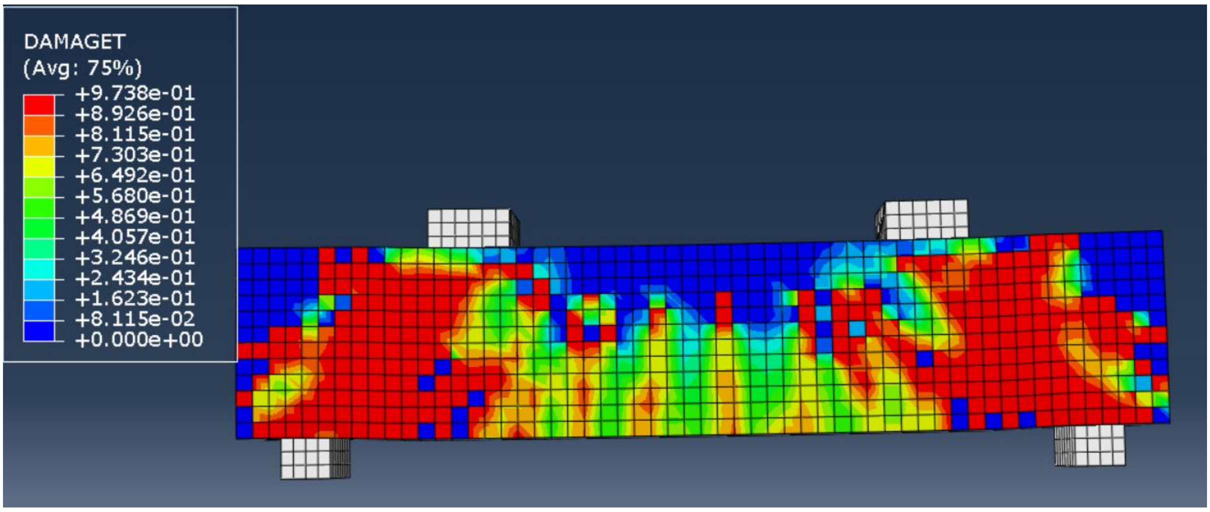


Figure 46 : with 20mm thickness of UHPC – ultimate crack Damage tension

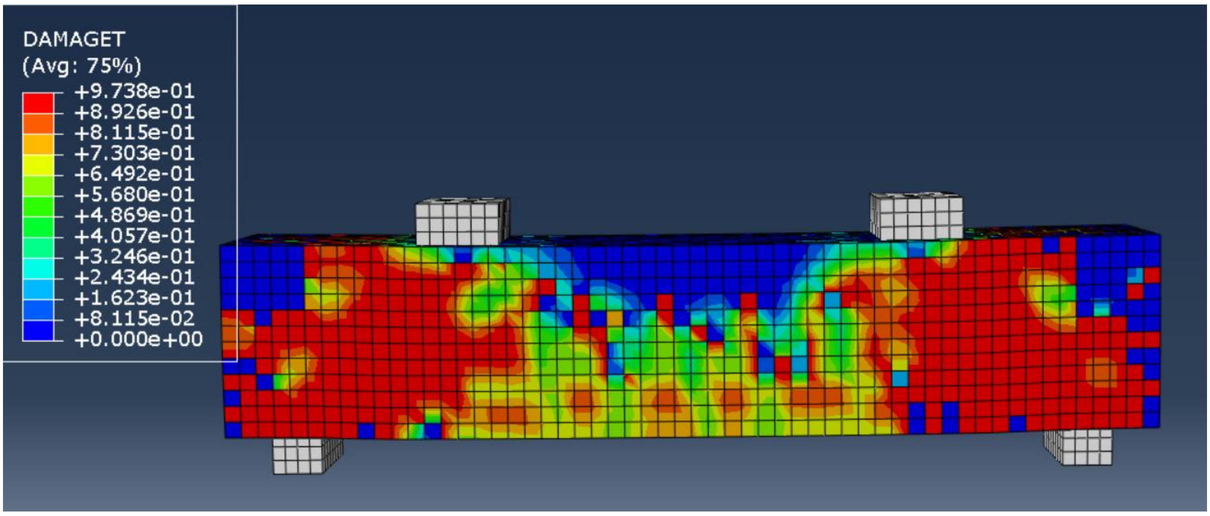


Figure 47: with 30mm thickness of UHPC – ultimate crack Damage tension

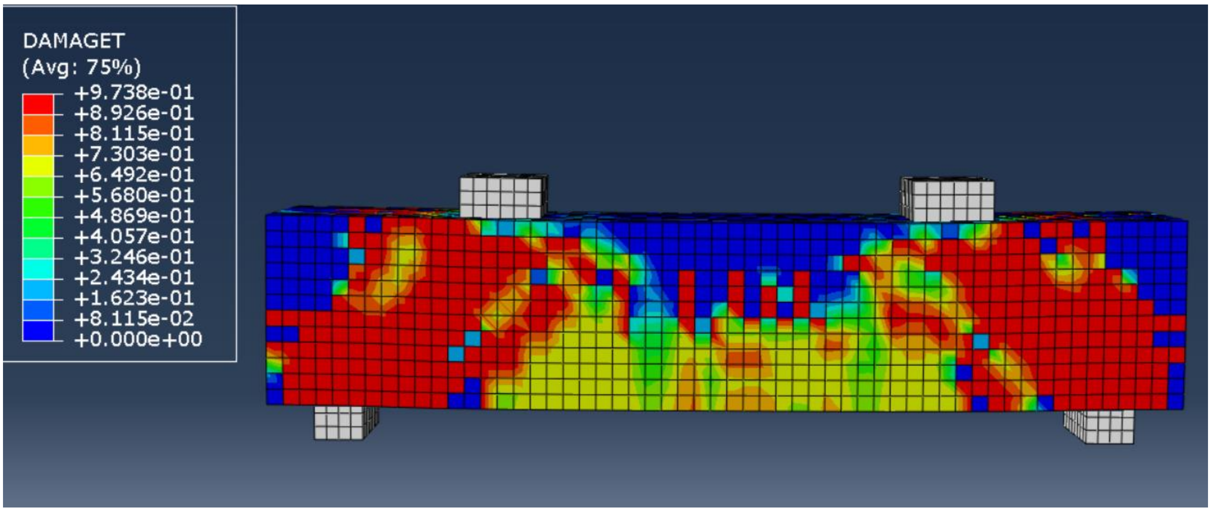


Figure 48: with 40mm thickness of UHPC – Damage tension at ultimate crack

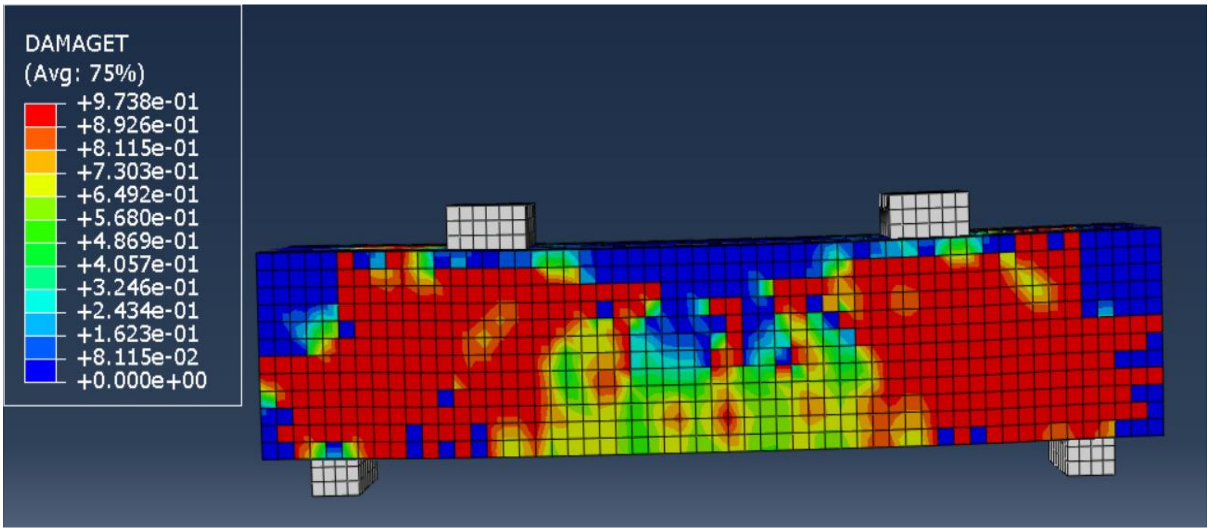


Figure 49 : with 50mm thickness of UHPC – Damage tension at ultimate crack

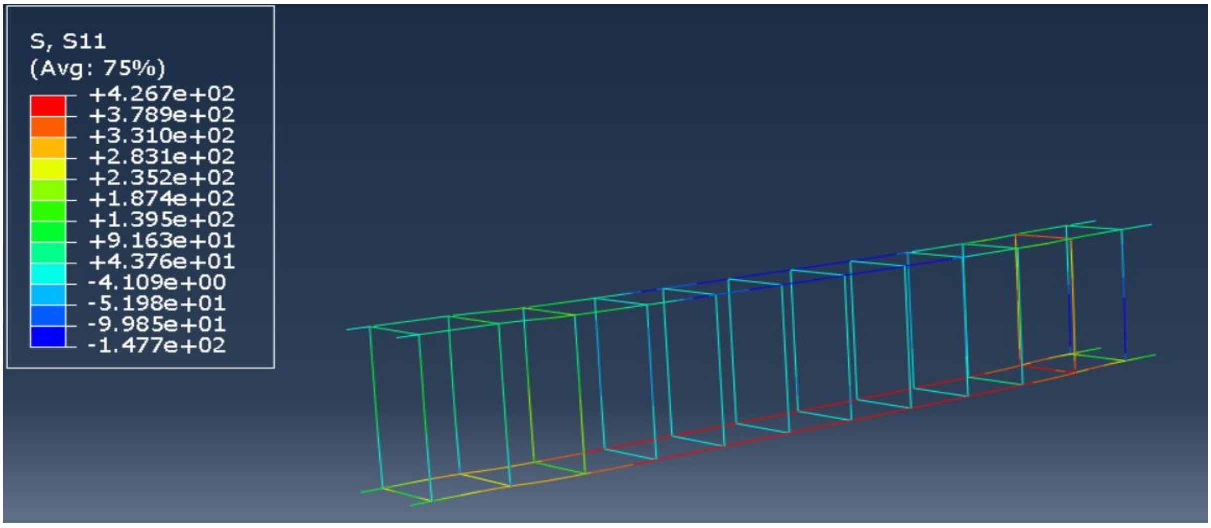


Figure 50: with 20mm thickness of UHPC – Steel normal strain at ultimate

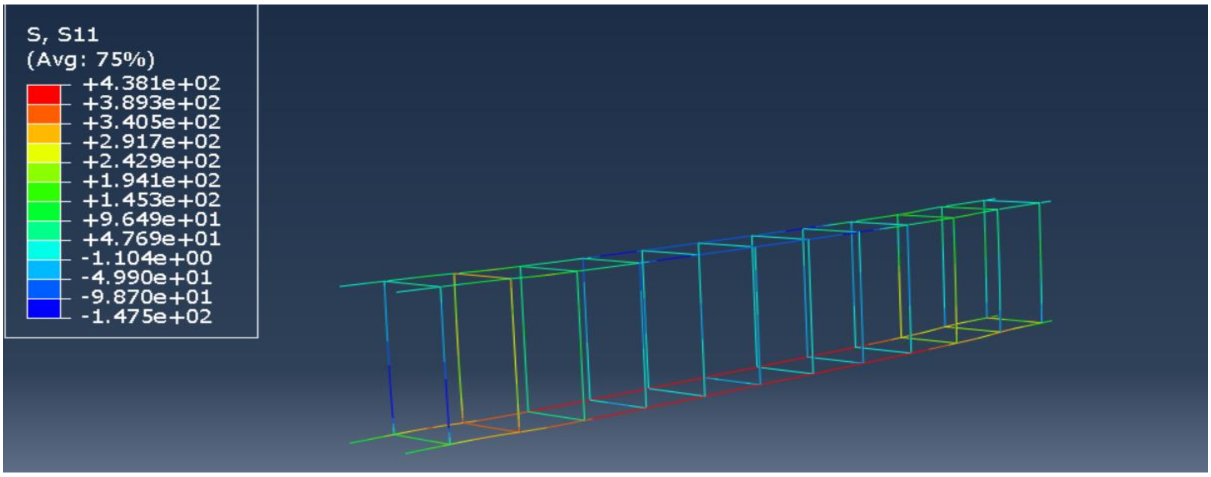


Figure 51: with 30mm thickness of UHPC – Steel normal strain at ultimate

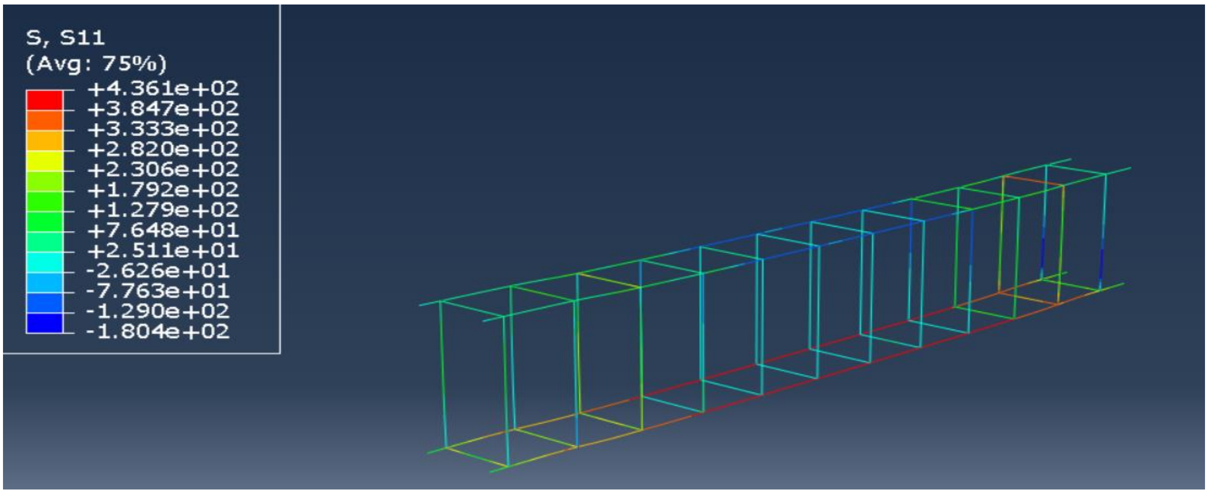


Figure 52: with 40mm thickness of UHPC – Steel normal strain

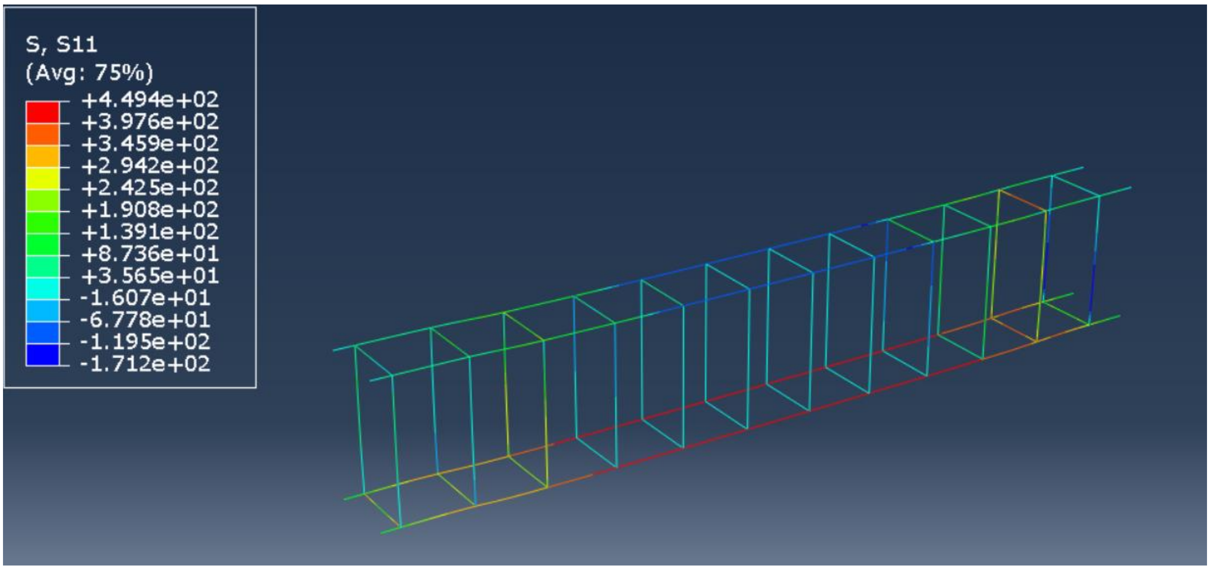


