ANALYSIS OF CRACK PROPAGATION USING DIGITAL IMAGE CORRELATION TECHNIQUE

a

THESIS

Submitted in partial fulfilment of the requirements for the award of the degree

of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision

of

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to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, SOLAN – 173234

HIMACHAL PRADESH, INDIA

MAY, 2019

STUDENTS DECLARATION

We hereby declare that the work presented in the Project Thesis entitled **"Analysis of Crack Propagation using Digital Image Correlation Technique"** submitted for partial fulfilment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Wakhnaghat** is an authentic record of our work carried out under the supervision of **Mr. Abhilash Shukla**. This work has not been submitted elsewhere for the reward of any another degree/diploma. We are fully responsible for the contents of our project thesis.

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CERTIFICATE

This is to certify that the work which is being presented in the project thesis titled **"Analysis Of Crack Propagation Using Digital Image Correlation Technique"** in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Ammaan Zahoor Chat (151617) and Akshay Bhardwaj (151619)** during a period from August, 2018 to May, 2019 under the supervision of **Mr. Abhilash Shukla** Department of Civil Engineering, Jaypee University of Information Technology, Wakhnaghat.

The above statement made is correct to the best of our knowledge.

Date: …………………

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LIST OF ABBREVATIONS

S.No.	Abbreviation Used	Description
1	ASTM	American Society for Testing and Materials
2	IS	Indian Standard
3	SFRC	Steel Fibre Reinforced Concrete
4	PFRC	Polypropylene Fibre Reinforced Concrete
5	OPC	Ordinary Portland Cement
6	DIC	Digital Image Correlation
7	W/C	Water Cement Ratio
8	CFRC	Carbon Fibre Reinforced Concrete

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ABSTRACT

The process of fracture in Fibre Reinforced structures of Concrete is difficult as it is related with the generation of both the micro and the major cracks. The behaviour of fractures is also associated with other phenomena like localization of strain, bridging of cracks and depends mainly on heterogeneity nature of the mix of concrete, type of reinforcement used, and also the concrete and specific properties of reinforcement. The primary purpose of this study is to probe the mode I type of crack propagation in the reinforced concrete beams by the technique called Digital Image Correlation (DIC). The DIC technique is a vigorous, non-contact well defined tool for fracture or crack measurements. Images are captured at altered stages of loading. By comparing these captured images during testing, it is achievable to deduce the deformation of object under external loads. In this thesis, the correlation between the properties of fracture and the concrete properties, with the fibre reinforcement are investigated experimentally at first and then analyzed on the software *GOM Correlate* by *Webinar*. The fibres used in this investigation are Flat Crimped Xorex Steel fibres of length 50 mm and width 3.5mm and Procon M Polypropylene fibres of length 19 mm and diameter 38 micro-meter, i.e. aspect ratio of 500. The Tests were carried out on fibre reinforced concrete beam samples by *Four Point Flexural Bending*. With the help of the DIC technique, the identification of cracking pattern and the fracture properties of fibre reinforced concrete can be analyzed. The DIC technique has turned out as an efficient way to determine the crack opening displacements.

Keywords: *Xorex, Procon, DIC, fracture, crack propagation, flexural, four point loading.*

Chapter 1
INTRODUCTION

1.1 General Introduction

Concrete is a solidified, non-natural structural mix of various materials that has a compound nature. The compound, concrete, is made of certain materials with binding nature, chemical or mineral admixtures, water and fillers in form of aggregates. As a guideline, the cement serves as binder and the fillers incorporate granular aggregates that are fine and\or coarse in size and texture, while the admixtures may incorporate both mineral and chemical admixtures. The word 'concrete' originates from a Latin expression 'Concretus', signifying 'to develop as one'. The admixtures might be included according to the prerequisite of setting time, both acceleration and impediment of strength gain, air entrainment, a decrease in water requirement and plasticity, which prompts better workability and improves various other factors governing performance of concrete. Concrete is generally isolated into non-hydraulic concrete, hydraulic concrete, polymer concrete, asphalt cement. The performance of concrete depends for the most part on the cement paste as it is the dynamic constituent of concrete. Different factors on which the execution of concrete depends are the amount of water utilized, nature of the crude materials utilized for cement manufacture, the properties of every raw material, the fineness of aggregates, the correct proportioning of constituents, curing time and the sort of curing, and so on.

As per the type of cement used, concrete is classified in various ways. If the concrete is readied with non-hydraulic cement, it is called non-hydraulic cement concrete. If the concrete is prepared from hydraulic cement, it is termed as hydraulic cement concrete. If the concrete is prepared from polymers, it is called polymer concrete or polymerized concrete. Lastly, if concrete is prepared from asphalt, it is called asphalt concrete. The non-hydraulic and hydraulic cement, both, require standard amount of water for mixing and for their hydration reactions. The only difference here is in the ability to gain strength in water. Non-hydraulic concrete does not attain its strength in water, while hydraulic concrete can attain its strength even in water.

1.2 History and Development

The most punctual records of utilization of solid go back to 6500 BC when the solid was first utilized by the Syrians. The kind of concrete utilized was non-water powered and its utilization was spread through the neighboring domains of Crete, Cyprus, and other Middle Eastern nations.

The essential type of cement was made out of chiefly Gypsum and Lime as covers. The Romans were the first to rethink and re-proportionate this blend. They included little rock and some sand with hot lime and water. They would likewise add creature blood to it.

Probably the most punctual utilizations of cement incorporate the 5300 miles of roadways developed by the Romans utilizing pozzalana, creature fat and blood as admixtures. The Romans had likewise figured out how to diminish the shrinkage in solid utilizing horsehair. The lime utilized was acquired from calcining limestone at 1000ºC. Around 3000 BC, Egyptians found that instead of lime, gypsum could calcine at significantly lower temperatures. Gypsum was then being utilized as restricting material in the development of the Pyramid of Cheops.

The Great Wall of China was worked by the Qin Dynasty around 220 BC utilizing lime as mortar.

Afterward, pressure driven lime was imagined by the Greeks and the Romans with limestone that contained argillaceous polluting influences. The water powered lime was generally utilized for development purposes in the field of hydrodynamics amid the second 50% of the primary century BC. The Greeks and the Romans additionally blended volcanic powder with lime to create water powered lime. The Greeks acquired volcanic fiery debris from the nearby situated island called Santorin, while the Romans got volcanic powder from the Bay of Naples. The mortar acquired by this procedure was increasingly impervious to water penetration and thus progressively tough. For around a thousand of years, the craft of calcining limestone to lime was lost and the argillaceous contaminations were not included. The amazing mortar was henceforth lost to the world for as long till 1756 AD when John Smeaton was appointed the development the board of revamping of Eddystone Light House off the shore of Cornwall, England. After various analyses, Smeaton made cement by blending totals (coarse) and ground block powder with bond. The Eddystone Lighthouse at that point went on for 126 additional prior years being supplanted with another cutting edge structure.

Afterward, Portland concrete was developed by Joseph Aspdin of England and the name Portland was given by Aspdin on the grounds that the shade of the bond after hydration was equivalent to that of limestone quarried in a southern English town of Portland. Portland concrete was set up by calcining the fine-ground limestone, blending it with finely separated dirt, and calcining the blend again in a furnace until the carbon dioxide was dispensed with. At that point, this blend was finely ground and utilized as concrete. Nonetheless, the temperature of calcination in Aspdin's development was insufficient to produce Portland concrete. Isaac Johnson was the person who first consumed the crude materials at temperature of clinkering to create present day Portland bond in 1845.

In the mid nineteenth Century, the use of Portland bond spread rapidly all through European and the North American nations basically because of fast development in the field of infrastructural advancement amid the Industrial Revolution. The principal deliberate testing of cement was directed in Germany, in 1836. The tests were directed to quantify the elasticity and the compressive quality of solid after recently made benchmarks. The fundamental utilization of Portland bond is to make concrete. Totals fill in as another principle quality giving element of solid, which incorporate sand, pounded stone, rock, dirt and shale. The Plain Cement Concrete (PCC) made of Portland bond and total is generally termed as the First Generation of cement. The second era of cement was later presented as the steel bar fortified cement (RCC). Francois Coignet is considered as a pioneer in the field of advancement of fortified bond concrete. (Day and McNeil, 1996.). Coignet tried different things with steel-fortified cement in 1852 and was the main manufacturer to utilize this second era of concrete as a structure material.

Concrete which was manufactured post 1980s mainly contained a significant amount of mineral admixtures like fly ash, slag, and silica fume and also various chemical admixtures, so its resultant mechanism of hydration, the products of hydration, and other micro-structural individuality are dissimilar from the concrete manufactured without the use of these mineral or chemical admixtures. The mechanical (tensile, compressive, flexural, etc,) properties of mineral or chemical admixture concrete are also dissimilar from the conventional concrete, therefore, such concretes are called as contemporary concretes. There are two major innovative developments in present-day concrete: 1) self-compacting concrete (SCC) and 2) ultra-high-strength concrete (UHSC). SCC is a high performance concrete, a concept developed in the 1980s. It is a concrete that can meet high performance, high durability and excellent uniformity pre-requisites, which cannot always be attained by using conventional raw materials and normal mixing proportions, placing techniques, and curing methods. The requirements may involve improvement in the mechanical and chemical characteristics of concrete, such as, long-term mechanical strength, high early-age strength, higher dimensional stability, ease of placement and compaction without segregation and bleeding, toughness, or longer service life span in rigorous environmental conditions.

Later in the 1990s, a further improvement in concrete was witnessed when the compressive strength of concrete higher than 200 MPa was achieved in France. Owing to the hefty amount of silica fume integrated in this material, it was originally named as reactive powder concrete (RPC) due to the chemically reactive nature of silica fumes and was later on altered to ultra-high strength concrete (UHSC) on account of its high compressive strength. The ultra-high-strength concrete has been brought up to the compressive strength of 500 MPa and above, with proper heat treatment. However, it is found to be brittle, so incorporating fibers into the UHSC has become very necessary. After the incorporation of steel fibers, flexural strength of about 50 MPa has been attained successfully. The first practical application of Ultra High Strength Concrete was recorded in the construction of a footbridge built in Sherbrooke, Canada.

Although the fibres are being used in concrete for many years, the actual acknowledgement of its properties and the use of fibre reinforced concrete began in the 1960's. The two main reasons to use fibre reinforced concrete are the resultant Shrinkage Crack Control and enhancement of Mechanical properties. Conventional concrete without any reinforcement provided to it is brittle and has low tensile strength and low toughness. These deficiencies of conventional concrete are overcome by the increase in tensile strength of concrete, hence reducing the brittleness of concrete, and increase in energy absorption capacity or toughness. Low modulus fibres, when added to concrete mix, lead to control of shrinkage cracking, which is seen during early ages of strength gain or hardening period. The mechanical properties are primarily enhanced by the increase in flexural strength. Fibres are added in fractions of total volume of concrete. The classification of Low fibre volume fraction is assigned to fibre reinforced concrete of volume fraction < 1%. The Moderate volume fraction employs between 1-2% of fibre volume. The high fibre volume fraction also named the High Performance Fibre-Reinforced Concrete (HPFRC) includes the fibre in volume fraction of the range of 5-20%. The low fraction FRC are mainly used for shrinkage cracking reduction. The moderate fraction FRC are used for improvement in mechanical properties like increased flexural strength, increased modulus of rupture (MOR), resistance to impact loading and toughness against fracture. This volume fraction of fibres can be used for partial replacement of steel stirrups (shear) and for crack bridge enhancement, or control of the width of cracks in concrete structural elements. Hence, this volume fraction of fibres is used as a partial replacement of reinforcement or as secondary reinforcement in concrete structures. The High Performance Fibre Reinforced Concrete (HPFRC) is used mainly for its unique behavior of strain hardening. The HPFRC exhibits a high tensile strain capacity of about 1.5%. This type of FRC includes 1.) Compacted reinforced Composite (CRC) matrix including 5-10% finer steel fibres. 2). SIFCON, a slurry infiltrated with 10-20% of steel fibres and 3). SIMCON, a slurry which is infiltrated with around 6% steel fibre mat.

The fibres being contemporarily used consist mainly of steel fibres glass fibres, polypropylene fibres (polymeric), carbon fibres, jute fibres, etc. Glass fibres have high tensile strength and high ultimate strain. However, they have low modulus of elasticity.Glass fibres also show very less resistance to moisture, creep and cyclic loads. Another major problem regarding glass fibres is that they are reactive in alkali solutions. Glass fibres like A-Glass (soda lime) and E-Glass (borosilicate) are readily attacked by alkali solutions and hence show poor durability. To counter this deficiency in durability, Zirconia (ZrO2) is added to alkali resistant glass fibres, which prevents alkali attacks on the glass fibres.

Fig. 1.1 Borosilicate Glass fibres (E-Glass)

Table 1.1 Mechanical Properties of Different Types of Glass fibres

Fiber	Density (g/cm^3)	Tensile strength GPa	Young's modulus (GPa)	Elongation (%)	Coefficient of thermal expansion ($10^{-7}/°C$)	Poison's ratio	Refractive index	Ref.
E-glass	2.58	3.445	72.3	4.8	54	0.2	1.558	17
C-glass	2.52	3.310	68.9	4.8	63	–	1.533	
S_2-glass	2.46	4.890	86.9	5.7	16	0.22	1.521	
A-glass	2.44	3.310	68.9	4.8	73	–	1.538	
D-glass	2.11–2.14	2.415	51.7	4.6	25	–	1.465	
R-glass	2.54	4.135	85.5	4.8	33	–	1.546	
EGR-glass	2.72	3.445	80.3	4.8	59	–	1.579	
AR glass	2.70	3.241	73.1	4.4	65	–	1.562	

The most widely used fibres in concrete based industry are steel fibres. With excellent tensile strength, high elastic modulus, high modulus of rupture and high ultimate strain, they have dominated in the construction industry among all other fibres. The shape and size of steel fibres are of many varieties like hooked, cramped, ribbed, etc that serve the purpose of required bond strength between the fibres and the concrete matrix. The increased bond strength directly increases the pull out energy of fibres.