Figure 53: with 40mm thickness of UHPC – Steel normal strain at ultimate crack

Based on the results shown in chapter 4 after using finite element method and after comparing the load-displacement curves of models with the thickness change of UHPC layer and as we observe in the figure below that the change in thickness of UHPC layer does not significantly affect the increase in loads and displacements, We note that the 20 mm thickness sample gave results very close to the original 30 mm thickness sample and also we note that the increase in thickness increases loads and displacements by less than 3%

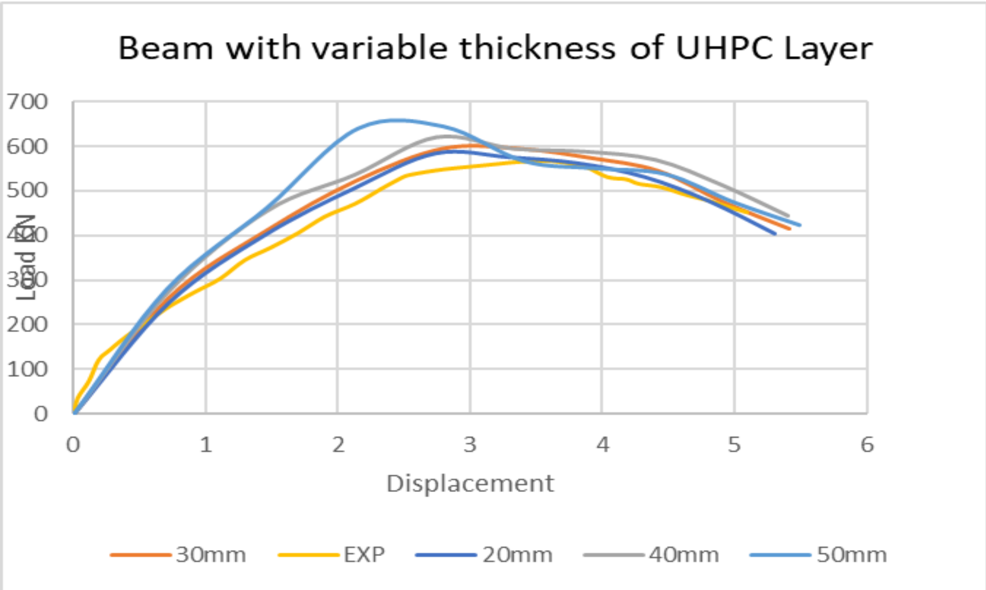


Figure 54 : load-displacement curve- for change thickness of UHPC

4-2 :Length of UHPC

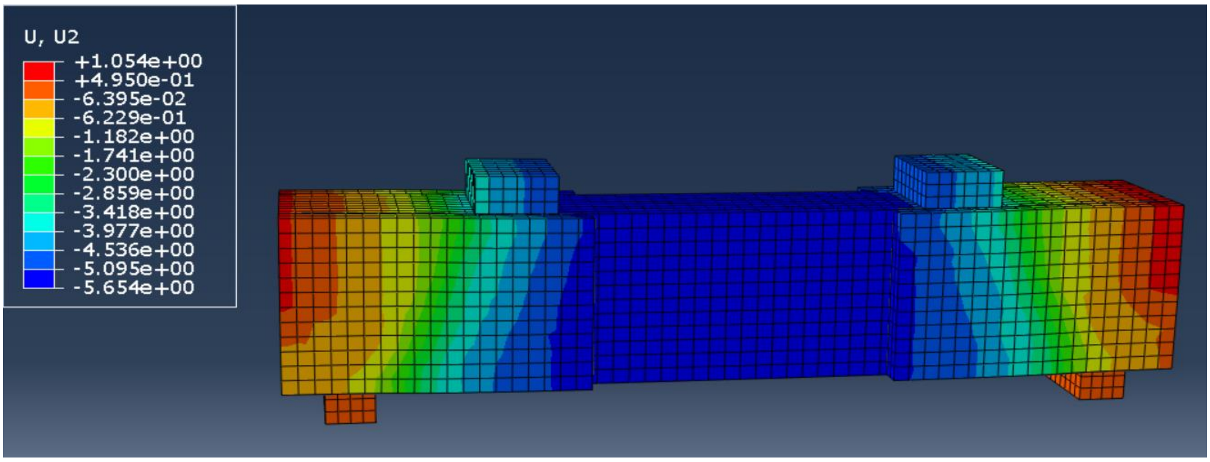


Figure 55: UHPC length 370mm at start and end of beam – U2 (vertical displacement) at ultimate crack

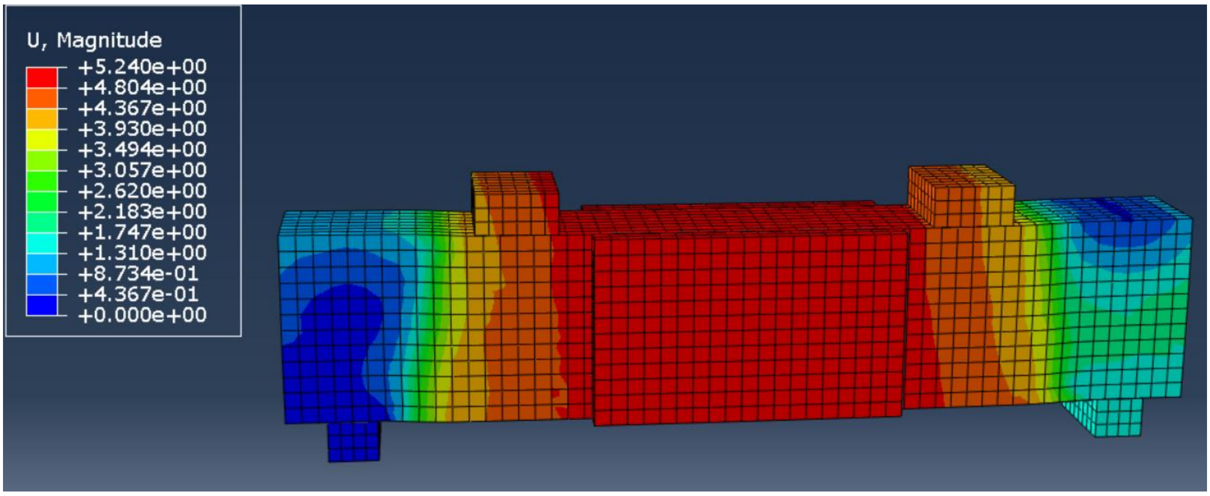


Figure 56: UHPC length 370mm at the middle of beam – U2 (vertical displacement) at ultimate crack

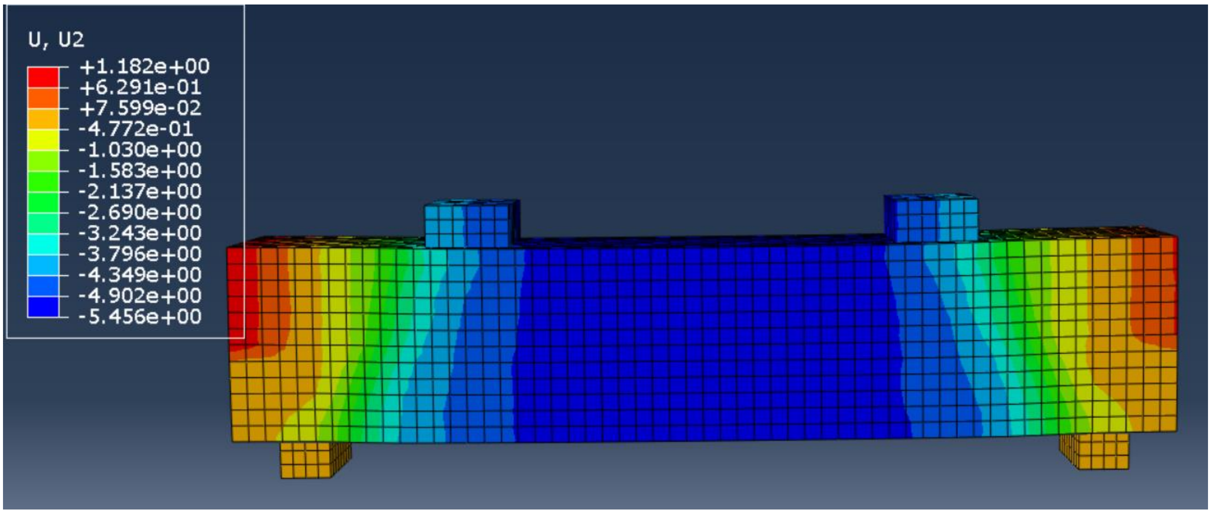


Figure 57: UHPC length 1120mm – U2 (vertical displacement) at ultimate

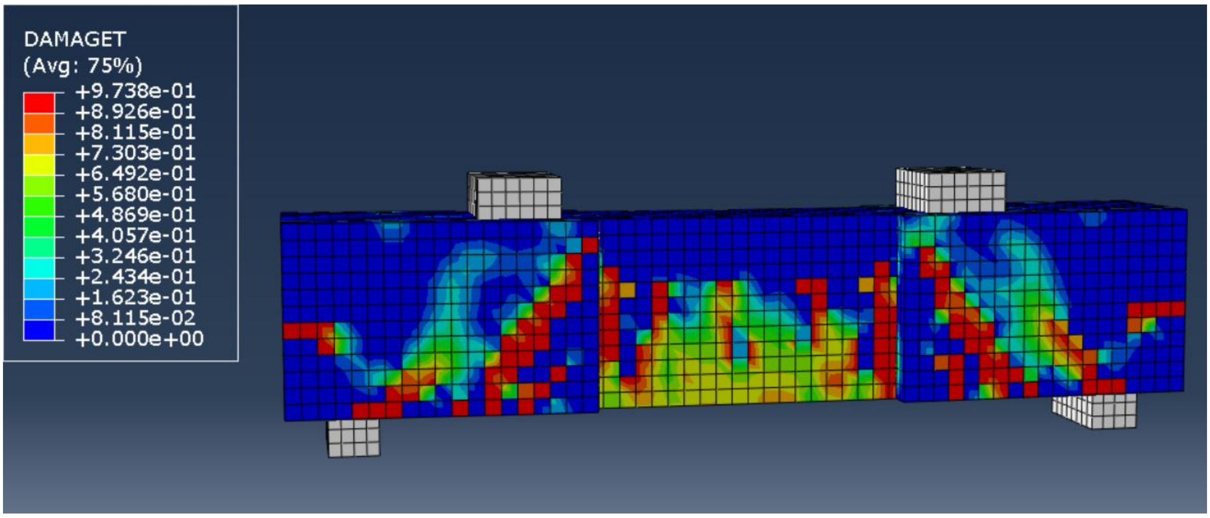


Figure 58 : UHPC length 370mm at start and end of beam – Damage tension at first diagonal crack

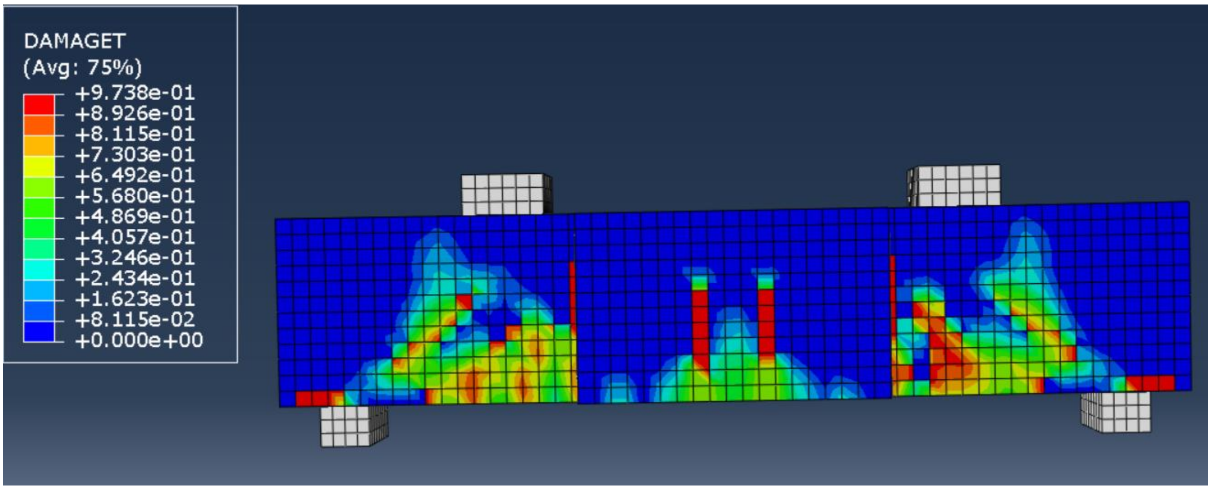


Figure 59 : UHPC length 370mm at the middle of beam – Damage tension at first diagonal crack