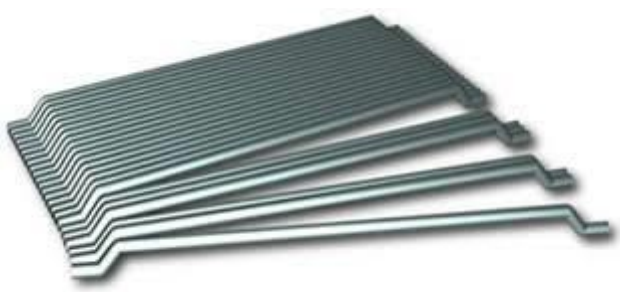

Fig.1.2 Various Types of Steel Fibre

Table 1.2 Mechanical Properties of Hooked Type Steel Fibres

	Steel Fiber Type	Length (mm)	Diameter (mm)	Density (gr/cm^3)	Tensile Strength (N/mm^2)
Long fibers	80/60	60	0,75	7,85	1225
	65/60	60	0,90	7,85	1160
Short fibers	55/30	30	0,55	7,85	1345
	40/30	30	0,75	7,85	1225

1.3 Digital Image Correlation Technique

The Digital Image Correlation Technique (DIC) is an optical, contactless technique of measuring deformations in materials. It is rapidly growing up-and-coming technological development that facilitates the scholars with a dependable and cost-effective means for measuring the strain of any structural element. Through this technique, user can observe cracks created in reinforced concrete beams and other structural elements and also the pattern of the cracking can be determined. The DIC method has been useful for analyzing the area of surface displacement/deformation and strain. This technique is not valid for measuring strain along any non-continuous area of deformation. However, if a unique point (i.e., among various points along the crack) is considered as the area of concentrated strain or concentrated deformation by replicating the handling of micro-cracks by the method of finite elements, the area of concentrated strain field based on analysis of Digital Images can be used for determining and visualising the location and growth of cracks. Experimental results support the fact that cracks generated in fibre reinforced concrete beams or cubes can easily be recorded and analysed with a good precision by using the strain field by Von Mises., The small and quantitatively higher subsets display a more accurate and better visualization of cracking pattern. Notwithstanding distinguishing visible cracks, the DIC picture investigation will empower researchers and scholars to find minute splits/cracks that are not noticeable to unaided eyes. Furthermore, the DIC technique has more reliability and accuracy than visual perception for examining crack loadings with the goal that prior alerts can be known before cracking is created in the object under study. Analysis of strain is a central issue for civil engineers and mechanical engineers relating to the occurrence of stress localization in the case of heterogeneous materials. Long-established technologies for determining deformation or measuring the strain consists of two widely used methods: 1) Strain Gauge that measures electrically the average strain in a section at target location and 2) Displacement Meter which measures the relative displacement of any two reference points, then mathematically relating the measured quantity into average strain. Few more techniques include 1) Drawing grid network on the sample\object before load test and then measuring the relative displacements of different grid lines with each other after the specimen is deformed to figure out the strain impact of seperate grids. The strain gauge method has the drawback of being incapable of measuring and recording the strain for the complete strain field. Displacement Meter method is wearisome and protracted. Consequently, the traditional methods or techniques do not suit the needs of a civil engineer or a mechanical engineer to execute study of strain or crack distribution. Additionally, the traditional methods for strain measurement rely on physical contact between measuring instrument and the surface of the sample under study, to acquire the magnitude of strain that might often turn out to be impossible to execute in many unfavorable circumstances For example, these conventional instruments can't be taken to physical contact with far off structures like scaffolds, steel structures under raised temperature and extensive weight, and articles in radioactive specialty, among various others. An increasingly extreme issue of utilizing the traditional estimating gadget is that the strain meter frequently isolates from the example when the last is experiencing extensive disfigurement to gravely meddle with the strain estimation amid the later phase of the trial arrange. DIC-based non-contact technique to beat these issues for estimating disfigurement has been created. Forming the DIC technique into a quick, savvy with high exactness innovation is made reachable by quick advances in computerized photography and PC innovation in ongoing time. Notwithstanding its utilization in substantial scale structural designing activities, the DIC strategy can be joined with an assortment of other estimating procedures, for example, radiography for watching outer deformation and the interior cracking pattern of any specimen simultaneously such that the observed material strain can be plainly connected to interior cracking and failure.. On account of steel rebar fortifications, when exposed to gravitational weight, strengthened solid structure will basically create cracking because of extension and compression due to thermal variations, and unruly establishment subsidence. This makes water or dampness get through the solid prompting extreme rust of the strengthening steel bars to debilitate the structure. Thus, to screen cracking created in strengthened solid structure is a significant connection for diagnosing basic structural quality of design. 'Chen & Liu (2004)' projected the acoustic emission (AE) technique by investigating the brittle failure of reinforced concrete beam under three-point loading. 'Yehia (2009)' applied the concepts of fracture mechanics to replicate the flexural strength of the reinforced concrete beam depending on the laboratory findings. However, this method was found to be incompetent to successfully and precisely telling differences in obtained strain caused by varying stress. Zhang and Liu (2003) connected the three-point load bend test to assess the impact of coarse aggregates and cementitious lattice quality on the stress with crack width relationship, elasticity, tensile strength and fracture energy parameters of concrete mix design. In any case, they neglected to demonstrate the connection between's crack or deformation\displacement and loads. Ozcan et al (2009) utilized the four-point test and the limited component technique or the finite element technique to examine the connection between loads at failure and the corresponding deformation. Swartz and Taha (1991) used limited component codes, with straight versatile crack mechanics and nonlinear break mechanics to depict the split proliferation and crack conduct of plain solid bars with Iosipscu-type geometry and stacking in four-point bowing with and without the nearness of pivotal pressure. Ru et al (2011) connected expanded limited component technique (XFEM) to break down the area of the split forces on the split engendering course of plain solid bar exposed to three-point bowing test. Beam and Kishen (2012) proposed the crucial standards of dimensional examination and self-likeness to beat the observational idea of the systematic models. This model is connected to contrast and the test trial of three-point twist bars and minimal strain examples. The outcomes show the validity of the model. The test techniques for previously mentioned investigations were trailed by the conventional exploratory strategy. Non-DIC techniques have been proposed in writing for watching breaks in fortified cement. In this way, the DIC technique (Chu et al 1985; Bruck et al 1989; Sutton et al 1991; Lu and Cary 2000) joins with the misshapening hypothesis by utilizing optical estimation to get computerized pictures of the example when distortion and afterward breaking down the pictures to decide the relative uprooting field so the strain circulation on the twisted surface of the example can be uncovered. Lately, numerous analysts (Vellinga and Onraet 2000; Vendroux and Knauss 1998) connected innovation that consolidates DIC strategy and micrographic perception to perform small scale run strains. Research facility results demonstrate that the DIC technique is achievable for watching and investigating nano-scale twisting. Dost et al (2003) proposed the utilization of DIC strategy to watch minute breaks and magnifying instrument to gauge the measurements in nano-scale, and the outcomes affirmed the undeniable discrete developments for either side of the split. Subsequently, in this exploration, the practicality of using the DIC strategy for watching the improvement of breaks in fortified solid shafts under stacking is contemplated. The examination further covers applying the DIC strategy as quantitative investigations for identifying early event and advancement of splits. The connections among different dim estimations of computerized pictures are broke down for getting the conveyance of uprooting and strain fields encompassing the break so as to examine the connection among strain and stress.

Hypothesis of the computerized picture connection technique The 'auxiliary dot' (Shih et al 2008) will be set up on the example surface first to make non-uniform dispersion of dim scales. This dim scale dispersion trademark will be utilized in the DIC strategy to look at the distorted and un-twisted pictures so as to acquire relative positions. These uprooting vectors of different picture indicate are determined deduce the typical strains, shear strain and von Mises strain field. The material testing consequence of fiber RC bar demonstrates when this benevolent material will be stacked past the yield quality of the material, plastic disfigurement will happen. Accordingly, Von Mises material model has projected to investigate the mechanics practices of FRC pillar in this exploration. 2.1 Two-dimensional advanced picture connection strategy DIC is generally connected in the field of picture distinguishing proof system by looking at the neighborhood connection of two pictures; the connection among twisted and un-distorted pictures can be recognized.

1.4 Objectives

- To include the fibres, Xorex Flat Crimped and Procon M Polypropylene, in the concrete beams for research purposes.
- To study the Strain and Deformability, and Flexural properties of the samples using Digital Image Correlation.
- To compare the results and conclusions with plain concrete samples using the software GOM Correlate by Webinar.

1.5 Scope and Need of Study

- The DIC technique has been most widely used in the field fracture mechanics of advanced materials like Carbon Fibre Reinforced Concrete (CFRC), Fibre Injected PE, metal foam, etc.
- The DIC Technique has found numerous applications in the field of material testing from analyzing strain and deformation behavior to the deductions of various mechanical properties of the materials.
- Some widely used applications have been recorded in various research papers for the testing of materials like Asphalt, Glass Fibres etc for their Young's Modulus of Elasticity, Poisson Ratio, Elasto Plastic Behaviour, etc.
- It is also used for component testing for the parameters of shape, displacements, strains, warpage, etc.
- The need of DIC technique lies all around the engineering tracks viz; Aerospace, Railways, Automobiles and various manufacturing firms.

Chapter 2

LITERATURE REVIEW

So as to explore the crack proliferation of steel fibre reinforced cement and polymer fiber strengthened concrete, the eminence papers distributed in the comparative tracks were analyzed and numerous parameters were chosen from the given papers that were pursued as indicated by the ASTM codes gave and pursued by the specialists. The parameters to be judged incorporate the volume portion of strands utilized, the mix design variations, the volume of super plasticiser utilized, and so forth.

1 % fiber volume was considered as far as possible because of practical reasons, for example, simplicity of blending and placing and compaction.. The material toughness increment results in higher shear quality of the solid and better deformability, for example the redirection at most extreme load is fundamentally higher for FRC beams than plain solid samples. In SFRC beams, the greatest loading expanded by around 20% as for the plain solid bars, with double the avoidance at most extreme load. "'Investigation of the shear conduct of fibre strengthened solid beams.' J. Turmo, N. Banthia, R. Gettu,. Materiales de Construcción, Vol.58, Pg. No 292 (2008) ". It appears that the expansion of steel strands has support on flexural strength of the superior cement containing fly powder and SiO_2 nano particles when the steel fibre content is under 2%, and the expansion of steel filaments has unfriendly impact of flexural sturdiness when the steel fibre content is past 2%. Expanding steel fibre content, a significant increment in the flexural quality of the blends was acquired; for instance, contrasted and the solid strengthened with 0.5% steel filaments, the increments were resolved as 36.5% for steel fibre substance of 2% at 28 days of restoring period.

" 'Flexural Toughness of Steel Fibre Reinforced High Performance Concrete Containing Nano-SiO_2 and Fly Ash' Peng Zhang, Ya-Nan Zhao, Qing-Fu Li, Peng Wang, and Tian-Hang Zhang".

Strain field of $yy\varepsilon$ parallel to the pressure course was observed to be most touchy than relocation (u, v, w) and other strain ($xx\varepsilon$,$xy\varepsilon$) fields for distinguishing breaks. On the off chance that $yy\varepsilon$ Δ/STDEV $\geq$3.7, where STDEV is the standard deviation of $yy\varepsilon$ field, and

$yy\varepsilon\delta$ is the distinction between pinnacle $yy\varepsilon$ of strain fixation situated on breaks and normal $yy\varepsilon$ of the base, is fulfilled, splits can be recognized. This measure is free of split length, subset estimate utilized in DIC, and regardless of surface and inward breaks. To fulfil this measure, long breaks or surface splits require lower stacking levels than little breaks or internal breaks. Breaks are much effectively recognized by utilizing substantial subsets than by little subsets. For examples with the proportion of split profundity to example thickness 0.77 ~ 0.82, the farthest point of break length that can be identified is (a/W)min=0.006991 (where an is the break length and W is the width of example) for inward splits and (a/W)min=0.004974 for surface splits inside the connected pressure scope of 0~1.2ysσ. Neighbourhood distortion around splits happens in the strain procedure, and its fixation degree increments with expanding load. This unavoidably reflects in the varieties in uprooting (u, v, w) and strain ($xx\varepsilon$, $yy\varepsilon$, $xy\varepsilon$) field on both front and back surfaces. As connected burden expanding, the nearby disfigured area unmistakably concedes from the neighbor areas. " 'Break Detection by Digital Image Correlation' Hai Qiu1, Junhui Yan2, Oh-Heon Kwon3, Michael A. Sutton2".

The DIC technique works by taking a reference picture of the example before stacking and in this manner taking different pictures (known as test pictures) all through the testing. Next, programming is utilized to contrast the test pictures with the reference picture and distinguish the distinctions. These distinctions are translated as disfigurements or developments of the example at the time the test picture was taken. This data at that point can be utilized to make and screen the full-field dislodging and strain forms of the example all through the test strategy. In four-point bowing tests, the vertical break are mostly Mode I crack brought about by tractable pressure. The Mode I break opening makes a hole between the two essences of the split when the shaft is in the greatest negative bowing position. Such irregularity results in DIC strain estimation mistakes that can prompt impossible and moderately high determined exx values (strain in the bar length bearing) and Von Mises strains. That is, the event of vertical breaking causes unexpected increments in the exx and von Mises strains. Such an abrupt increment in strain esteems gives the likelihood to utilize parallel strain shapes for break tip recognition.

A strategy for numerical handling of the exploratory removal fields gotten by DIC is introduced in this work. Plausibility of programmed bookkeeping of the genuine position and introduction of the split by methods for characterizing of proper geometrical parameters, permits disentangling the technique for estimating of the uprooting fields and post preparing. As it is adequate to catch the intrigue territory with a break, without being attached precisely to the split tip (which did not at first known) and the break introduction. The technique has an incredible potential for application on full-scale objects on the grounds that the approach represents the moving and turn of the area of intrigue considered. " 'DIC Technique to Investigate Crack Propagation in Grid-Reinforced Asphalt Specimens' Seyed Amirshayan Safavizadeh, Ph.D.1; and Youngsoo Richard Kim, Ph.D., P.E., F.ASCE2".

The irregular force conveyance is called dot design, which is framed when intelligible light is reflected from a harsh surface or when light is proliferated through a medium with arbitrary refractive record variances [17]. All in all the factual properties of spot designs depend both on the rationality of the episode light and the point by point properties of the arbitrary surface or medium. The surfaces of most materials are very harsh on the size of an optical wavelength ($\lambda \approx 5x10^{-7}$ meters). At the point when monochromatic light is reflected from such a surface, the optical wave coming about at any far off point comprises of numerous sound parts; the impedance of the considerable number of segments is then called the spot design.

Composite materials often exhibit multifaceted mechanical and thermal properties, thus may show anisotropic, i.e. not invariant with direction, and nonlinear practices. Thusly, subsets of pictures in which the pixels have a similar width (w) and stature (h) as in the first picture can be chosen. Each picture subset has a region of w×h pixels and a particular greyscale Value. The dislodging field (du and dv) can be acquired by looking at the article when misshapening in the picture subset." 'Utilizing Digital Image Correlation Method for the Measurement of Residual Stress in Nickel Coating of Specimen' C.- H. Chien1, T.- H. Su1, C.- T. Wang, and B.- S. Chen1".

Chapter 3
MATERIALS

3.1 Flat Crimped Xorex Steel Fibre

3.1.1 Introduction

Steel fibres are widely used to strengthen tensile strength of concrete by 20-25%. Steel fibres have different shapes and sizes. They are used to enhance several mechanical properties of the designed concrete which are:

- Toughness
- Flexural Strength
- Tensile Strength
- Compressive Strength

The bents and hooks have been found to be vital to the **anchoring performance of the fibres** and the **subsequently resulting concrete ductility**. These special features, in combination with **elongation of steel**, are the primary differentiators of Xorex steel fibre reinforcement concrete series. Unlike traditional reinforcement, Xorex steel fibre reinforced concrete dynamically reinforces each part of concrete sample, allowing them to **detect minute crack openings** immediately as they crop up.