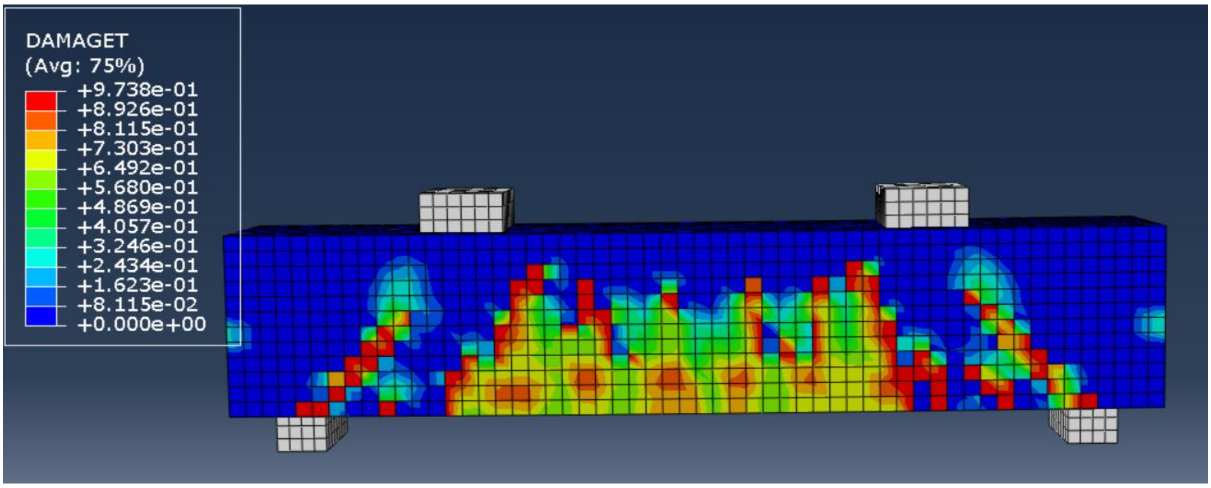


Figure 60 : – UHPC length 1120mm - Damage tension at first diagonal crack

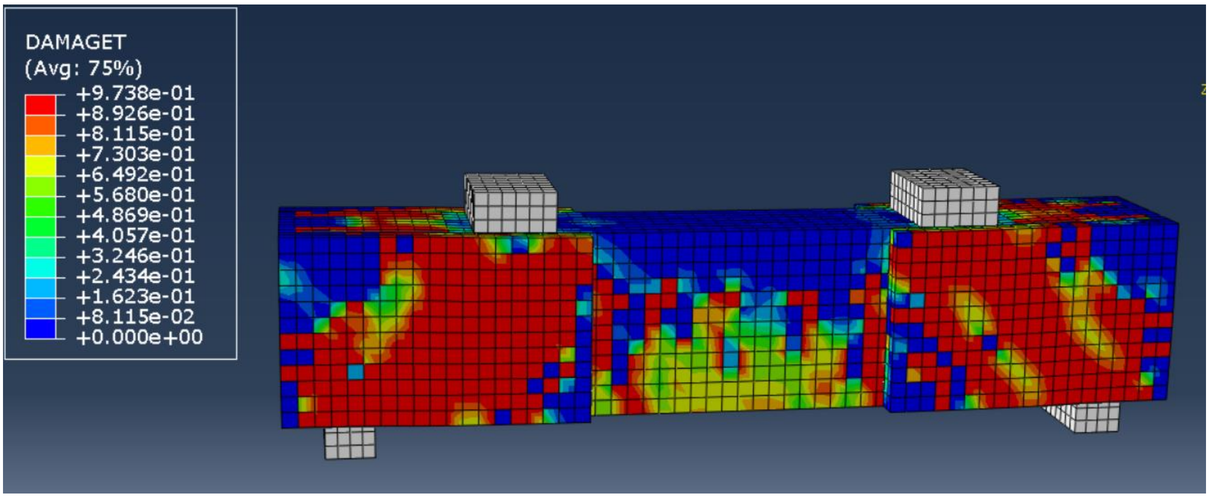


Figure 61: UHPC length 370mm at start and end of beam – Damage tension at ultimate crack

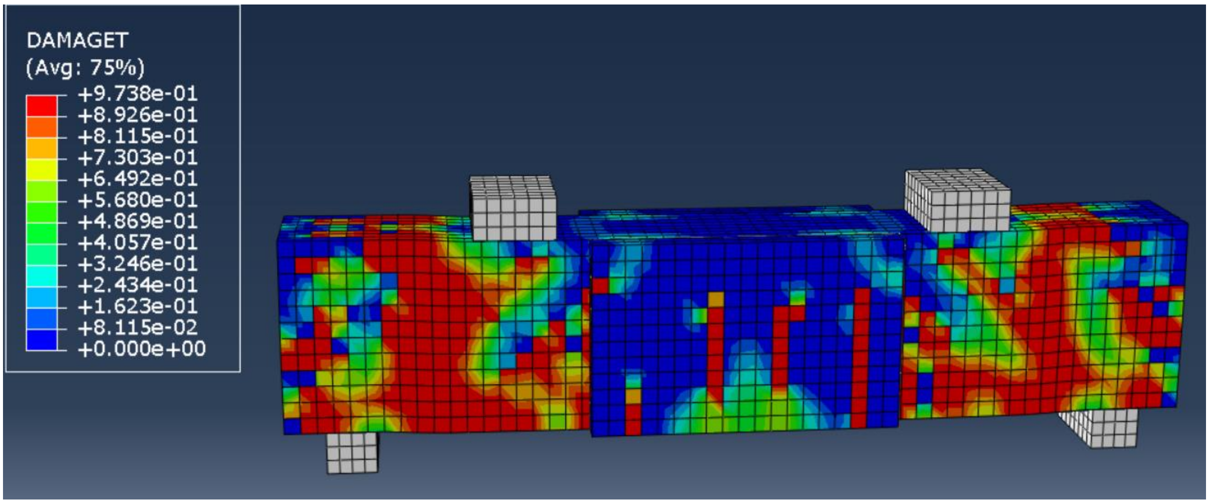


Figure 62: UHPC length 370mm at the middle of beam – Damage tension at ultimate crack

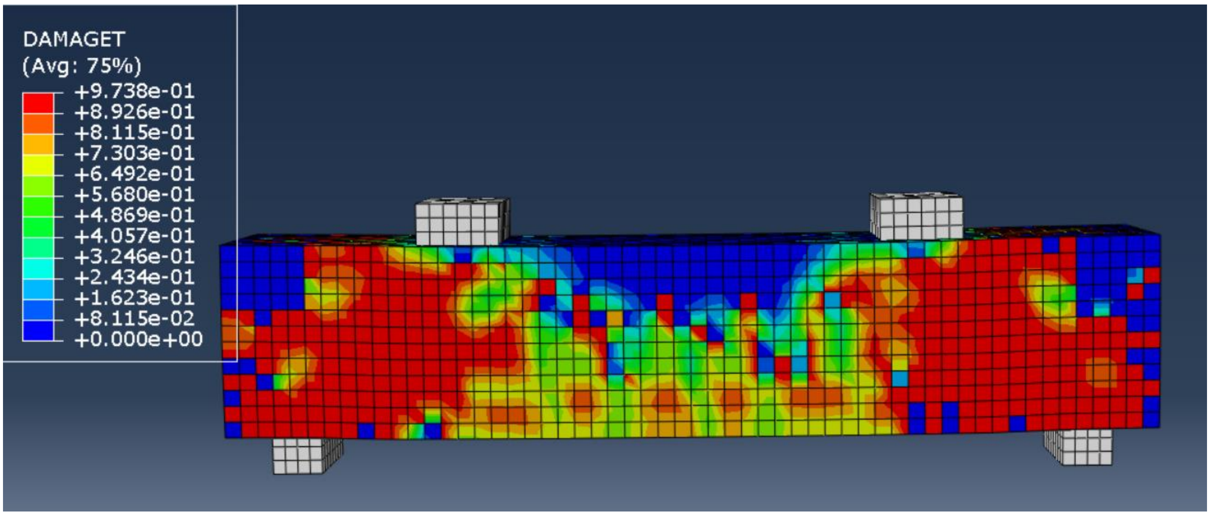


Figure 63: – UHPC length 1120mm – Damage tension at ultimate crack

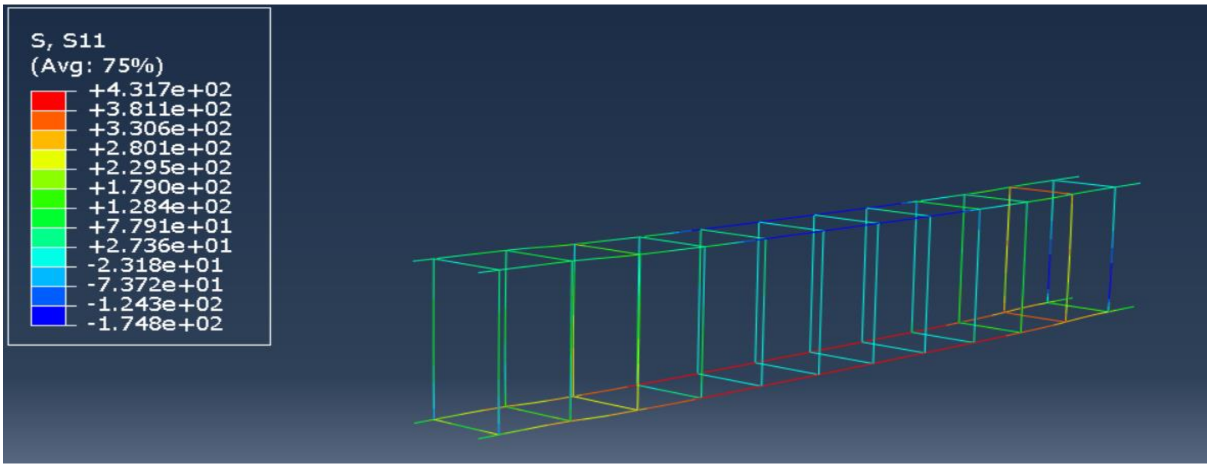


Figure 64: UHPC length 370mm at start and end of beam – steel normal strain at ultimate crack

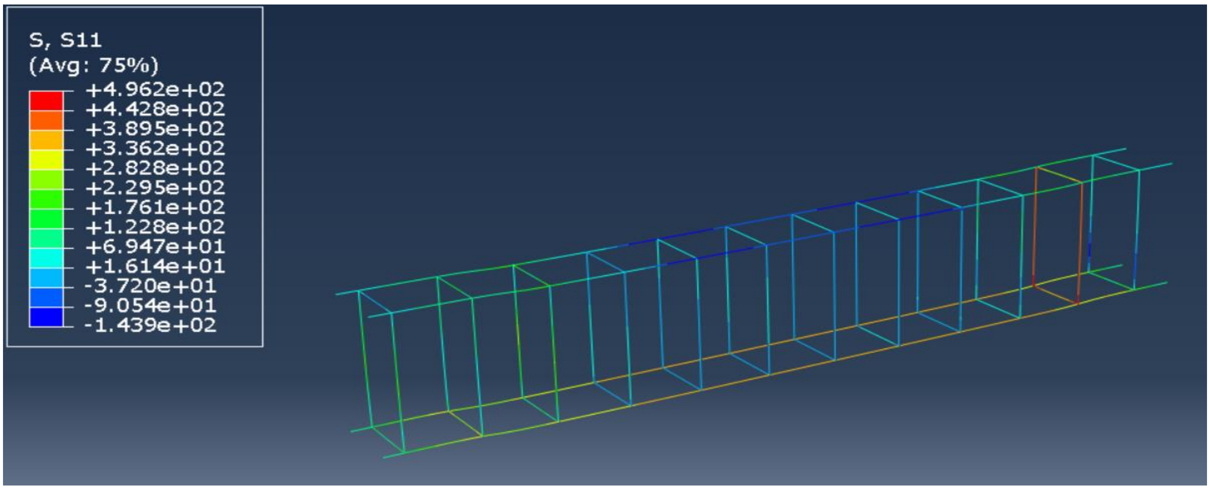


Figure 65: UHPC length 370mm at the middle of beam – Steel normal strain at ultimate crack