Specifications:

- Fibre Length- 50 mm
- Equivalent Diameter 0.045” (1.14 mm)
- Aspect Ratio- 44
- Tensile Strength - 1242 MPa

3.1.2 Procurement

Flat Crimped Xorex Steel Fibre used in this project was procured from a construction site at Noida under ***Universal Contractors and Engineers Pvt. Ltd***.

Fig 3.1. Flat Crimped Xorex Steel Fibre

3.2 Procon M Polypropylene Fibres

3.2.1 Introduction

Polypropylene fibres limitedly affect the properties of the solidified concrete. They don't give any noteworthy post first cracking ductility. Their capacity to decrease bleed and segregation helps with keeping up the first water/cement proportion of the surface mortar, which can prompt enhancements in the surface layer along these lines expanding protection from scraped spot. Polypropylene fibres might be powerful in dispersing shear forces and giving some improvement to freezing and thawing. They have additionally been appeared to decrease the spalling of cement in a flame.

Polypropylene fibres are likewise utilized in spray concrete or shotcrete, to improve the underlying properties and to diminish sloughing and bounce back.

It is important to recognize the short polypropylene fibres and the bigger engineered fibres that are being created, which ought to give some basic advantages like steel fibres.

Specifications:

- Length- 19mm
- Diameter- 30µm
- Aspect Ratio- 500
- Tensile Strength in MPa- 2000
- Elastic Modulus in GPa- 72
- Specific Gravity- 2.7

3.2.2 Procurement

Fibres used in this project were procured from a construction site at Noida under Universal Contractors and Engineers Pvt. Ltd.

Fig 3.2. Procon M Polypropylene Fibres

3.3 Aggregates

3.3.1 Introduction

The American Society for Testing and Materials (ASTM) has published a thorough catalogue of specifications including ASTM D 692 and ASTM D 1073 for a variety of building aggregate produce, which, by their characteristic plan, are suitable for particular construction requirements. These products comprise of certain types of coarse and fine aggregate considered for uses as fillers to asphalt mixes and concrete mixes, and also other construction purposes.

Aggregates are the major components of concrete which acquire almost three-quarters of the volume. Such proportions of a constituent contribute to important properties of the concrete after it has been used. Aggregates affect the properties in both, fresh as well as hardened concrete. Aggregates are supposed to be inert. However, physical, chemical, thermal and sometimes surface properties of the aggregates make it a non inert material which affects the properties of concrete as a whole.

Effects of Aggregates:

(a) In fresh and plastic concrete: The surface texture and size gradation of the aggregates used influence the fluidity, cohesiveness and rheological behaviour of cement-water-air paste. The aggregates must be so selected that fulfill the requirements of the end product.

(b) In hardened concrete: Use of proper aggregates in concrete mix reduce the shrinkage and cracking. General properties of aggregates such as weight, strength, thermal properties, water resistance and stiffness affect the properties of the concrete as a whole.

Fine Aggregate- Aggregate, that passes 4.75-mm IS Sieve and contains only insignificant amount of coarser material.

Natural Sand - Fine aggregate produced by the natural breakdown of rocks which have been deposited by rivers, wind or other glacial agencies.

Crushed Stone-Sand - Fine aggregate obtained by crushing hard stone in crushers at stone quarries.

Crushed Grace1 Sand - fine aggregate formed by crushing the natural gravel.

Coarse Aggregate- Aggregate which is retained on 4.75-mm IS Sieve after passing from 20mm or 10 mm sieves depending on the requirements, and containing only as much amount of finer material as is permitted for various types as described in the standard codes. Coarse aggregate is illustrated as:

a) uncrushed gravel or stone that is obtained from the natural disintegration of rock,

b) Crushed gravel or stone obtained from crushing of gravel/hard stone.

c) Partially crushed gravel or stone

Specifications-

Size- 20mm and less

10mm and less

3.4 High Range Water Reducers

3.4.1 Introduction

CICO PLAST SUPER C-300 High Range Water Reducers are used to enhance the workability and flow properties of the designed mix without adding the extra water. HRWR produces self levelling concrete used for congested reinforcement. It also increases bond strength of concrete to reinforcing steel and also decreases shrinkage and cracking. HRWR used are for self compacting concrete.

3.4.2 Procurement-

CICO PLAST SUPER C-300 used in this project is procured from CICO Company.

Fig 3.3. Cico C-300 Super Plastisizer

3.5 Ordinary Portland Cement (Grade 43)

3.5.1 Introduction

Ordinary Portland Cement (OPC) is graded according to their strength. The grade demonstrates the compressive strength (MPa) of the concrete that will achieve following 28 days of setting. This cement is utilized for general common development work under ordinary environmental conditions. It very well may be utilized for plaster works and single storeyed individual houses.

Because of low compressive strength, this grade of cement is ordinarily not utilized where high desired strength of cement viz, M-20 or more is required. The accessibility of higher levels of OPC in the market are influencing the utilization of 33 level OPC and now a days 43 level OPC is ordinarily utilized for general development work rather than 33 grade OPC.

3.5.2 Procurement

Two cement bags of Grade-43 each were procured from Gyan Chand Traders, Chandigarh.

CHAPTER 4
METHODOLOGY

4.1 Apparatus:

The testing machine used for the flexural test was **Universal Testing Machine (UTM).** The machine used had the capacity of 1000KN with suitable loading variations sich as point loading, surface loading, and multiple point loading.

The bed of the testing machine was equipped with a setup of rollers which could be adjusted according to specific needs. The rollers were of steel with 38mm of diameter which acted as a support to the testing specimens.

According to **IS 516-1959,** the rollers are supposed to be kept at a centre to centre distance of 600mm for 150 mm specimens and 400mm for 10mm specimens. As the specimens were of 100mm, rollers were placed at 400mm apart with two similar rollers which were mounted at the upper surface of the specimen. The rollers kept on the specimen were 200mm apart and were placed symmetrically to the centre of the casted specimen.

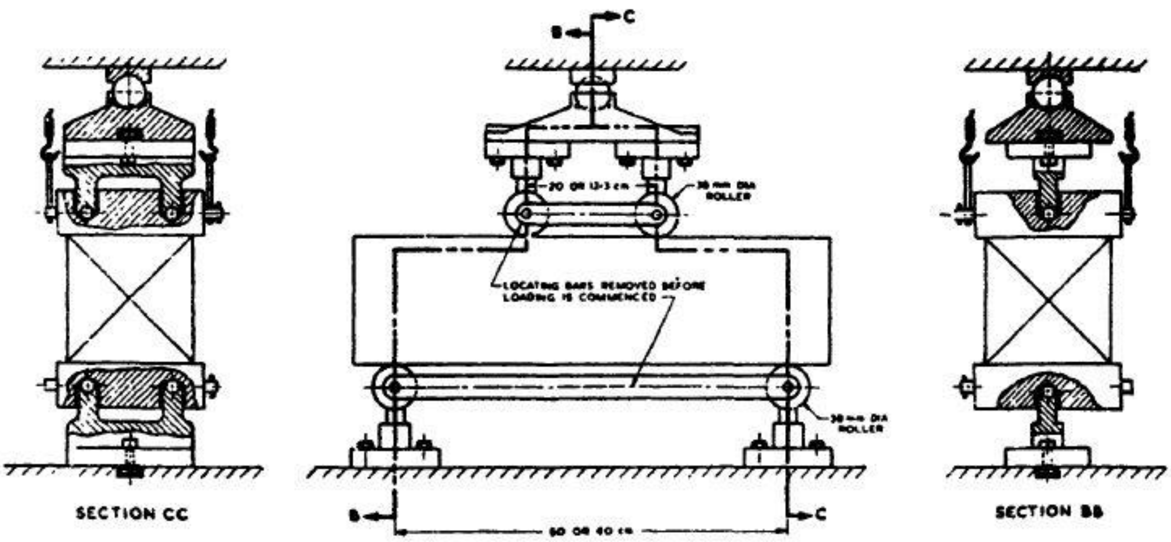

Fig 4.1. Apparatus according to IS 516-1959

The lines inscribed on the specimen helped in the orientation of the camera apparatus as well as the loading axis could be matched easily with that of the specimen. This helped to increase the uniform distribution of the applied load. The cameras were kept 75cm normal to the surface which was to be examined. Tripod had dumpy level which ensured the straight line of axis. The grid lines were also enabled in the camera which also increased the accuracy in terms of adjustment of the camera. The source of extra light was also kept in order to brighten up the surface of the specimen. LED lights were used for the illumination of the setup. Another camera was setup at the digital meter of th UTM machine. The simultaneous recording of the digital meter as well as the specimen was made sure with the help of a stopwatch. This simultaneous recording of both areas helped us to detect the same number of stages which were to be used in the software. The deflection and loading was noted and recorded in the Camera 2. Firstly, it was ensured to have a loading rate as a constant too with the help of the knob provided on the operating interface of the Universal Testing Machine.

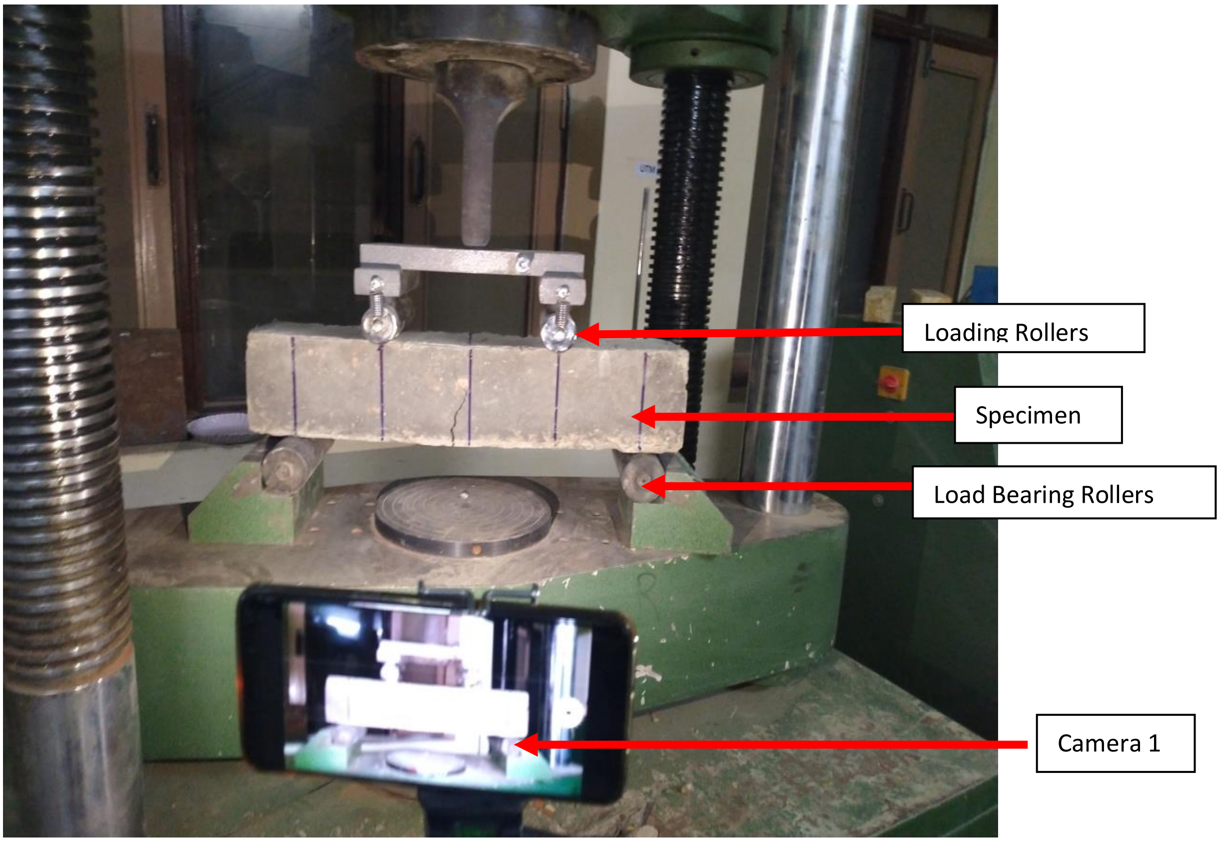

Fig 4.2 Full Apparatus

4.2 Mix Design:

Total No of samples casted = 24

No of samples casted per session = 6

The mix design is as per one cubic meter volumetric calculations later converted to the volume of 6 sample moulds of total volume= 0.03 m^3

Of these 6 samples, 3 samples are prepared with Xorex Flat Crimped Steel fibres and 3 samples with Procon M Polypropylene Fibres. For each fibre type, net volume of concrete to be produced is 0.015m^3.

Dimmensions= 500mm*100mm*100mm.

The mix design M-50 grade (Using Admixture –Cico C-300)

Parameters for desired mix

Grade Designation - M-50

Grade of cement - O.P.C-43 grade

Cement Manufacturer - Ambuja

Chemical Admixture - Cico Plast Super C-300

Fine Aggregate - Quarry Sand

Coarse Aggregate(crushed) - 10mm and 20mm

Specific Gravity of Components

Cement = 3.15

Fine Aggregate (quarry sand) = 2.61

Coarse Aggregate (20mm) = 2.65

Coarse Aggregate (10mm) = 2.66

Minimum Cement to be used (As per the codal provisions) =400 kg / m^3

Maximum water cement ratio to be used (As per the codal provisions) = 0.45

1. Mix Design Calculations : –

1. Target Mean Characteristic Strength = 50 + (5 X 1.65) = 58.25 Mpa,
   where 1.65 is the factor of safety.

2. **Water cement ratio:-**

Assume water cement ratio = 0.35

2. Water to be used: –

Approximately, water content to be used for 20mm maximum Size of aggregate = 180 kg /m^3 (As per codal Table No. 5 IS : 10262-2009). However, super plasticizer is being used , so we can reduce water content by 20%. (IS: 10262-2009)

Now, Net Water Content = 180 X 0.8 = 144 kg /m^3

3. Cement Content Calculation:-

Adopted Water cement ratio for design = 0.35

Water Quantity per cubic meter of concrete= 144 kg

Cement content obtained from water cement ratio = 144/0.35 = 411.4 kg / m^3

Hence, Cement content to be used in the mix = 412 kg / m^3

4. Coarse and Fine Aggregates Calculation

Volume of concrete considered reference calculations = 1 m^3

Calculated volume of cement = 412 / (3.15 X 1000) = 0.1308 m^3

Calculated volume of water = 144 / (1 X 1000) = 0.1440 m^3

= 4.994 / (1.145 X 1000) = 0.0043 m^3

Cumulative volume of all ingredients but coarse and fine aggregates = 0.1308 + 0.1440 +0.0043 = 0.2791 m^3

Therefore, volume of fine and coarse aggregate obtained = 1 – 0.2791 = 0.7209 m^3

Volume of Fine Aggregates. = 0.7209 X 0.33 = 0.2379 m^3 (33% by volume of total aggregate is assumed for fine aggregates)

Therefore, Volume of Coarse Aggregates Obtained = 0.7209 – 0.2379 = 0.4830 m^3

Hence, weight of Fine Aggregates. = 0.2379 X 2.61 X 1000 = 620.919 kg/ m^3

Round the weight of Fine Aggregates to. = 621 kg/ ^{3}

Hence, the weight of Coarse Aggregates = 0.4830 X 2.655 X 1000 = 1282.365 kg/ m^3

Take the rounded off weight of C.A. = 1284 kg/ m^3

The ratio of 20 mm: 10mm coarse aggregates taken as = 0.55: 0.45

Therefore, weight of 20mm C.A.= 706 kg.

and, Weight of 10mm C.A.= 578 kg.