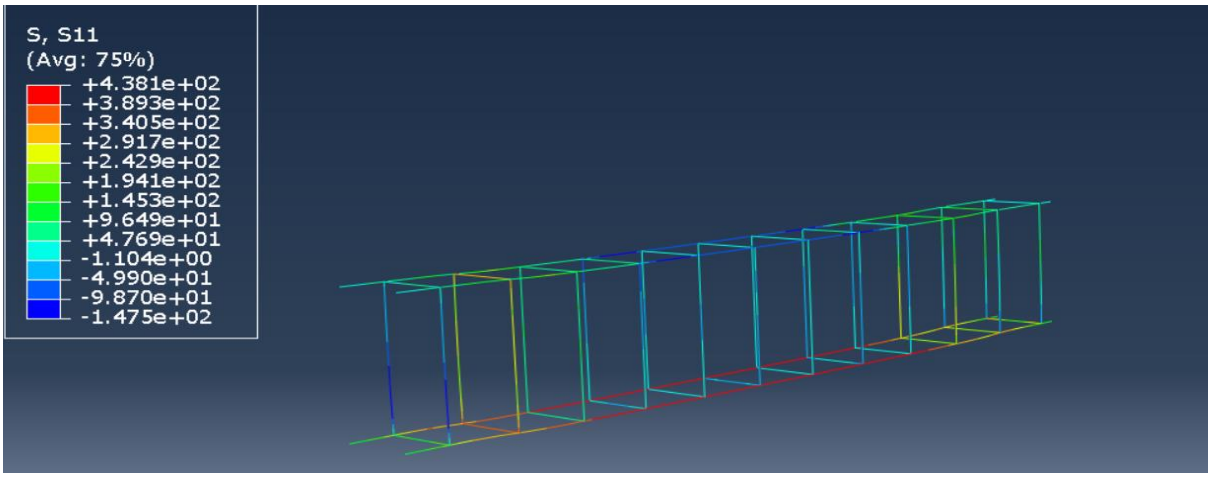


Figure 66: UHPC length 1120mm– Steel normal strain at ultimate crack

Based on the results described in chapter 4 after using the limited element method and after comparing the loading and displacement curves of models with a change in length for UHPC layer and where we note in the figure below that if we put UHPC 370mm in length at the beginning and end of the concrete beam gives a very close result to UHPC along the concrete beam, Also if we put the UHPC layer in the middle of the sample, gives a better result than the sample without the UHPC layer and gives a result less than put UHPC along the concrete beam by 16%.

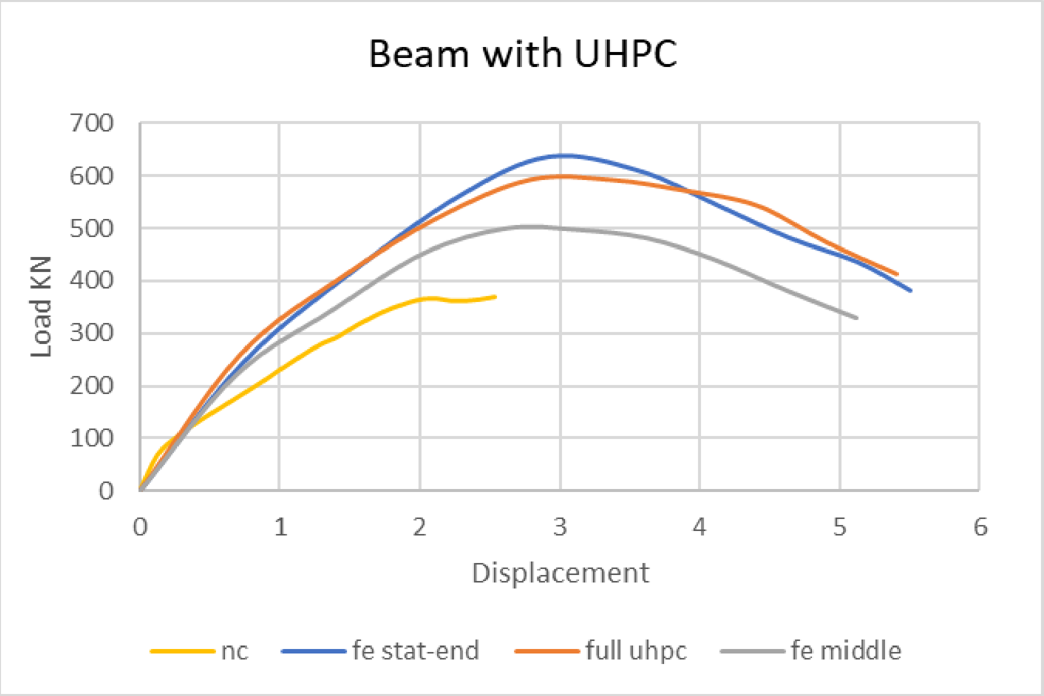


Figure 67 : load-displacement curve- for change length of UHPC

4-3 :The ratio of shear reinforcement

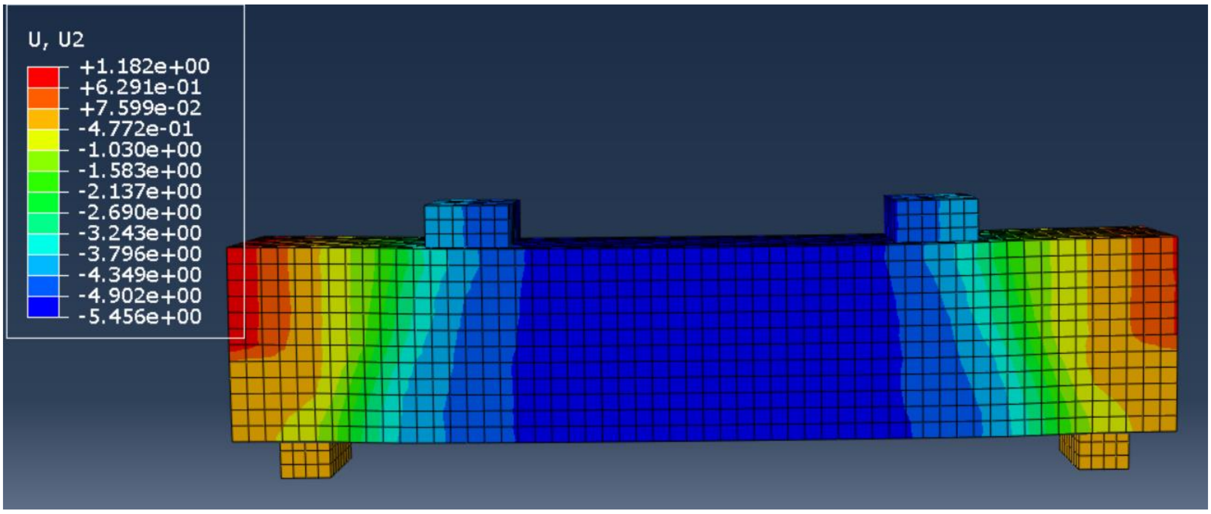


Figure 68: phi8/12cm stirrups– U2 (vertical displacement) at ultimate crack

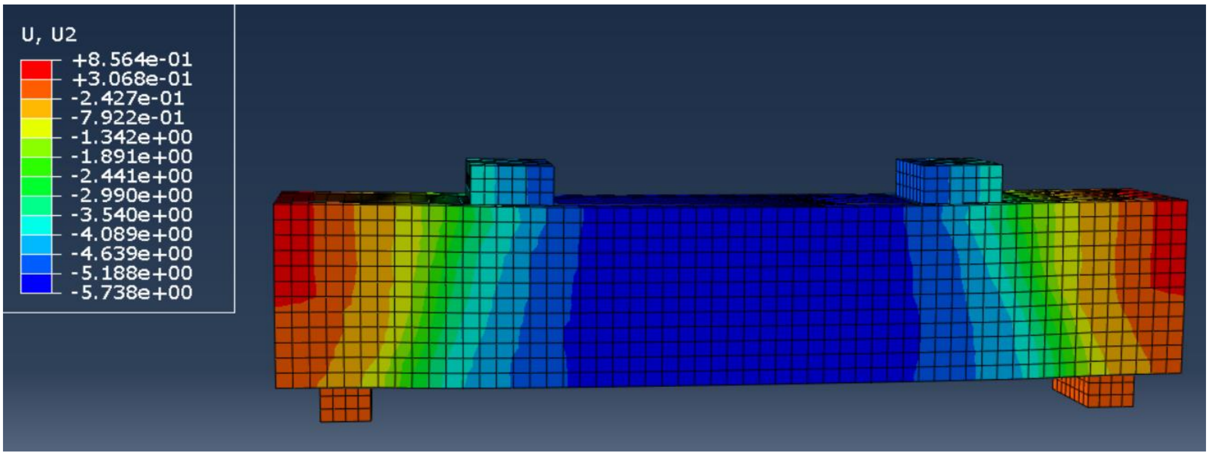


Figure 69: phi8/20cm stirrups– U2 (vertical displacement) at ultimate crack

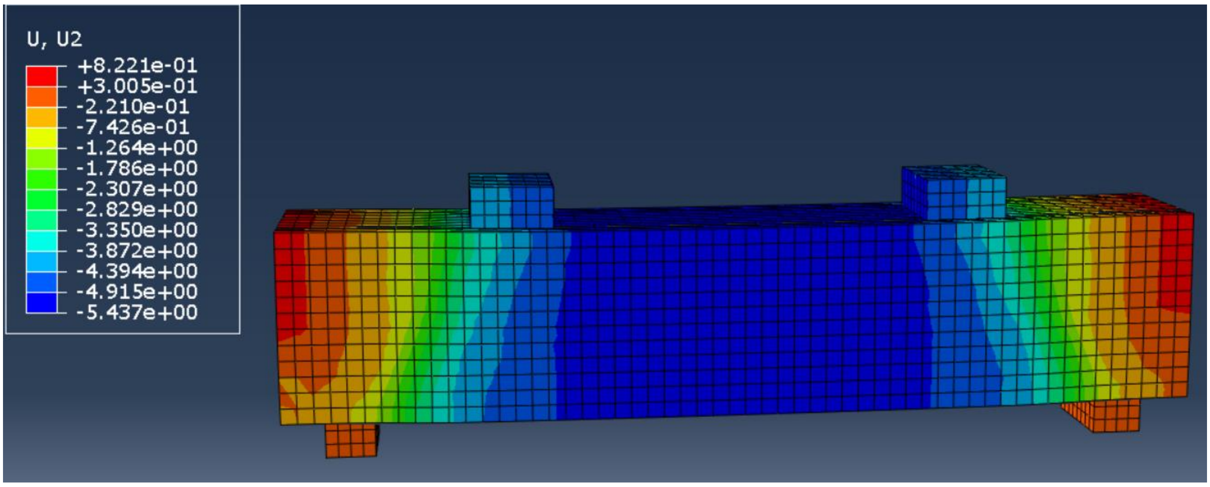


Figure 70: phi8/12cm stirrups at start and end of beam- U2 (vertical displacement) at ultimate crack