Hence, the net Mix design features per m3 of concrete to be produced are as follows: (cement, water and admixture weights are increased by 2.5% for this trial)

Weight of Cement = 412 X 1.025 = 422 kg

Weight of Water = 144 X 1.025 = 147.6 kg

Weight of Fine aggregate = 621 kg

Weight of Coarse aggregate of 20 mm size = 706 kg

Weight of Coarse aggregate of 10 mm size = 578 kg

Weight of Chemical Admixture = 1.2 % by weight of cement = 5.064 kg.

Ratio of Water: Cement: Fine.Agg.: Coarse.Agg. = 0.35: 1: 1.472: 3.043

5. Inclusion of Xorex Flat Crimped Fibre

1) Volume fraction in percentage of fibre to be included = 1%.

Total volume of mix for Xorex fibre= 0.015 m^3.

Therefore, volume of Xorex used = 0.00015 m^3.

Density of Fibre= $5*10^6 g/m^3$

Weight of fibre = 0.75kg

2) Volume Fraction in percentage of fibre to be included = 0.5%

Total volume of mix for Xorex fibre= 0.015 m^3.

Therefore, volume of Xorex used = 0.000075m^3.

Density of Fibre= $5*10^6 g/m^3$

Weight of fibre = 0.375kg

6.Including Procon M Polypropylene Fibre:

1) Volume fraction in percentage to be used = 1%

Total volume of mix for Polypropylene fibre= 0.015 m^3.

Therefore, volume of fibre used = 0.00015 m^3.

Density of fibre= $0.91*10^6$ g/m^3

Weight of fibre = 0.1365kg

2) Volume fraction in percentage to be used = 0.5%

Total volume of mix for Polypropylene fibre= 0.015 m^3.

Therefore, volume of fibre used = 0.000075 m^3.

Density of fibre= $0.91*10^6$ g/m^3

Weight of fibre = 0.06825 kg

Table 4.1 Weighed Materials for 1% Fibre Inclusion:

Material	Weight per 0.015 m^3 volume of mix (kg)
Cement 43-grade	5.45
Fine Aggregate (Quarry sand)	12.06
Coarse Aggregate (10mm)	8.685
Coarse Aggregate (20mm)	6.96
Net Water Usage	2.715-0.543=2.172 (20% reduction due to HRWR)
Super Plasticiser Cico C-300	0.03
Xorex Flat Crimped Fibre	0.75
Procon M Polypropylene Fibre	0.136

Table 4.2 Weighed Materials for 0.5% Fibre Inclusion:

Material	**Weight per 0.015 m³ volume of mix (kg)**
Cement 43-grade	5.45
Fine Aggregate (Quarry sand)	12.06
Coarse Aggregate (10mm)	8.685
Coarse Aggregate (20mm)	6.96
Net Water Usage	2.715-0.543=2.172 (20% reduction due to HRWR)
Super Plasticiser Cico C-300	0.03
Xorex Flat Crimped Fibre	0.375
Procon M Polypropylene Fibre	0.068

4.3 Specimen Preparation

The coarse aggregates, fine aggregates were first dry mixed according to the design. Superplastisizer was used with water with the proportion suggested in '"*Study of the shear behaviour of fibre reinforced concrete beams*" by J. Turmo, N. Banthia, R. Gettu. Steel fibres were also added to the dry mix and it was followed with addition of cement and then water. During casting, it was kept in notice to clear the abrupt surface of the specimen when kept on vibrator.

The mould used should be machined in a specific manner which after casting would produce the dimensions and specifications mentioned below:

a) The depth of the mould (100x100x500) should be 10+- .02 cm. The angle between each face of the mould should be 90° ± 0-5°. The internal surface should also be flat and smooth with the allowed variation of 0.01mm.

b) The base plate must be provided in order to support the side plates. It must be rigid and very tightly placed below the plates in order to prevent any leakage of the material.

The moulds were oiled before casting to enable the easiness while opening the moulds after setting. The moulds were opened after 24 hours of casting. Tamping bar of weight 2kg and length 40cm with ramming face of 25mmsq was used in order to densify the concrete mix in th moulds. Tamping was done to reduce the porosity and to increase the density of the specimen.

The curing conditions were normal for 28 days and specimens rested on a free flat surface without any additional induced stresses on them.

On the day of testing, the specimens were first taken out to let their surface dry. After drying the top surface and front surface were both hand wiped in order to remove the free sand and other useless particles. After all the surfaces were cleaned, markings were made in order to set the rollers which were kept for the reaction support as well as for the rollers which were kept on the specimen in order to provide external loading. Front face of the specimen, which was to be examined by the software was also cleaned and marked with the parallel lines in order to calibrate the software. The lines were marked with the help of measuring tape and were made visible during the video recording too. Not only it helped for the software calibrations but also helped during the placement of the specimen on the rollers.

4.4 Testing

The dimensions were again checked after removing specimens from the curing tank. The surfaces were treated as is discussed earlier. The bearing surface and the loading surface were made sure they were smooth. The front face which was to be examined under Camera 1 was inscribed with the parallel lines each marked at 50 mm from free end, 150mm from free end and 250mm from free end (centre). The bearing rollers were kept on the line which was 50 mm from the free end which made the distance between rollers as is suggested by the code, i.e. 400mm. The inscribed line thus align the axis of loading and axis of the specimen. According to IS516-1959, no packing was used during the test between the bearing surface and loading surface too.

The load was applied with a constant rate of 180kg/min without any sudden application. The load was increased until the specimen fails and bridging of the fibres was visible. The maximum load and deflection measured using the digital meter of UTM was noted. The cracking behaviour and pattern was noted of all the specimens of different kinds.

4.4.1 Procedure for 7 Day Strength Testing:

For the total volume of concrete mix of 0.015 cubic meter for each of the two fibres according to the calculations from M50 mix design.

Sieving of Fine aggregates:

The quarry sand was sieved through 10mm and 4.75mm IS Sieve. The sand passing 4.75 mm sieve was taken to the cumulative weight of 12.06 kg as per the M50 mix design.

Sieving of 10mm and 20mm Coarse aggregates:

The crushed 10mm and below coarse aggregate was passed through 10 mm IS Sieve and retained on 4.75mm IS Sieve to the total weight of 8.685 kg as per the M50 mix design. The crushed 20mm and below coarse aggregate was passed through 20 mm IS Sieve and retained on 16mm IS Sieve to the total weight of 6.96 kg as per the M50 mix design.

The Xorex fibre was added in the mix ($0.015m^3$) during dry mixing.

Mix Preparation

1. For the mix with Polypropylene fibre, the fibre was added after dry mixing and addition of water to prevent the lumping and balling of fibres.

2. The mix was prepared in the mixer and thoroughly mixed for about 5 minutes and then tamped into the moulds with thorough compaction.

3. The samples were taken out from their moulds after exactly 24 hours and placed in acuring tank for the next six days.

4. On the 7th day, the samples were removed from the curing tank and left to surface dry for 2 hours.
5. The testing was done on a UTM with 4 point loading, as shown in the picture.

6. The Camera, Tripod and the LEDs were set up to record the cracking pattern and the deformations.

7. The videos were uploaded in the GOM Correlate Software for the purpose of analysis.

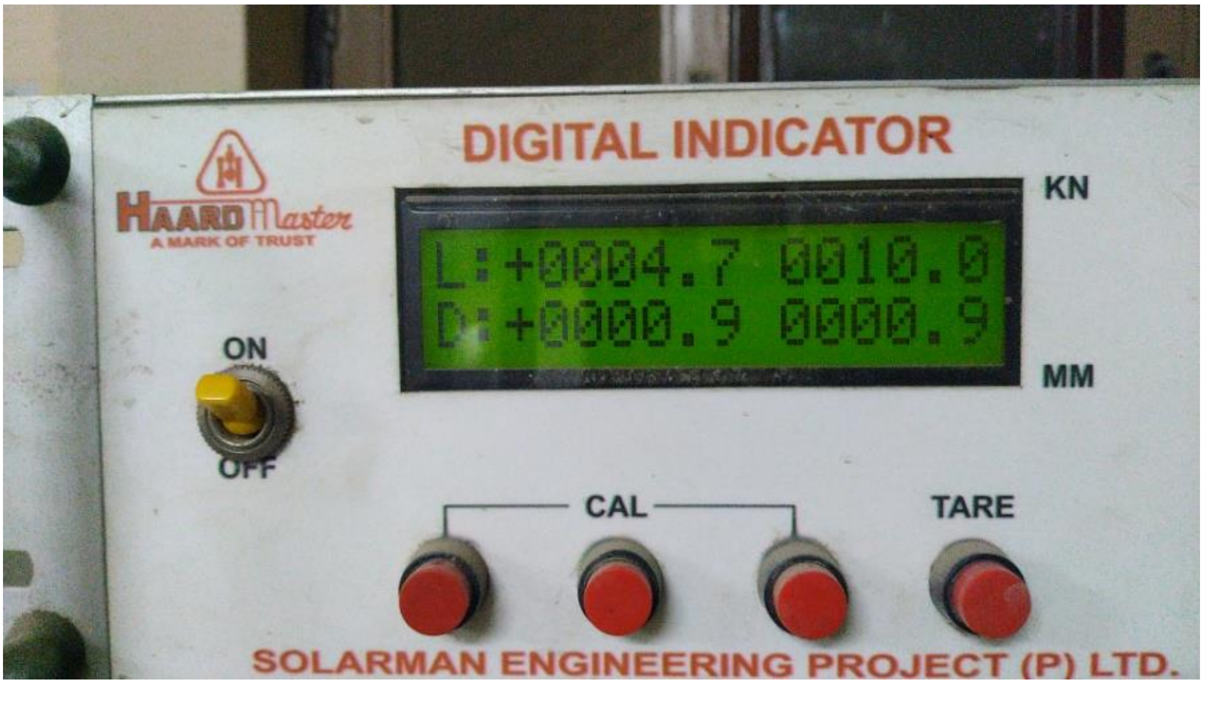

Fig. 4.3 Camera 2 shot

Fig. 4.4 Detailing of the specimen

(a= 18.12 cm, i.e. minimum distance of the crack from support.)

4.4.2 Procedure for 28 Days Testing

For the total volume of concrete mix of 0.015 cubic meter for each of the two fibres according to the calculations from M50 mix design.

Sieving of Fine aggregates:

The quarry sand was sieved through 10mm and 4.75mm IS Sieve. The sand passing 4.75 mm sieve was taken to the cumulative weight of 12.06 kg as per the M50 mix design.

Sieving of 10mm and 20mm Coarse aggregates:

The crushed 10mm and below coarse aggregate was passed through 10 mm IS Sieve and retained on 4.75mm IS Sieve to the total weight of 8.685 kg as per the M50 mix design.

The crushed 20mm and below coarse aggregate was passed through 20 mm IS Sieve and retained on 16mm IS Sieve to the total weight of 6.96 kg as per the M50 mix design

4.5 Calculations

Modulus of Rupture, f_b, defines the flexural strength of the specimen. Where 'a' is the distance between the nearest support and the point where the crack has started which is measured at centre line of tensile side (bottom) of the specimen in cm.

$$f_b = \frac{p.l}{b.d^2}$$

when 'a' must be greater than 20.0 cm for a 15 cm sample or greater than 13.3 cm for 10.0cm example, or

$$f_b = \frac{3p.a}{b.d^2}$$

when 'a' is lesser than 20.0 cm but greater than 17.0cm for a 15 cm sample, or less than 13.3 cm but greater than 11.0 cm for 10.0 cm sample.

Where,

b = width of the specimen in cm

d = the measured depth (cm) of the sample at the point of failure,

l = span of the specimen

p = maximum load in kg that is applied to the sample

If 'a' is lesser than 17 cm for 15 cm sample, or lesser than 11 cm for 10 cm sample, the findings of the experiment must be discarded.

4.6 Software Analysis

The software used to analyse the deformation of the casted specimens was **GOM CORRELATE 2018.** GOM Correlate is a software meant for digital image correlation (DIC) and evaluation for material research and testing of components. The program detects the point markers which are hence used to describe the discrete images which are taken from a video which was captured by a camera with user defined settings for shutter speed, resolution and fps. Sub pixel accuracy of the software thus analyse the image deformation. Point wise and full field measuring results are created and used to analyse the deformations. DIC enables an analytical investigation of the complex measurements of a material.

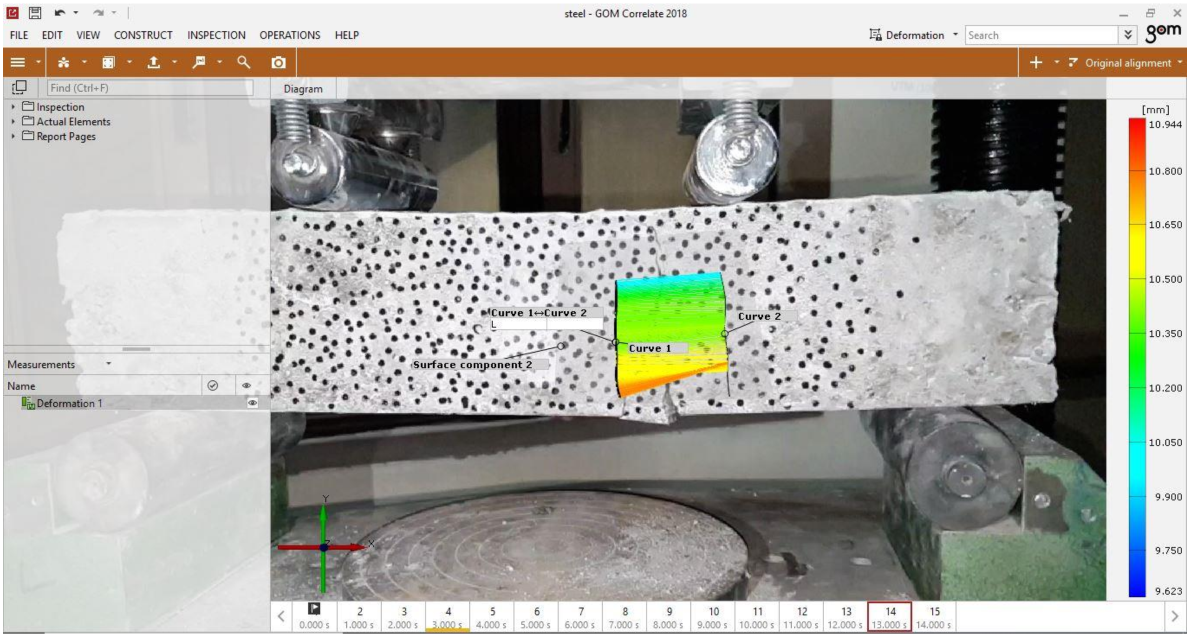

Fig. 4.5 Software Interface

4.6.1 Defining Scale

Software was calibrated using markings which were made during specimen preparations. Camera was levelled using bubble tube which was installed on the tripod. Gridlines were also enabled in the camera settings which also increased the levelling accuracy. The y-axis ordinates were kept same in order to make sure the horizontal orientation of the line used for calibration. Outer distances of the marked lines were 100 mm apart and hence were used in the software calibration.