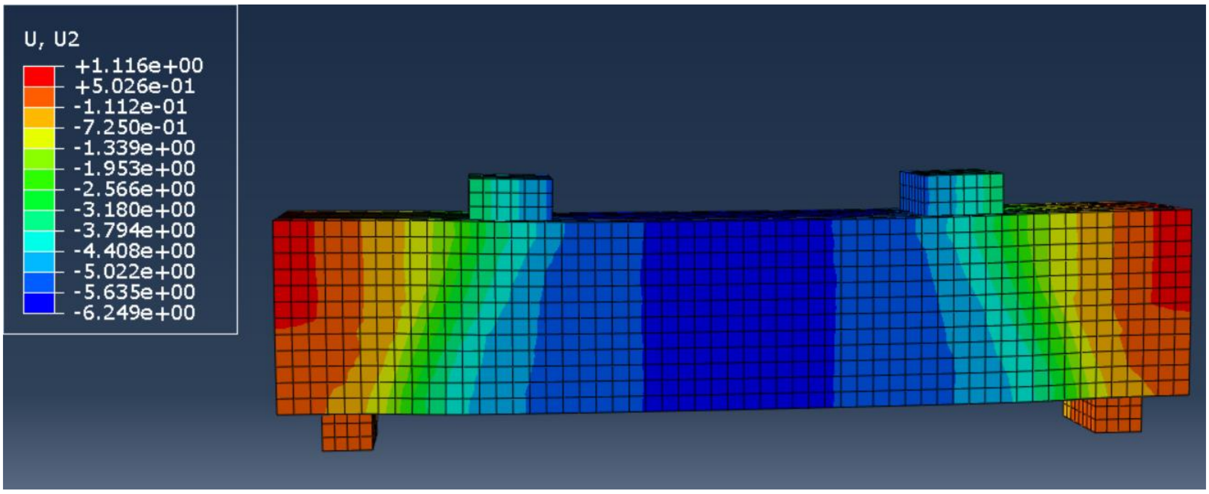


Figure 71 : no shear reinforcement - U2 (vertical displacement) at ultimate crack

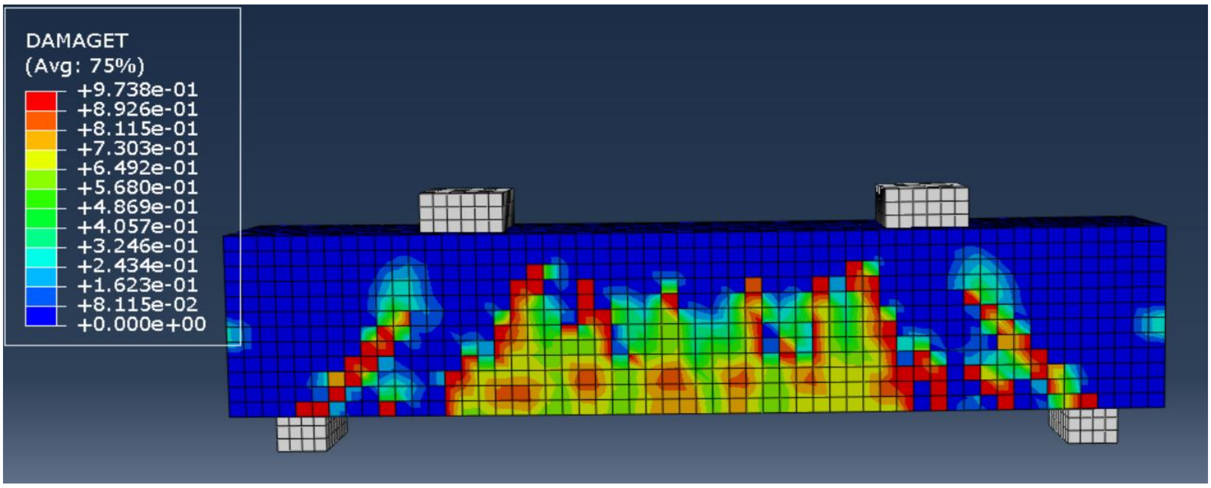


Figure 72 : – phi8/12cm stirrups - Damage tension at first diagonal crack

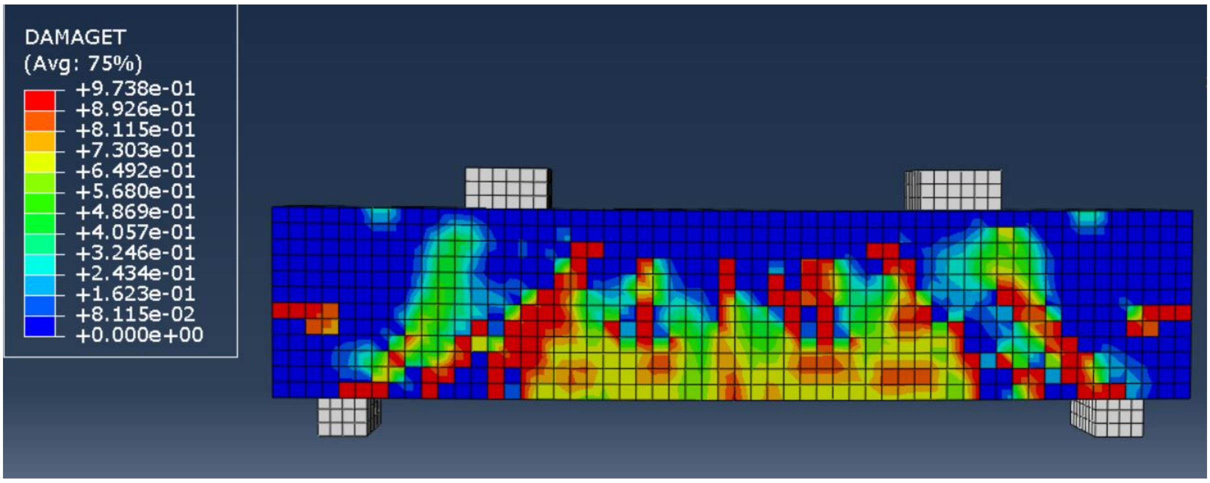


Figure 73 : phi8/20cm stirrups – Damage tension first diagonal crack

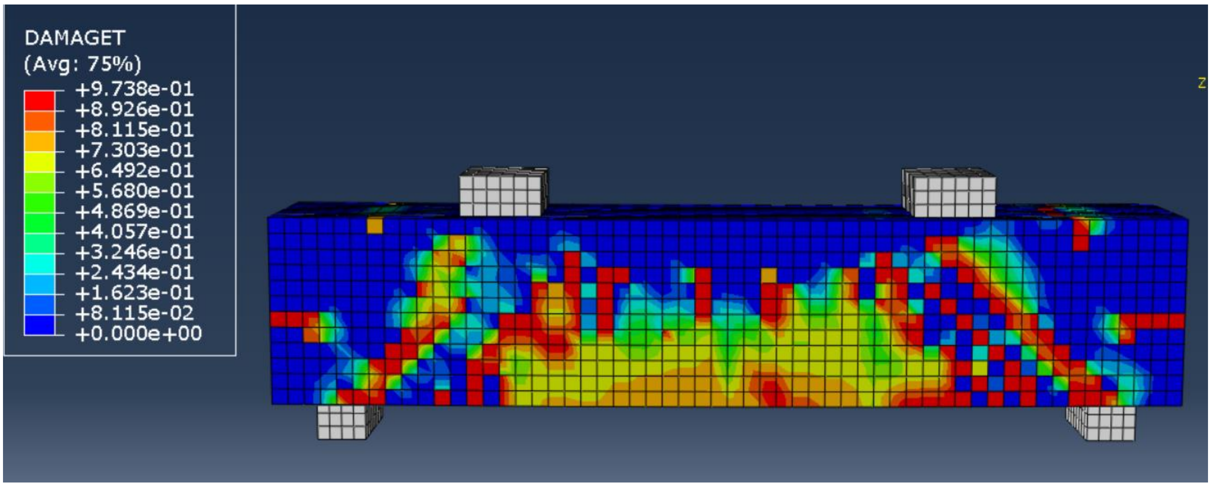


Figure 74 : phi8/12cm stirrups at start and end of beam– Damage tension at first diagonal crack