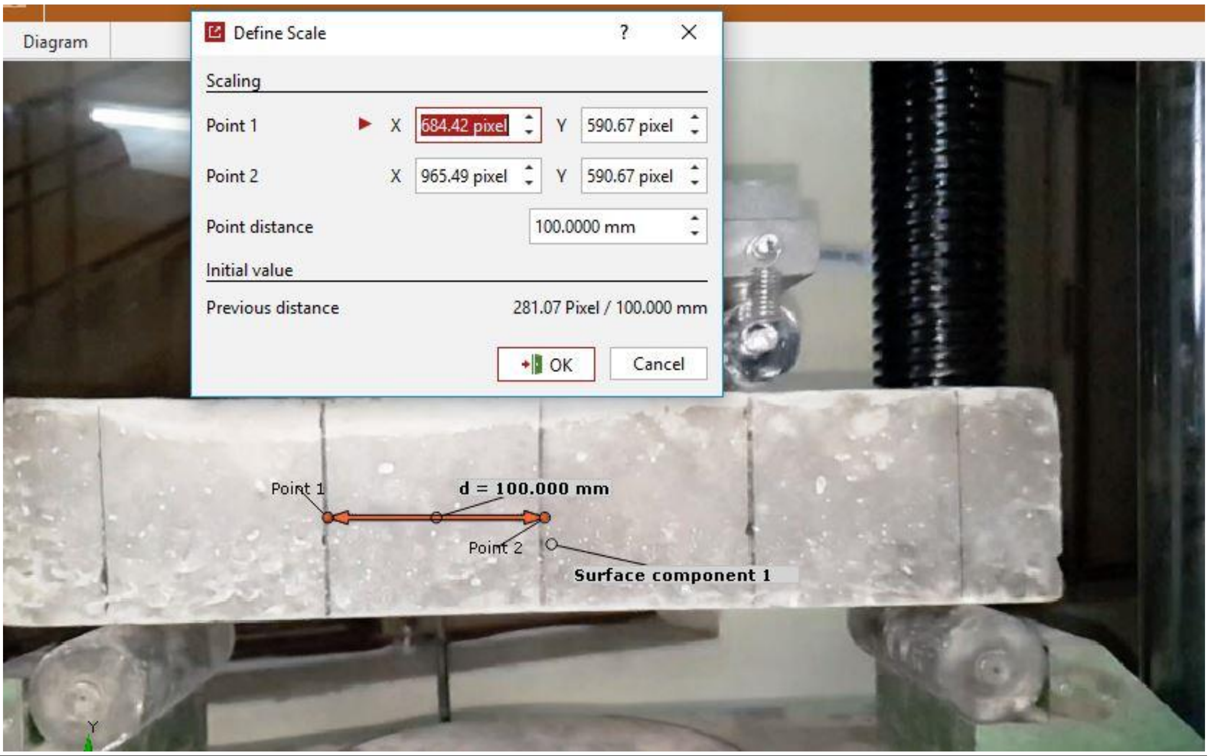

Fig. 4.6 Defining Scale

CHAPTER 5
RESULTS AND DISCUSSIONS

Cracks formed in reinforced concrete structures follow a twisted path. To spot the crack profile, the crack opening was determined between points at an equivalent vertical distance from the bottom of the beam. To determine the crack openings at different locations along the crack, two DIC patches were chosen on both sides of the crack with a mean distance between the patches of 5 mm. The displacement vectors of these patches were tracked with rising loading. The crack opening was determined at different heights of the beam. For all the test beams, it is noted that at load levels up to 50% of the peak load the surface displacements show a certain scatter suggesting that there are micro-cracks rather than a macro crack. After the main crack starts to form and propagate, the crack opening is smaller at the level of the reinforcement which is proof of the crack bridging provided by the reinforcement.

In SFRC beams, the load carrying capacity increased by about 20% compared to the plain cement concrete beams.

5.1 Software Results

Specimens were tested after 7 Days and 28 Days of curing respectively. While & Days testing, number of stages were taken as 10-15. Video while testing was analysed by discrete movement of facets. The video was broken down to 15 stages and the distances of the point were measured in horizontal axis, i.e. X axis. The surface of the specimens was sprinkled with acrylic oil paint in order to detect the movement.

To increase the accuracy, specimens with 28 days of curing, number of stages were increased from 10-15 to 600-700. Software was calibrated with already marked lines.

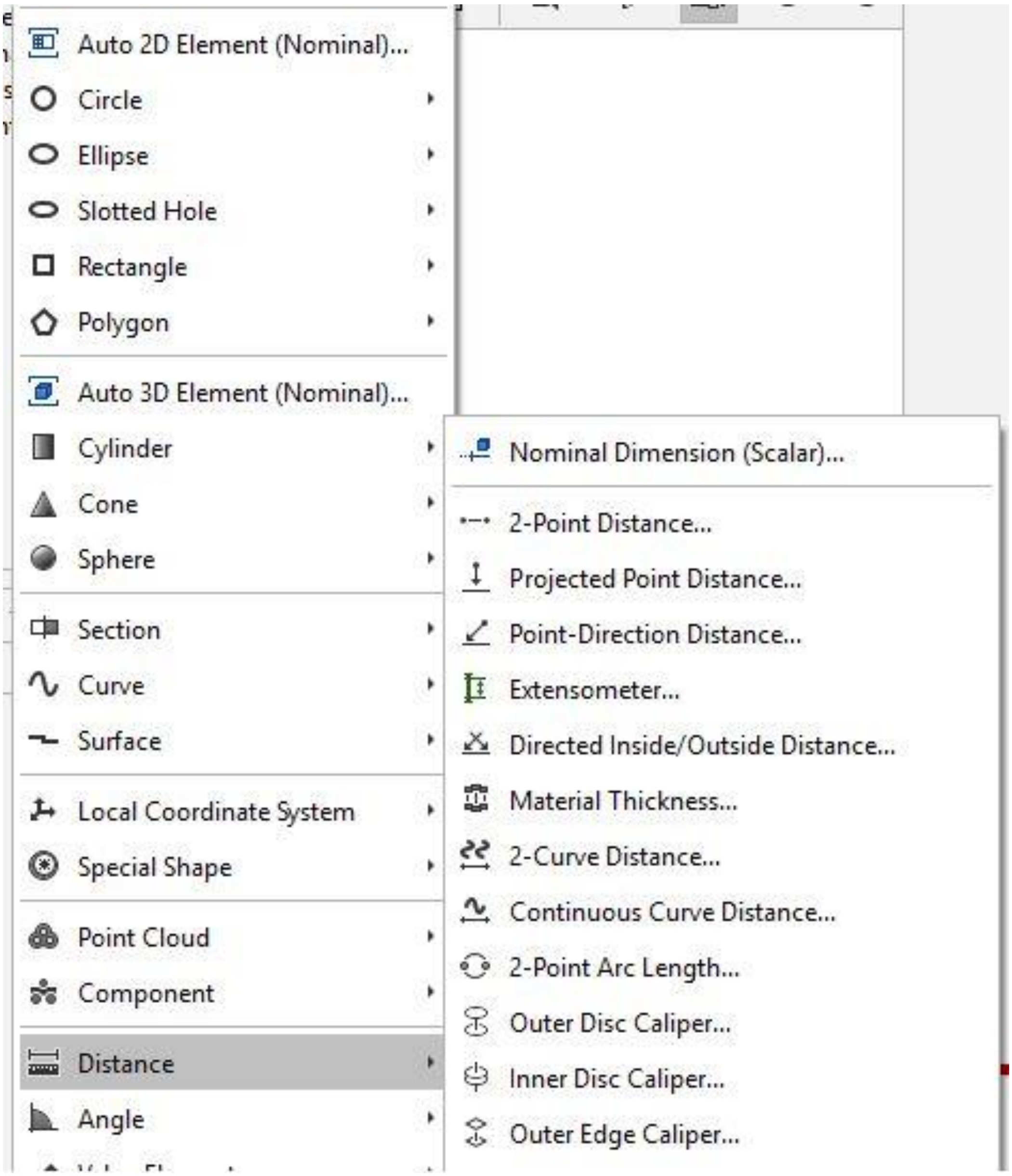

Fig. 5.1 Operations for analysis

5.2 Experimental Results

Table 5.1 7-days feature of Steel Fibre Reinforced Concrete 1% Specimen

Specimen Name	SFRC7.1	SFRC7.2	SFRC7.3
Fibre Percentage	1%	1%	1%
Age of Specimen	7 Days	7 Days	7 Days
Curing Conditions	Normal	Normal	Normal
Size	100mm x 100mm x 500mm	100mm x 100mm x 500mm	100mm x 100mm x 500mm
Span Length	500mm	500mm	500mm
Maximum Load	11.8kN	12.5kN	10.8kN
Point of Fracture	13.9mm	12.6mm	15.3mm
Modulus of Rupture	1.548 N/mm^2	1.693 N/mm^2	1.418 N/mm^2
Number of Stages	15	15	15
Displacement Axis	X-axis	X-axis	X-axis
Facet Size	19	19	19
Point Distance	8	8	8
Reference Stage	Stage 1	Stage 1	Stage 1

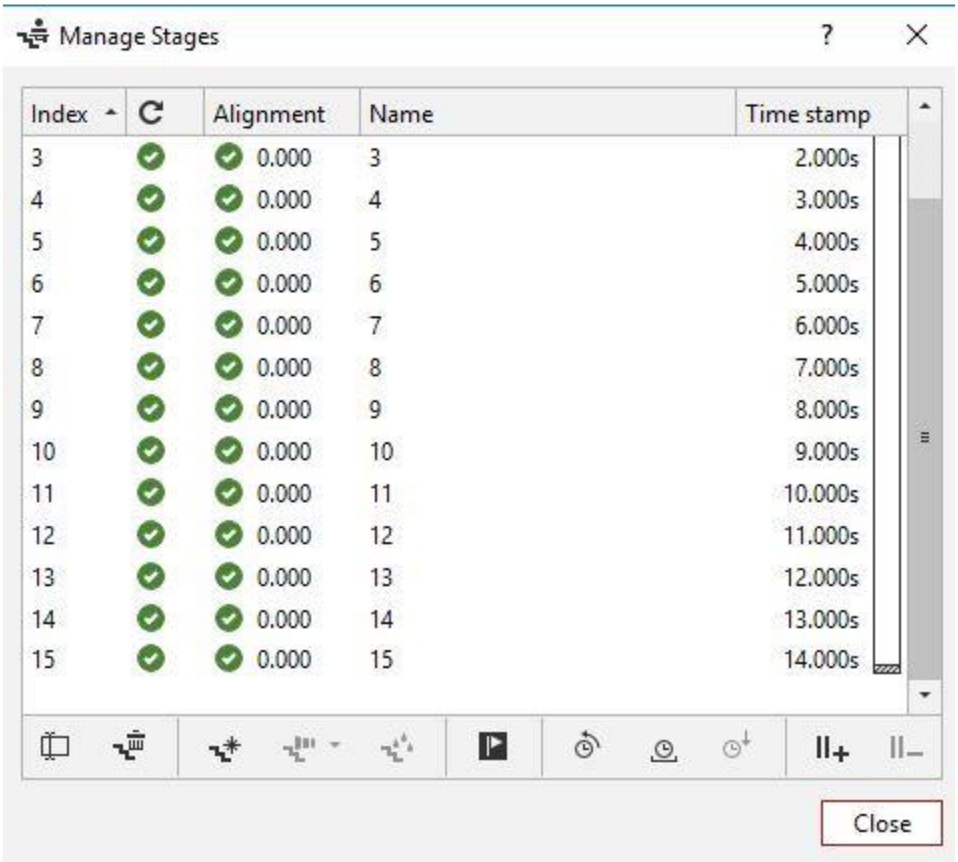

Fig. 5.2 Number of stages to be analysed

Initially, time stamp for stages to be considered was 1 second. Every movement after 1 second was observed and the change in displacement of the located points were noted and was plotted against each stage.

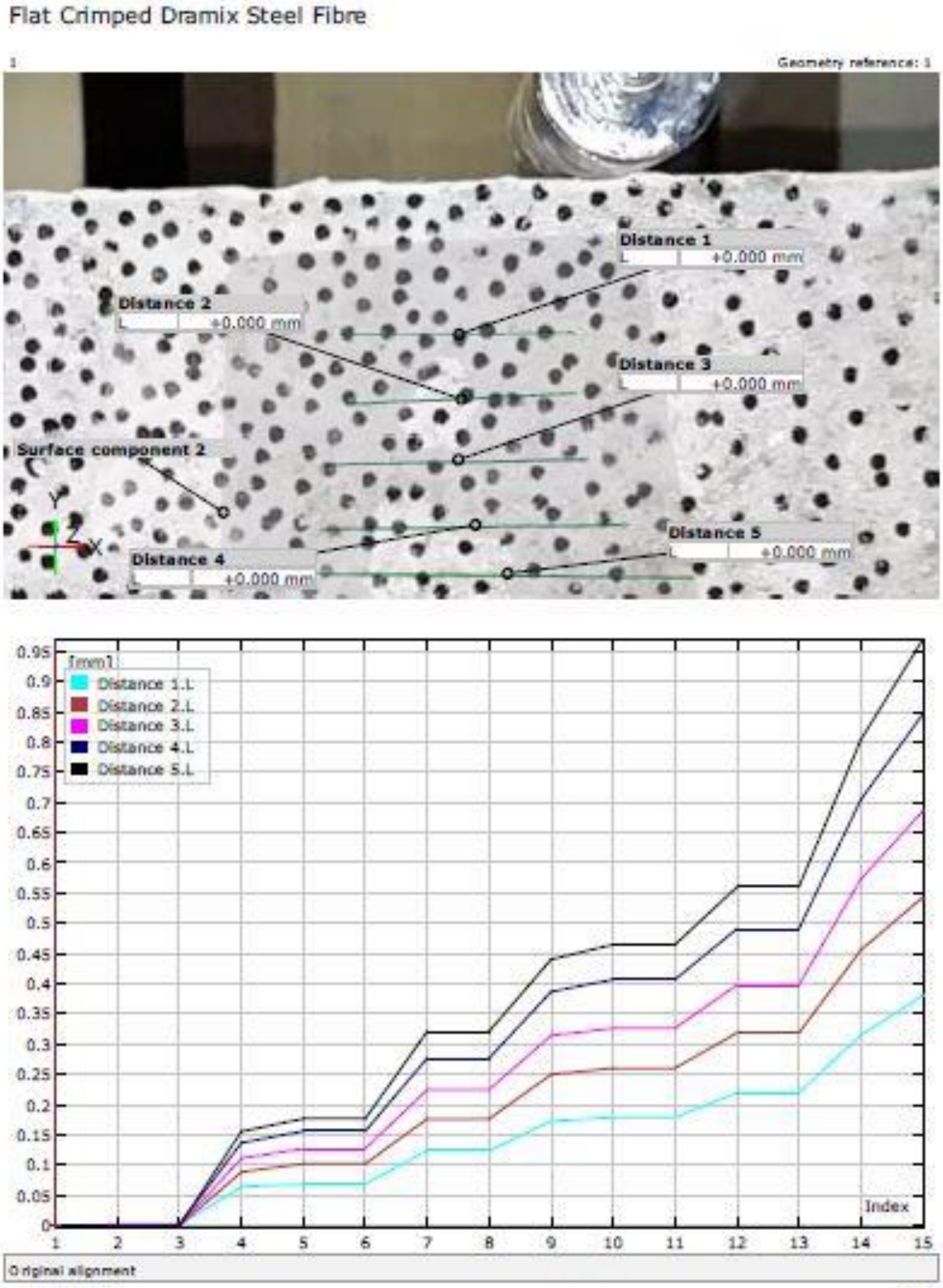

Fig 5.3. SFRC Displacement Curves (Stage 1)

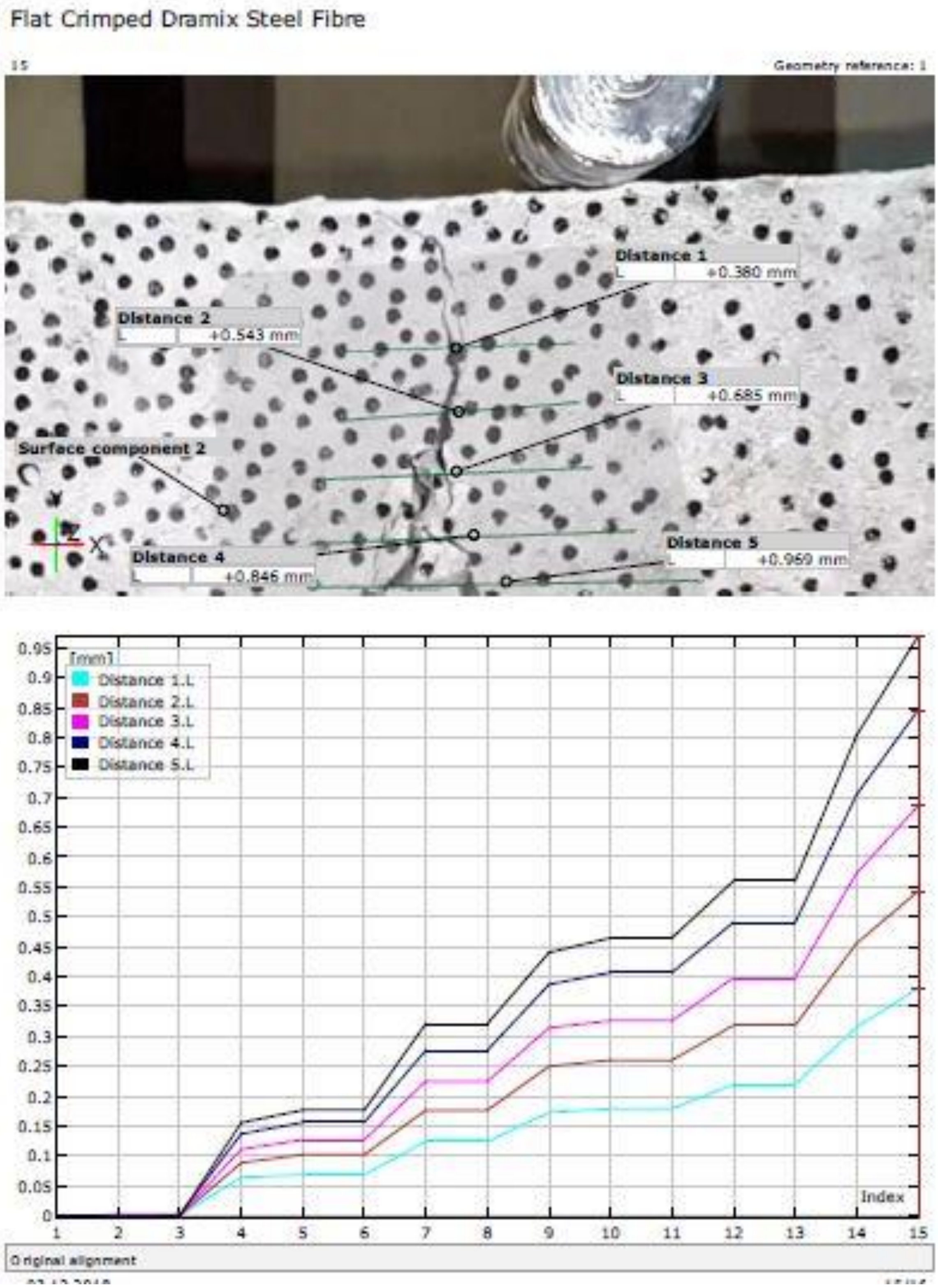

Fig 5.4. SFRC Displacement Curve (Stage 14)

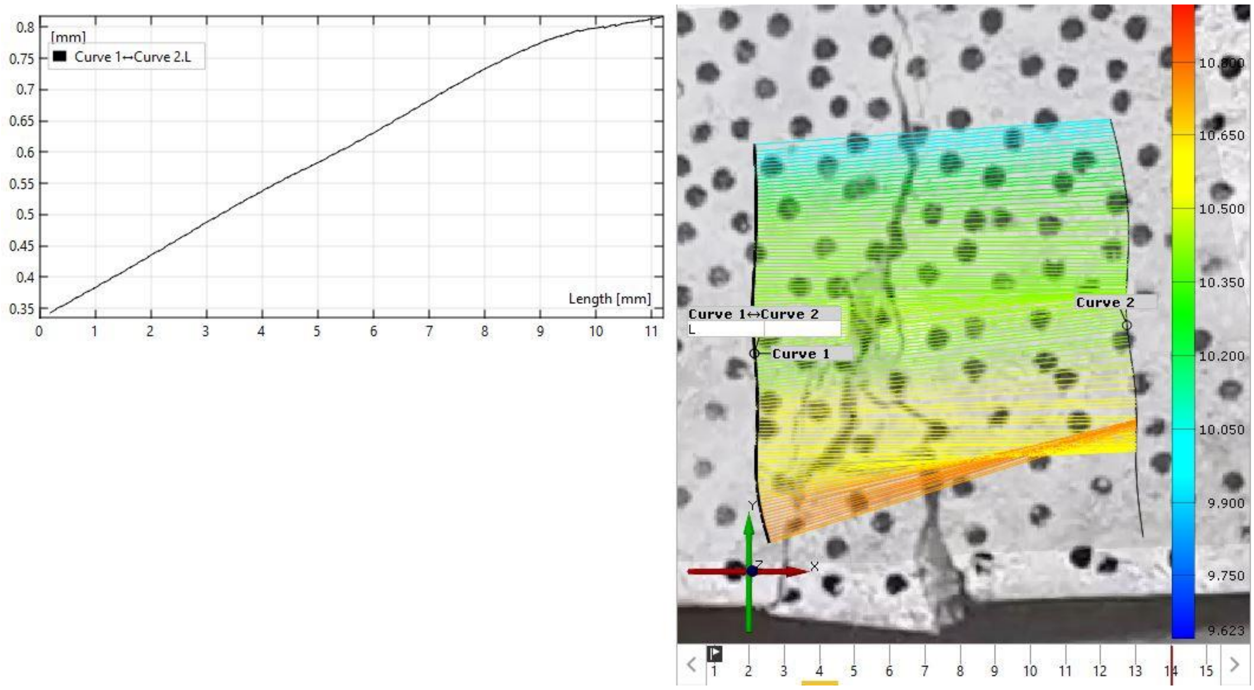

Fig 5.5 Curve Displacement

Table 5.2 7-Days features of Polypropylene Fibre Reinforced Concrete @1%

Specimen Name	PFRC7.1	PFRC7.2	PFRC7.3
Fibre Percentage	1%	1%	1%
Age of Specimen	7 Days	7 Days	7 Days
Curing Conditions	Normal	Normal	Normal
Size	100mm x 100mm x 500mm	100mm x 100mm x 500mm	100mm x 100mm x 500mm
Span Length	500mm	500mm	500mm
Maximum Load	20.8.8kN	16.9kN	18.4kN
Point of Fracture	9.6mm	10.1mm	11.7mm
Modulus of Rupture	2.627 N/mm^2	2.198 N/mm^2	2.393 N/mm^2
Number of Stages	13	13	13
Displacement Axis	X-axis	X-axis	X-axis
Facet Size	19	19	19
Point Distance	8	8	8
Reference Stage	Stage 1	Stage 1	Stage 1

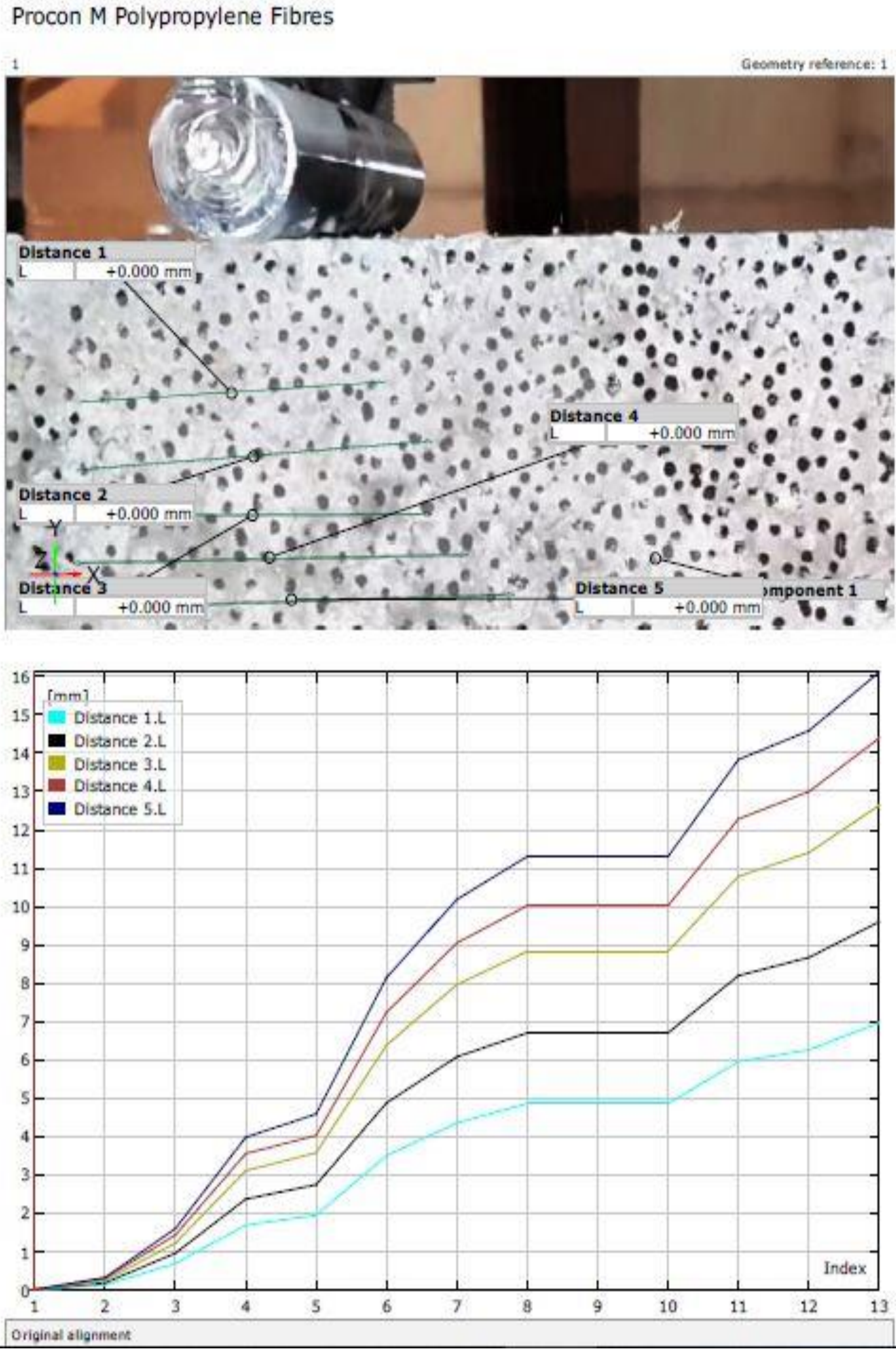

Fig 5.6. PFRC Displacement Curve (Stage 1)

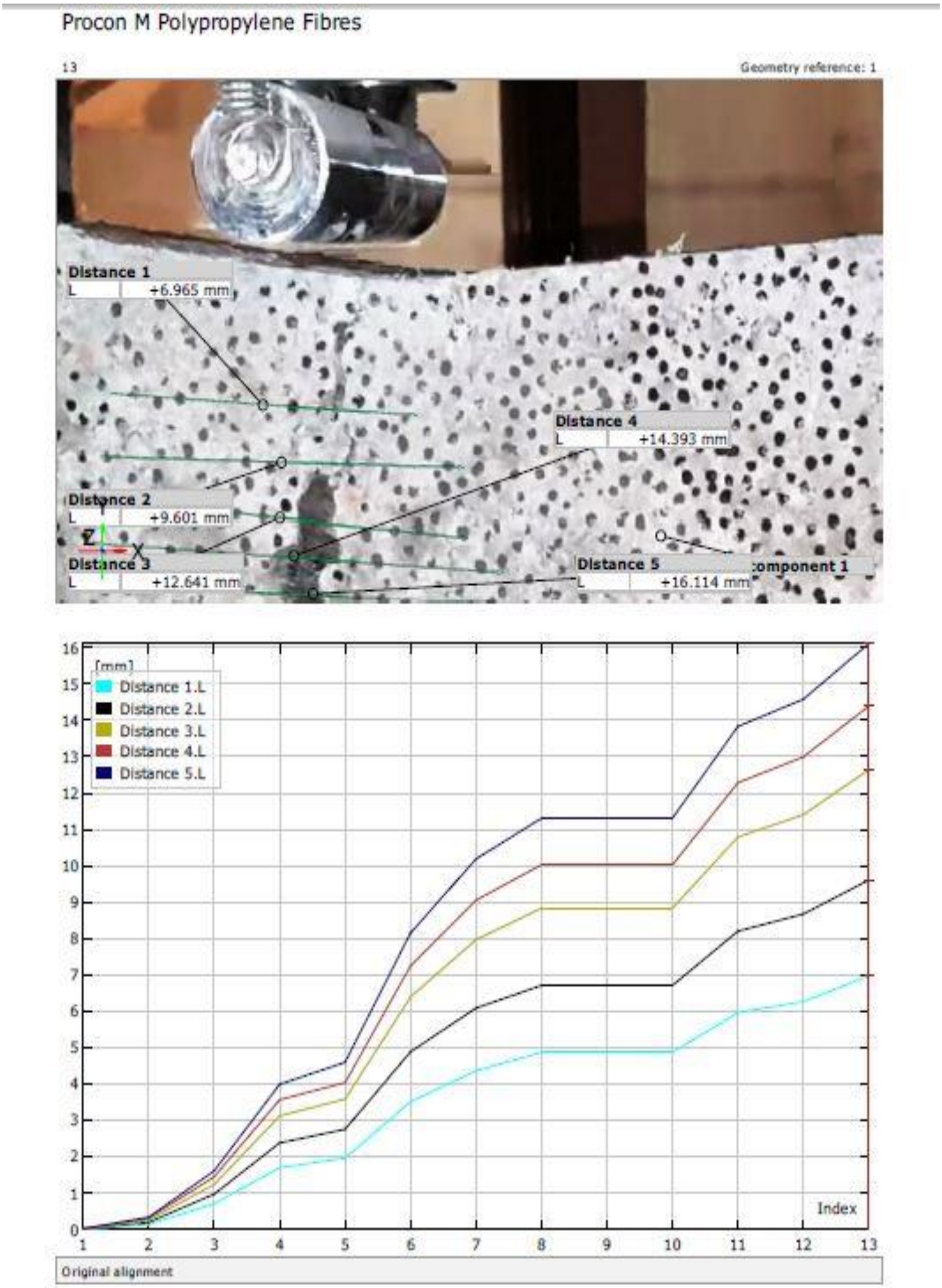

Fig 5.7. PFRC Displacement Curve (Stage 14)