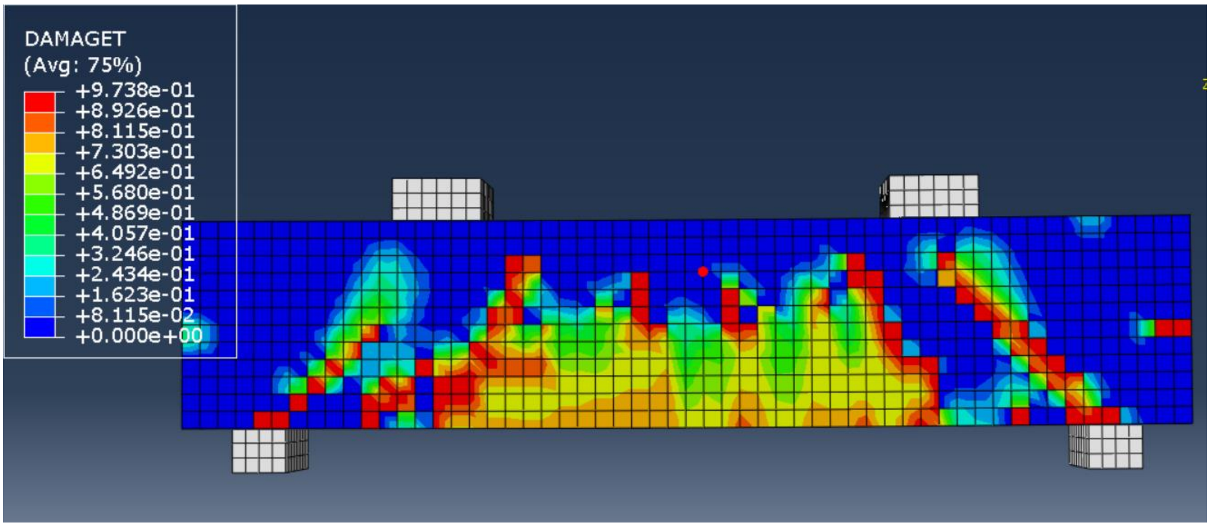


Figure 75: no shear reinforcement - Damage tension first diiagonal crack

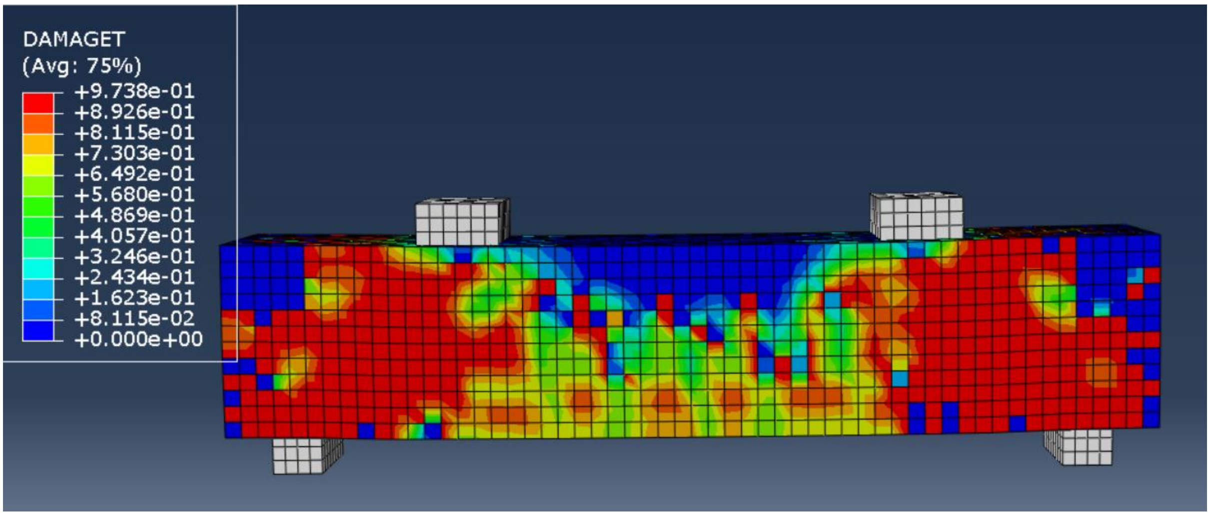


Figure 76: – phi8/20cm stirrups – Damage tension at ultimate crack

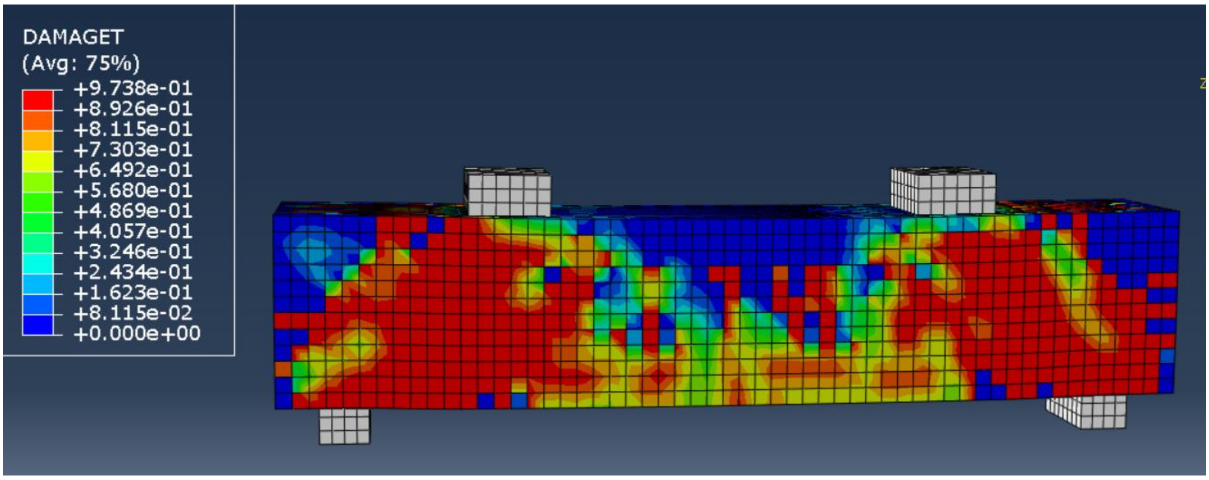


Figure 77: phi8/20cm stirrups – Damage tension at ultimate crack

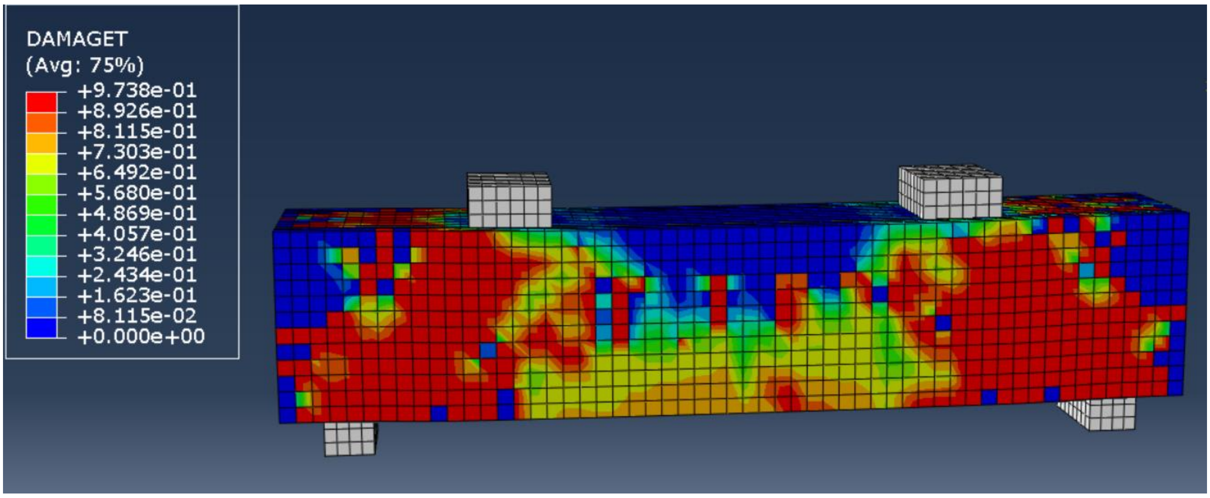


Figure 78: phi8/12cm stirrups at start and end of beam– Damage tension at ultimate crack