Table 5.3 28-days features of Steel Fibre Reinforced Concrete 0.5% Specimen

Specimen Name	0.5SFRC28.1	0.5SFRC28.2	0.5SFRC28.3	0.5SFRC28.4	0.5SFRC28.5
Fibre Percentage	0.5%	0.5%	0.5%	0.5%	0.5%
Age of Specimen	28 Days	28 Days	28 Days	28 Days	28 Days
Curing Conditions	Normal	Normal	Normal	Normal	Normal
Size (mm^3)	100x100x500	100x100x500	100x100x500	100x100x500	100x100x500
Span Length	500mm	500mm	500mm	500mm	500mm
Maximum Load	20.8kN	23.6kN	19.6kN	24.2 kN	22.3 kN
Point of Fracture	145 mm	181 mm	175 mm	169 mm	154 mm
Modulus of Rupture ($N/mm^{2)}$	9.048	12.828	10.29	12.269	10.302
Number of Stages	797	514	546	612	620
Displacement Axis	X-axis	X-axis	X-axis	X-axis	X-axis
Facet Size	19	19	19	19	19
Point Distance	8	8	8	8	8
Reference Stage	Stage 1	Stage 1	Stage 1	Stage 1	Stage 1

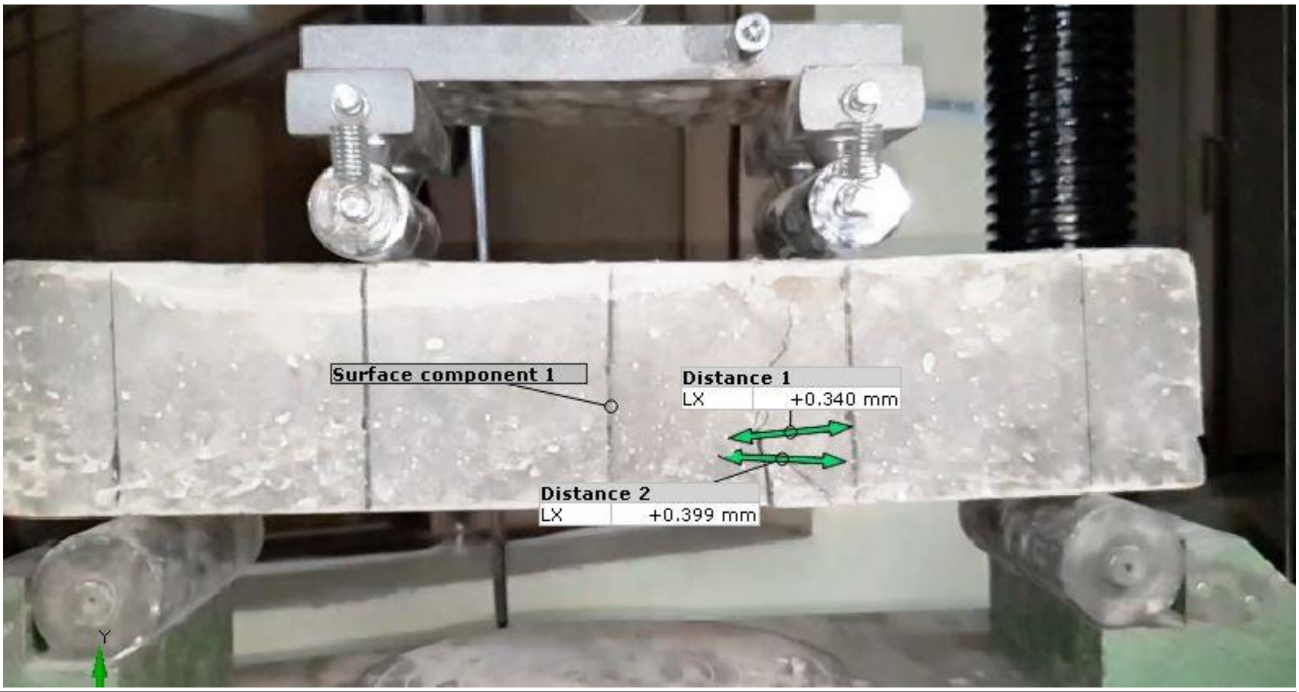

Fig. 5.8 Horizontal points detected by software- Camera 1

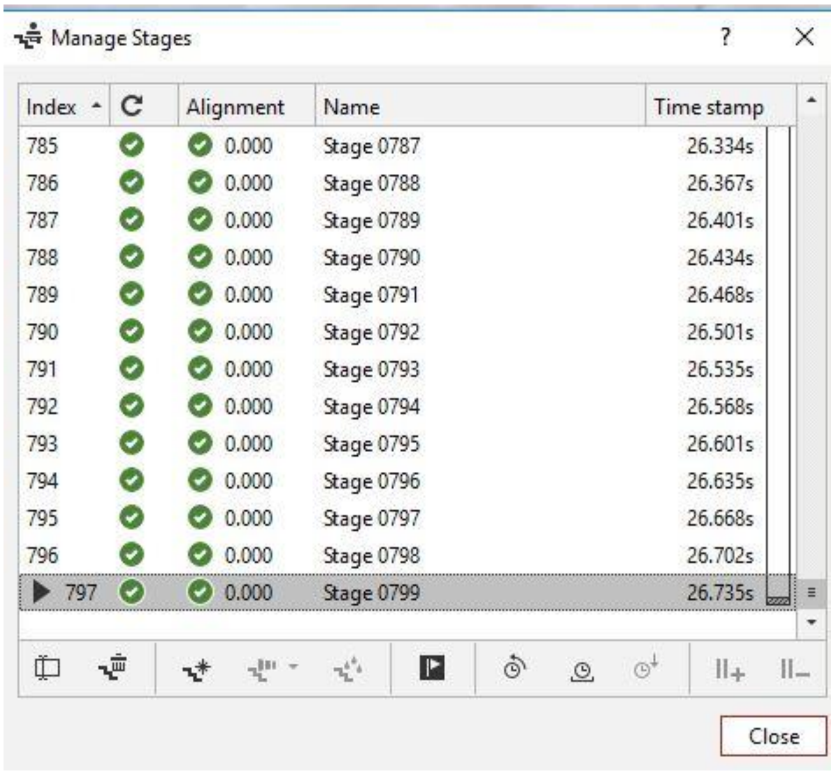

Fig. 5.9 Increased number of stages

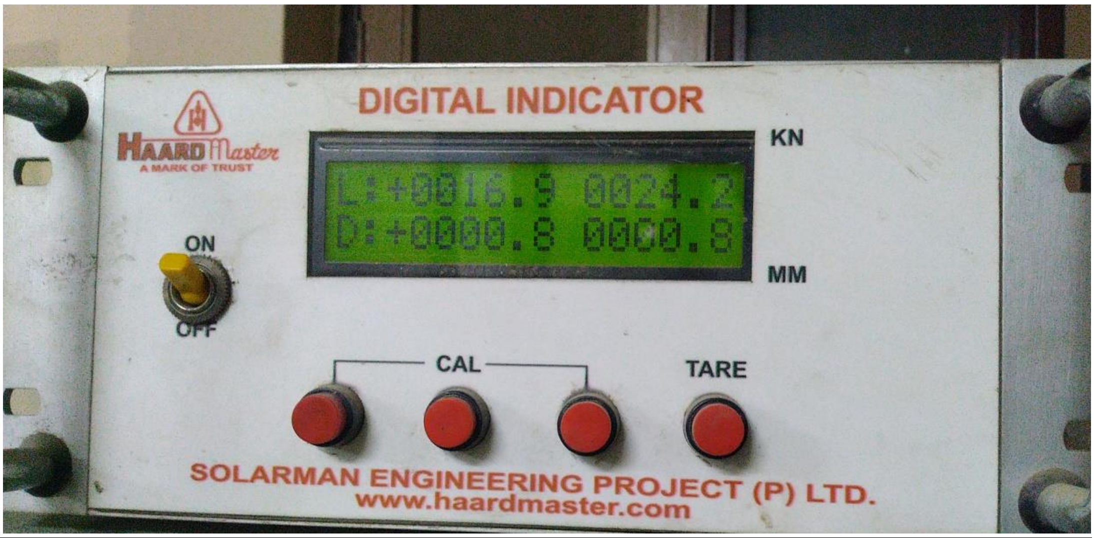

Fig. 5.10 Camera 2 shot- UTM Meter Readings

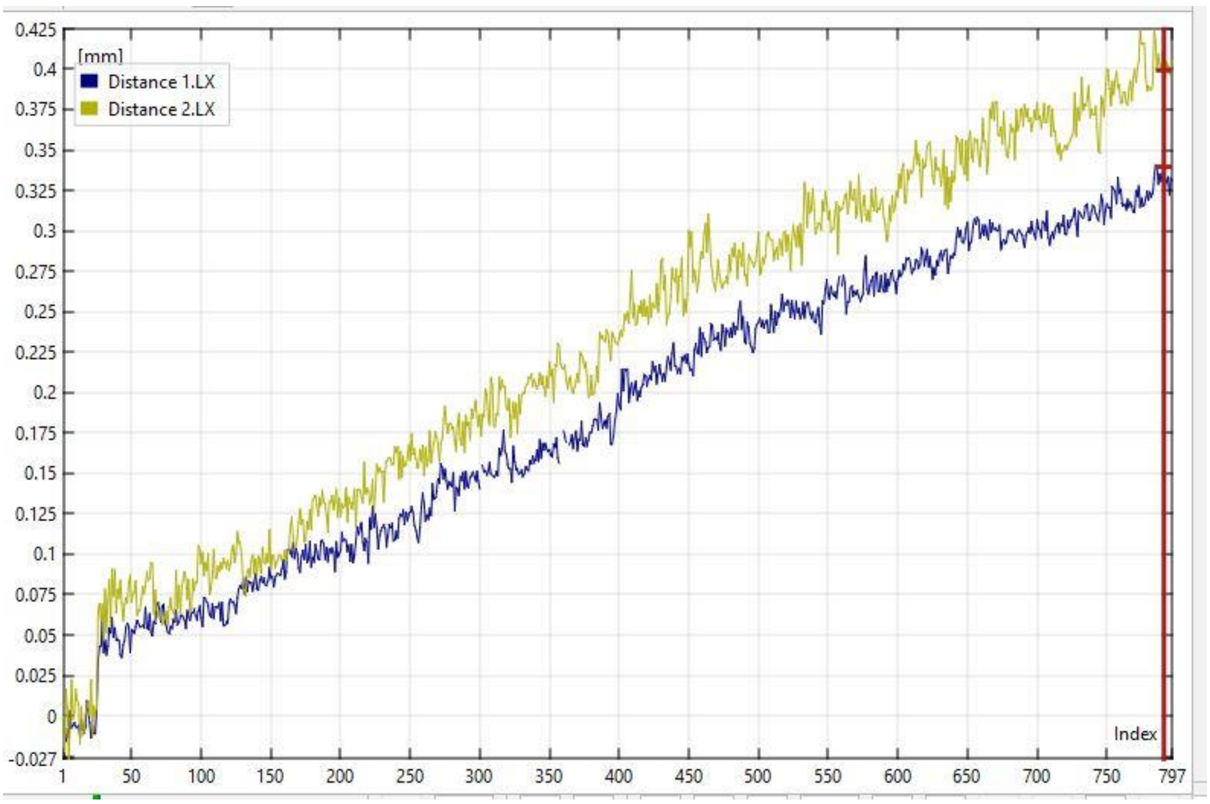

Fig. 5.11 SFRC-28 Days Stages vs Displacement graph

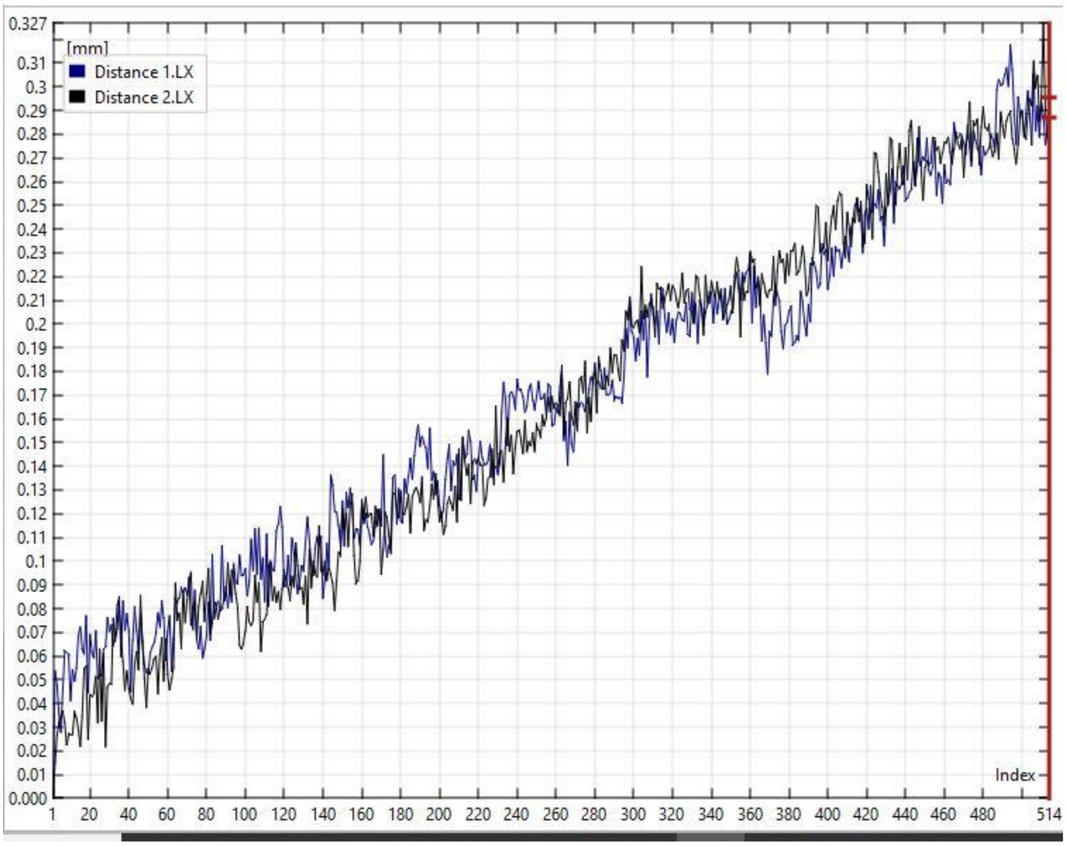

Fig. 5.12 SFRC-28 Days Stages vs Displacement graph

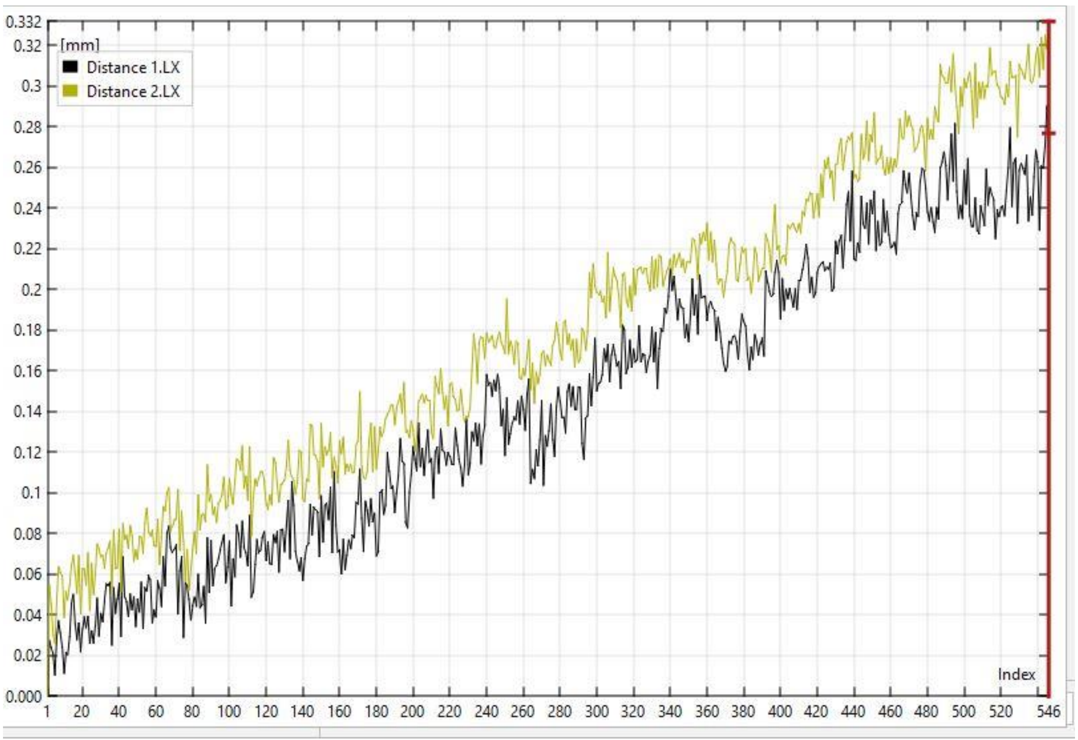

Fig. 5.13 SFRC-28 Days Stages vs Displacement graph

Table 5.4 Polypropylene Fibre Reinforced Concrete 0.5% Specimen-28days

Specimen Name	0.5PFRC28.1	0.5PFRC28.2	0.5PFRC28.3	0.5SPRC28.4	0.5PFRC28.5
Fibre Percentage	0.5%	0.5%	0.5%	0.5%	0.5%
Age of Specimen	28 Days	28 Days	28 Days	28 Days	28 Days
Curing Conditions	Normal	Normal	Normal	Normal	Normal
Size (mm^3)	100x100x500	100x100x500	100x100x500	100x100x500	100x100x500
Span Length	500mm	500mm	500mm	500mm	500mm
Maximum Load	19.8kN	21.3kN	18.7kN	19.2 kN	20.3 kN
Point of Fracture	154 mm	163 mm	184 mm	175 mm	162 mm
Modulus of Rupture ($N/mm^{2)}$	9.148	10.415	10.324	10.08	9.865
Number of Stages	800	800	800	800	800
Displacement Axis	X-axis	X-axis	X-axis	X-axis	X-axis
Facet Size	19	19	19	19	19
Point Distance	8	8	8	8	8
Reference Stage	Stage 1	Stage 1	Stage 1	Stage 1	Stage 1

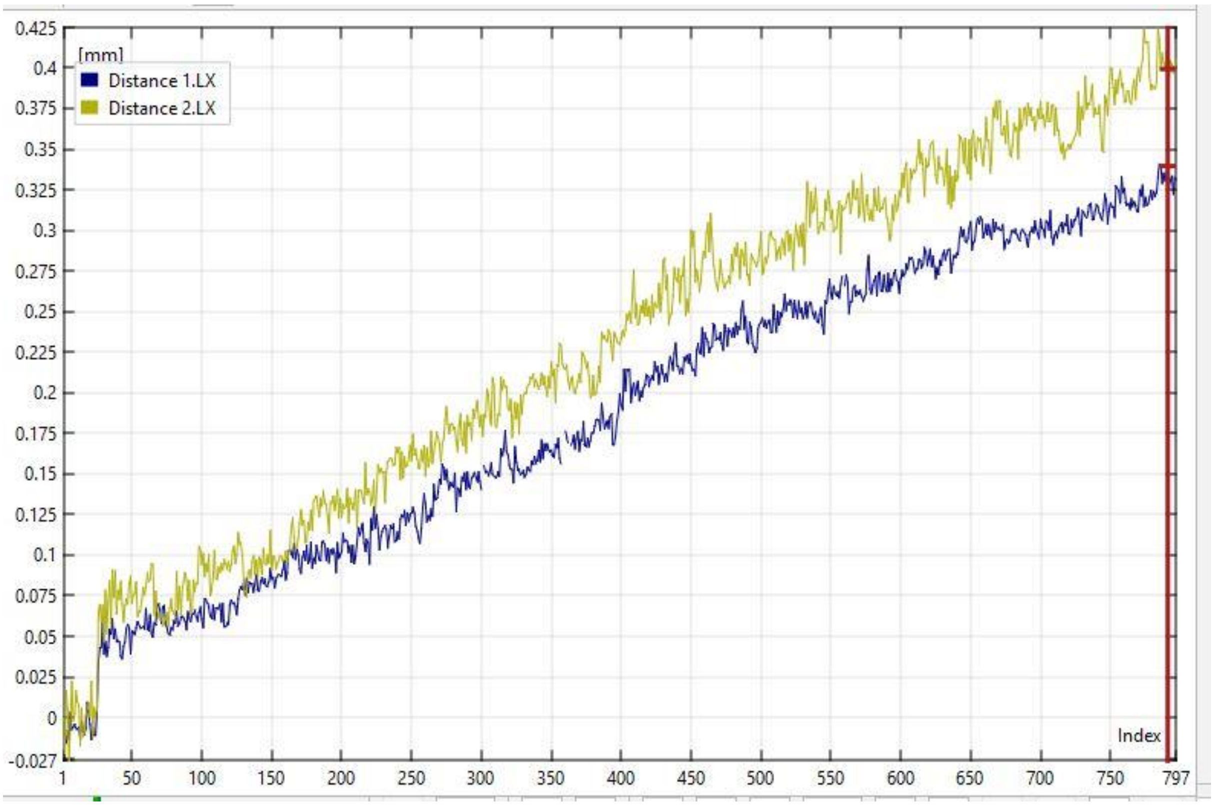

Fig. 5.14 PFRC-28 Days Stages vs Displacement graph

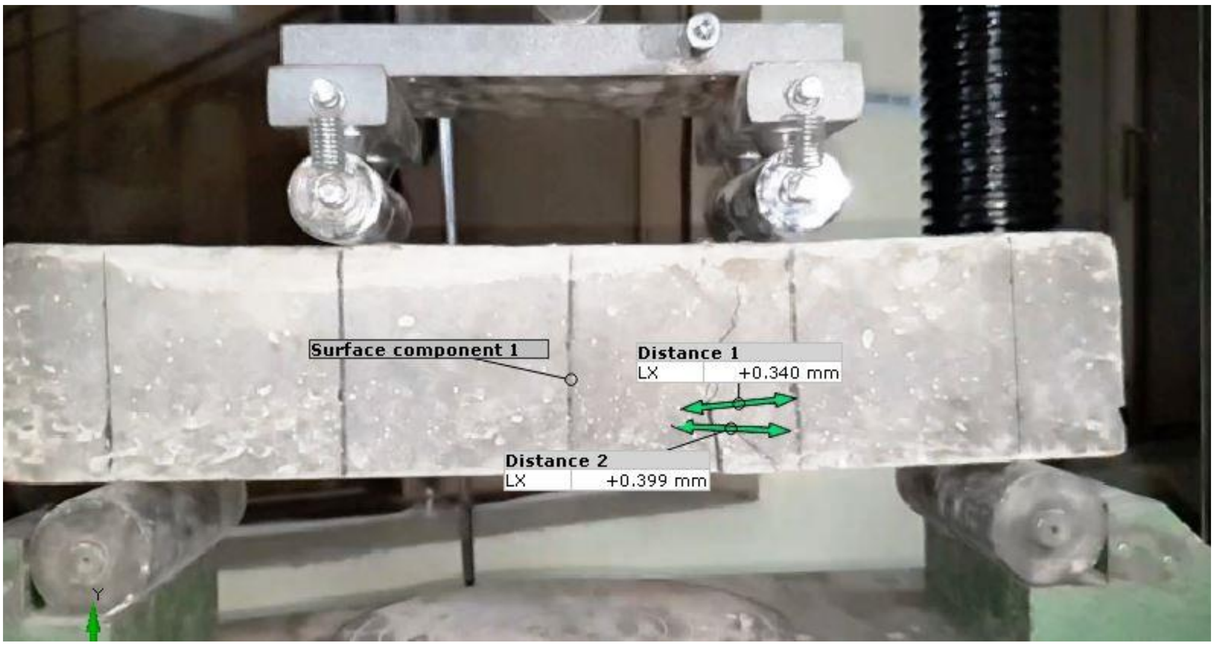

Fig. 5.15 PFRC-28 Days Points detected

Fig 5.16 PFRC Post Fibre Bridging

Fig 5.17 SFRC Post Fibre Bridging

CHAPTER 6
CONCLUSIONS

The technique of Digital Image Correlation has enabled us to visualise and quantify the fracture mechanics properties in reinforced concrete beams. This Digital Image Correlation technique has been found as very efficient and cost effective in investigating the cracking profile in reinforced concrete beams. The crack mouth opening which causes a displacement was recorded from Digital Image Correlation analysis and was used to relate the impact of various parameters of reinforced concrete beams. It was discovered that strength of concrete has only a limited effect on cracking occurrence and crack opening, however, the bond strength between the provided fibre reinforcement and the concrete matrix seems to play a crucial role in the observed propagation of cracks and bridging of cracks.