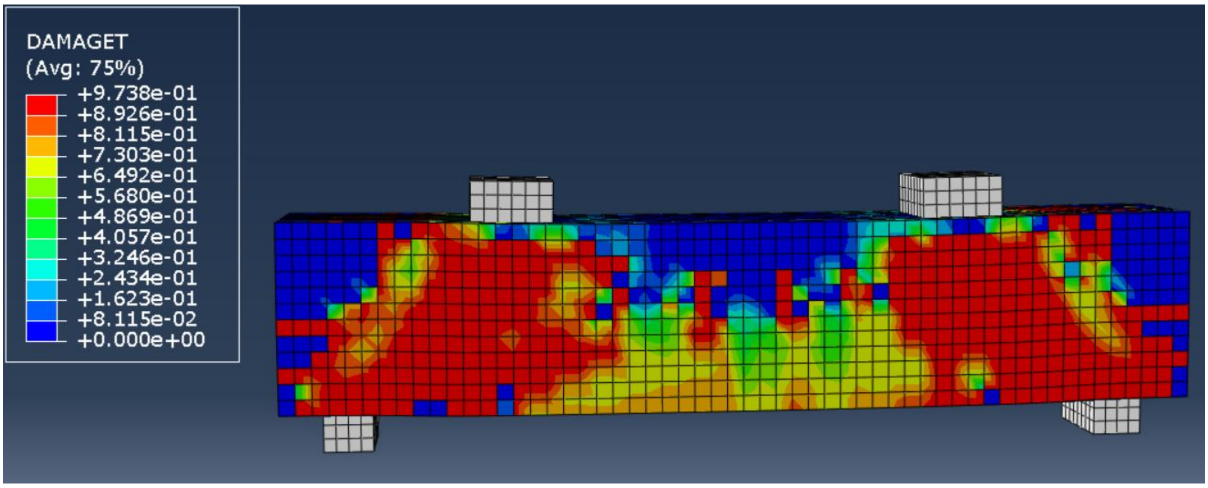


Figure 79 : no shear reinforcement - Damage tension at ultimate crack

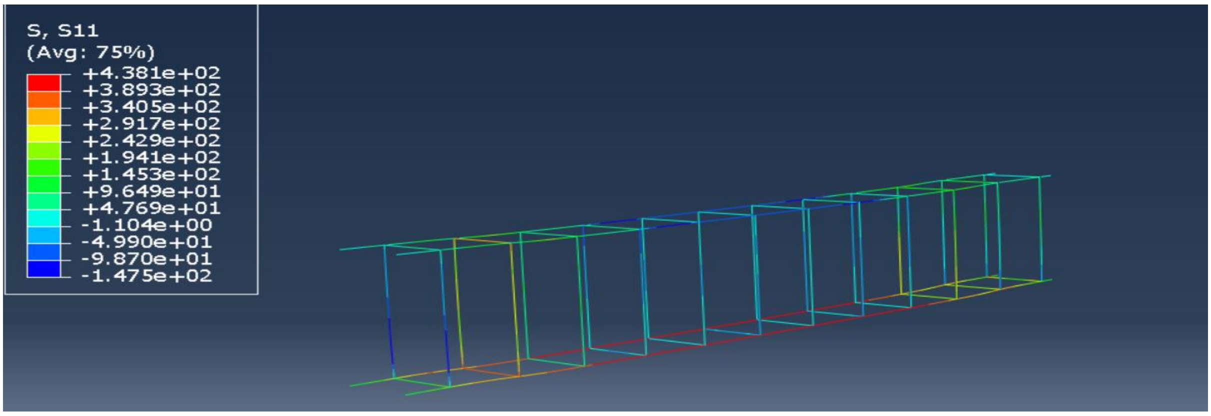


Figure 80: phi8/12cm stirrups – Steel normal strain at ultimate crack

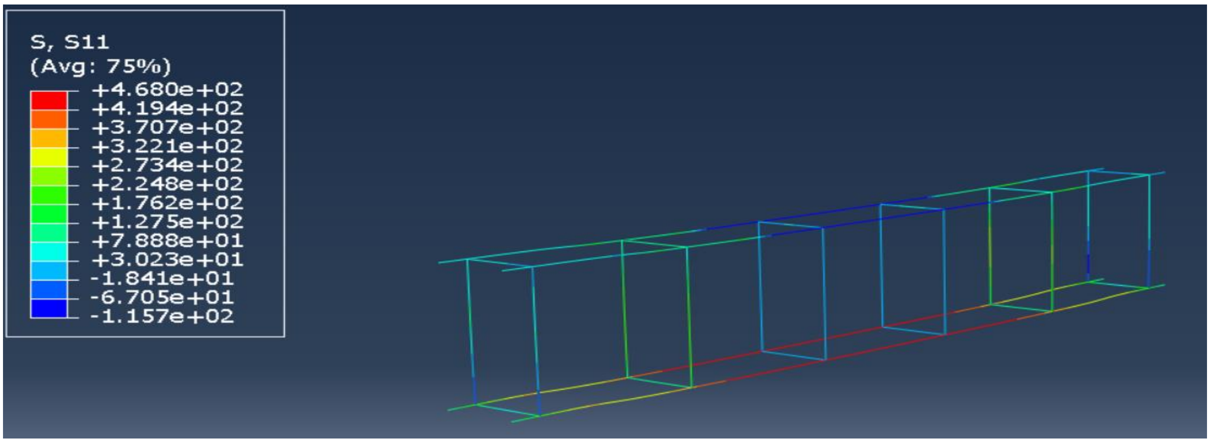


Figure 81 : phi8/20cm stirrups– steel normal strain at ultimate crack

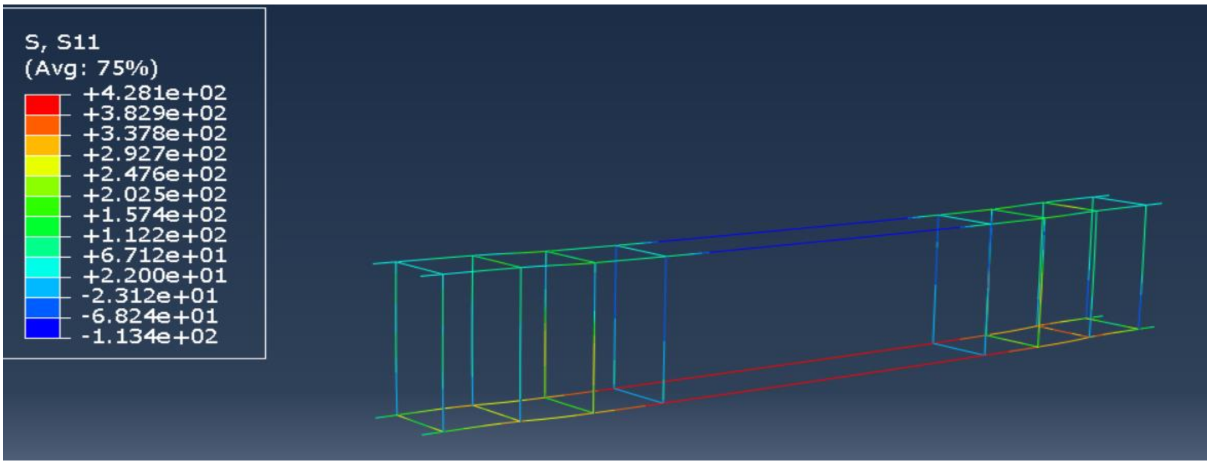


Figure 82: phi8/12cm stirrups at start and end of beam– steel normal strain at ultimate crack

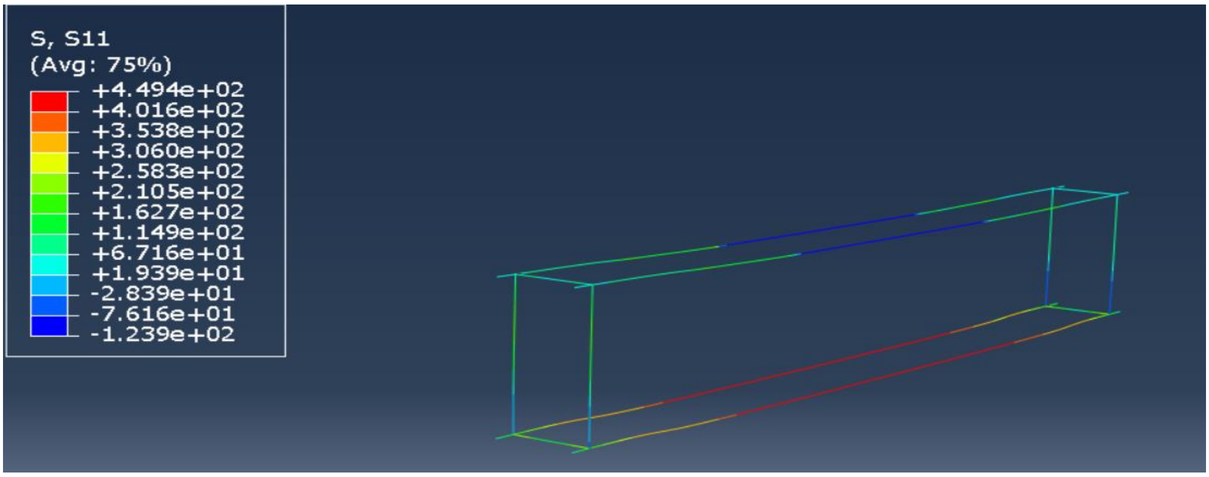


Figure 83: no shear reinforcement – steel normal strain

Based on the results shown in chapter 4 after using finite element method and after comparing the curves of load-displacement of models with a change in ratio of shear reinforcement, Since we observe in the figure below that all results are close to each other where we conclude that after removing stirrups and replacing by UHPC layer it gives a close result in terms of loads and displacement.

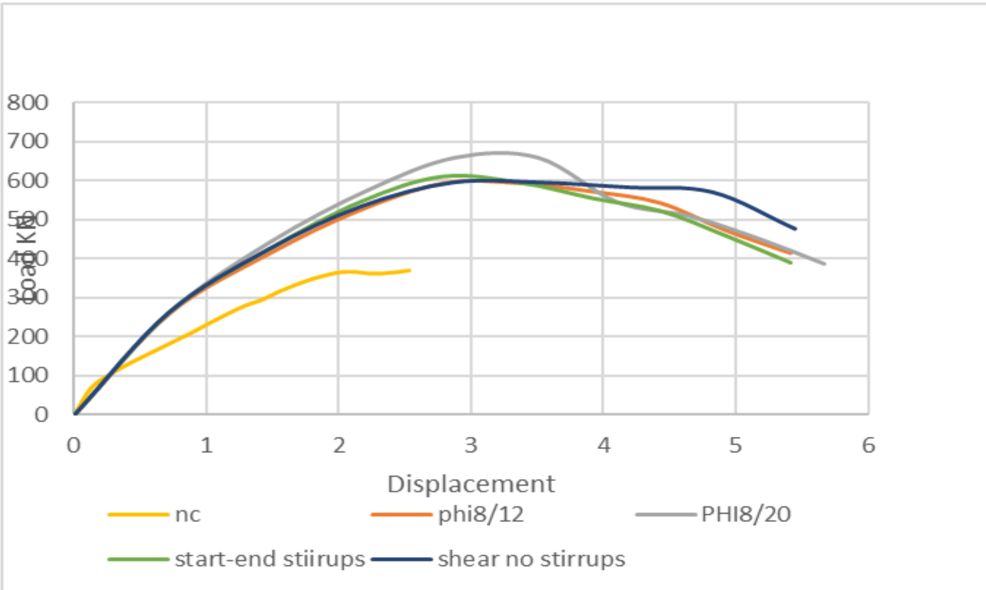


Figure 84: load-displacement curve- the ratio of shear reinforcement

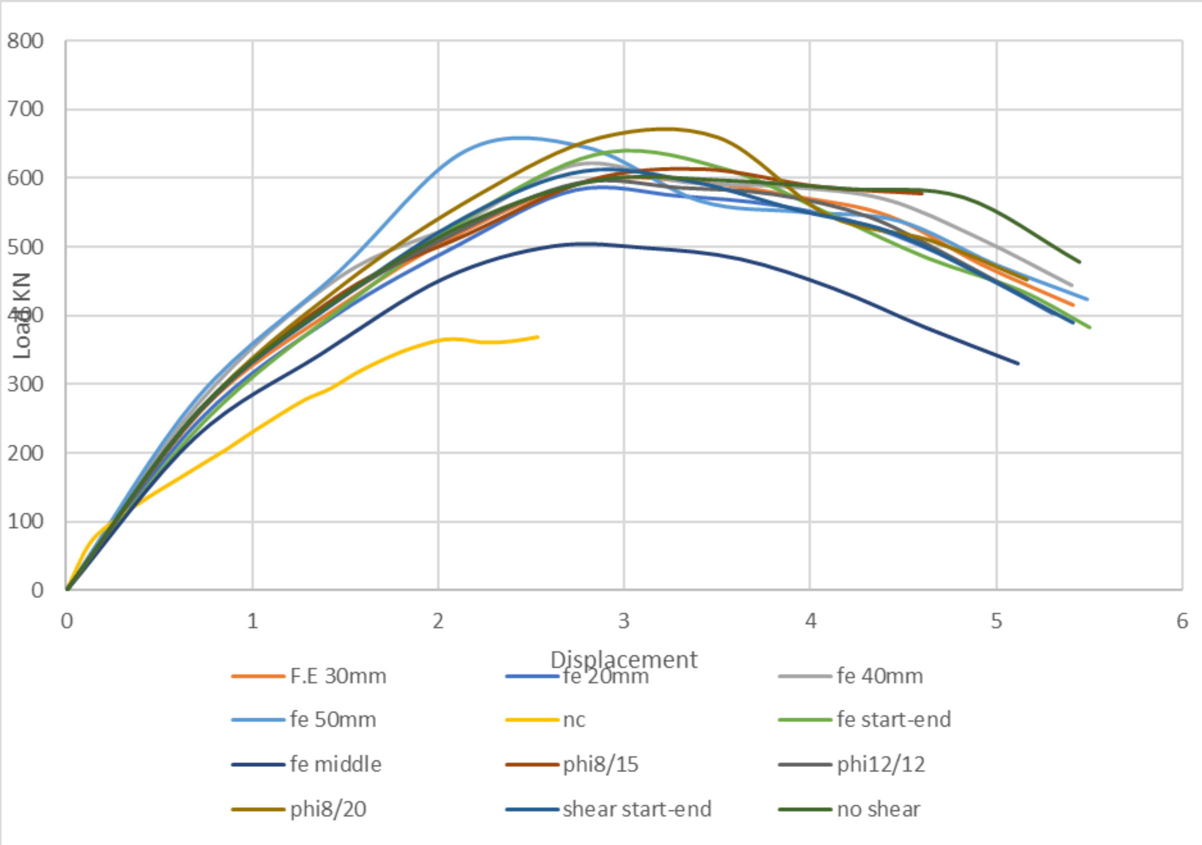


Figure 85 : load -displacement curve for all considered models

The previous figure shows load-displacement curve for all considered beams and parametric studies .we can see that the most advantageous and best way to strengthen the concrete beam is to strengthen the 370mm UHPC layer at the beginning and end of the beam with 20mm thickness.

Chapter 5- Conclusion

- The change in thickness of UHPC layer does not significantly affect the increase in loads and displacements.
- If we put UHPC 370mm in length at the beginning and end of the concrete beam gives a very close result to UHPC along the concrete beam.
- After removing stirrups and replacing by UHPC layer it gives a close result in terms of loads and displacement.
- While failure of control beams took place in shear, the failure of two-sided UHPC strengthened beams shifted to flexure-shear mode
- The beneficial effects of strengthening the RC beams using UHPC, as evident from enhancement of the shear capacity and shifting of the failure mode from brittle to ductile with more stiff behavior

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