A significant increase in the ductility of Steel Fibre Reinforced Concrete Beams and Polymer Fibre Reinforced Concrete Beams was observed clearly with respect to the plain concrete beams or the steel rebar reinforced beams. This was indicated by the recorded increase in the deformability of the structural elements (beams). For any load below ultimate stress of the sample, the noted deflection was higher compared to plain concrete or steel rebar reinforced concrete.

REFERENCES

- ASTM C 1018 - 97, "Standard Test Method for Flexural Toughness and First Crack Strength of Fibre-Reinforced Concrete" (1998)
- C109/C109M − 16a Standard Test Method for Compressive Strength of Hydraulic Cement Mortars.
- **Study of the shear behaviour of fibre reinforced concrete beams**

  J. Turmo(*), N. Banthia(**), R. Gettu(***) y B. Barragán(****) Materiales de Construcción, Vol.58, Pg.No 292 (2008)
- **Flexural Toughness of Steel Fiber Reinforced High Performance Concrete Containing Nano-SiO2 and Fly Ash**
  Peng Zhang, Ya-Nan Zhao, Qing-Fu Li, PengWang, and Tian-Hang Zhang
- **Crack Detection by Digital Image Correlation**

  Hai Qiu[1], Junhui Yan[2], Oh-Heon Kwon[3], Michael A. Sutton[2]
- **DIC Technique to Investigate Crack Propagation in Grid-Reinforced Asphalt Specimens**

  Seyed Amirshayan Safavizadeh, Ph.D.1; and Youngsoo Richard Kim, Ph.D., P.E., F.ASCE2
- **Mathematical and numerical correction of the DIC displacements for determination of stress field along crack front**
  Chernyatin A.S.a*, MatvienkoYu.G.b, Lopez-Crespo P.c
- **Concrete Stress-Strain Characterization by Digital Image Correlation**

  Saldaña HA, 1, Márquez Aguilar PA2* and Molina OA2

[9] **Using Digital Image Correlation Method for Measuring Residual Stress in the Nickel Coating of the Specimen**

C.-H. Chien1, T.-H. Su1, C.-T. Wang2, and B.-S. Chen1

[10] IS: 456-2000, “Indian Standard Code of Practice for Plain and Reinforced Concrete”, ISI, New Delhi.
[11] IS: 516-2004, “Indian Standard Code of Methods for Tests for Strength of Concrete”, ISI, New Delhi.
[12] IS: 10262-1982, “Recommended guidelines for concrete mix design”, ISI, New Delhi.
[13]. IS: 383-1970, “Indian standards specification for coarse and fine aggregates from natural sources for concrete”, Bureau of Indian Standards, New Delhi
[14] “ACI 363 R State-of-the-art Report on High Strength Concrete”, January 1-1992.
[15] ACI (2010). "Report on high strength concrete." Report ACI 363R-10, Farmington Hills, MI, American Concrete Institute.
[16]. BS 1881: Part 121:1983,” Testing concrete Method for determination of static modulus of rupture in compression”.
[17]. ASTM C 469-94” Standard Test Method for Static Modulus of Rupture and Poisson’s Ratio of Concrete in Compression”
[18] Shetty, M. S., “Concrete Technology Theory and Practices”, Reprint 2008.
[19] Santhakumar, A. R., “Concrete Technology

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