Digital Image Correlation in Civil Engineering Structural Monitoring

A

PROJECT REPORT

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

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WAKNAGHAT, SOLAN -173234

HIMACHAL PRADESH, INDIA

MAY-2024

STUDENT'S DECLARATION

We hereby declare that the work presented in the Project report entitled "**Digital Image Correlation in Civil Engineering Structural Monitoring**" submitted for partial fulfilment of the requirements for the degree of Bachelor of Technology in Civil Engineering at the **Jaypee University of Information Technology, Waknaghat** is an authentic record of our work carried out under the supervision of **Dr. Tanmay Gupta** and lab assistant **Mr. Jaswinder Singh**. This work has not been submitted elsewhere for the reward of any other degree/diploma. We are fully responsible for the contents of our project report.

Signature of Student	Signature of Student
Arushi	Prateek Sharma
201625	201626

CERTIFICATE

This is to certify that the work presented in the project report titled "**Digital Image Correlation in Civil Engineering Structural Monitoring**" submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering is an authentic record of work carried out by **Arushi (201625) and Prateek Sharma (201626)** under the supervision of **Dr. Tanmay Gupta.**

To the best of our knowledge, the preceding statement is correct.

Date:23-05-2024

Signature of Supervisor	Signature of HOD
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JUIT, Waknaghat	JUIT, Waknaghat

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The success and end of this study project necessitated a great deal of direction and assistance from our supervisor, and we are extremely fortunate to have received it all as part of the project's completion. We owe everything we have accomplished to his oversight and help, and we would like to express our gratitude. We would like to express our sincere gratitude to Dr.Tanmay Gupta and lab assistant Mr. Jaswinder Singh for their valuable guidance and kind supervision throughout the project. We would like to extend our sincere thanks to him. We are highly indebted to him for his guidance and constant support.

ABSTRACT

Strain and relocation are basic parameters inside designing and development ventures. In any case, measuring these parameters exterior of the lab requires a troublesome choice between routine procedures, as precision, effortlessness and fetched must all be adjusted. Digital Image Correlation (DIC) could be a procedure which may demonstrate to be in a perfect world suited for the ponder of break propagation and fabric misshaping in real-world applications, because it has the potential to gotten to be a cheap, basic however exact arrangement.

Full field, non-contact assessments of relocations and stresses of a wide variety of specimens are made possible using the Digital Image Correlation (DIC) approach. a modification to the DIC protocol for monitoring civil engineering structures. A typical understanding of the intricate, programmed observation system, where the DIC sensor is essential, is shown. Computer program highlights, which point to encourage open air estimations and speed up the relationship examination, Advanced Picture Relationship procedure (DIC) could be a non-contact optical strategy for fast auxiliary wellbeing checking of basic framework. DIC is utilized to extricate Minute (M) – Ebb and flow (κ) connections utilizing irregular dot designs. The irregular dot design is assessed for 2D DIC estimations and appears an made strides relationship with ordinary estimations. It is discovered that the extreme moment-curvature values calculated from the irregular dotted design agree quite well with conventional estimates.

This investigates the application of DIC techniques in the analysis of RCC beams and I-section specimens. By capturing surface deformations, DIC provides detailed strain and displacement data that are critical for assessing structural performance and integrity. The study involves experimental testing of RCC beam, I-section specimens and on the railway track under different loading conditions, where DIC is employed to monitor and record the resulting deformation patterns. The results demonstrate that DIC effectively captures the complex stress distribution and deformation behaviour in these structural elements, offering insights that traditional measurement methods might overlook.

Keywords: DIC, Random Speckle Pattern, Deflection, strain, RCC Beams, I-Section, Railway track

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LIST OF ABBREVIATION

DIC	Digital Image Correlation
SHM	Structural Health Monitoring
PPC	Portland Pozzolana Cement
RCC	Reinforced Cement Concrete
CMM	Coordinate Measurement Machine
ITZ	Interface Transition Zone
DCAs	Deformation Concentration Area
NDT	Non-Destructive Testing
FOSs	Fibre Optic sources
NDT	Non-Destructive Technology
OMA	Operational Modular Investigation
EMA	Exloratory Modular Investigation
ECC	Engineered Cementitious Composite
PLS	Pointwise Local test Square
FEM	Finite Element Modal
SCFs	Stress Concentration Factor
DOFS	Distribution Optic Fibre Sensors

AE	Auto Focus
FOSs	Fibre Optic Sensors

Chapter 1

INTRODUCTION

1.1 General

Structural elements may encounter fluctuating and rising demand conditions over the course of their service life (such as a rise in traffic in transportation infrastructures). In addition, they are subjected to external factors that may deteriorate their abilities and impact their functionality. Digital Image Correlation (DIC) is a sophisticated optical technique that is widely used in fundamental observation to quantify surface strains, displacements, and distortions.

This non-contact, full-field strategy includes capturing high-resolution pictures of the structure some time recently and after distortion, regularly with a random speckle pattern connected to the surface to upgrade differentiate. By isolating these pictures into littler subsets, the DIC program tracks their developments, calculating relocation areas and determining strain areas from this information. DIC is essential in different applications, counting inactive and dynamic load testing, harm discovery, fabric characterization, and long-term structural health monitoring. Its non-invasive nature, tall precision, and ability to supply comprehensive information over the whole field of see make it predominant to conventional point-based sensors

1.2 Digital Image Correlation (DIC):

A vision-based process called Digital Image Correlation (DIC) uses image recognition and mapping techniques to accurately measure changes in 2D and 3D images. DIC is widely used in many branches of research and construction. It is widely used to determine moves and strains across regions, divide engendering, avoid fabric, and analyse the beginning and progression of damage in basic frameworks. DIC can capture images of the target framework at various moments and be used for either continuous or sporadic monitoring. Program can be utilized to optically review pictures from distinctive time periods and degree distortion from the information. Numerous vision-based calculations have been proposed, counting edge discovery, thresholding, division, and filter-based calculations. These methods are utilized to survey harm to wood tests, bridge and concrete surfaces, asphalts, and steel. Certain visual strategies, such as other conventional non-destructive technology (NDT) and radioactive computed tomography, require nitty gritty setups and low-vibration situations, making them expensive and troublesome to utilize exterior of research facility settings. Although exceptionally troublesome, DIC is financially doable. And it gets to be less demanding to get it. DIC is more quantifiable and precise than conventional estimation methods. In expansion, DIC employments ordinary electronic pictures that can be utilized in civilian development strategies to produce sufficiently accurate evaluations of component frameworks in ordinary open-air situations. Also, no uncommon lighting is required and the layers display within the target framework have appropriate photo surfaces, so in a few cases DIC can work without uncommon surface treatments.

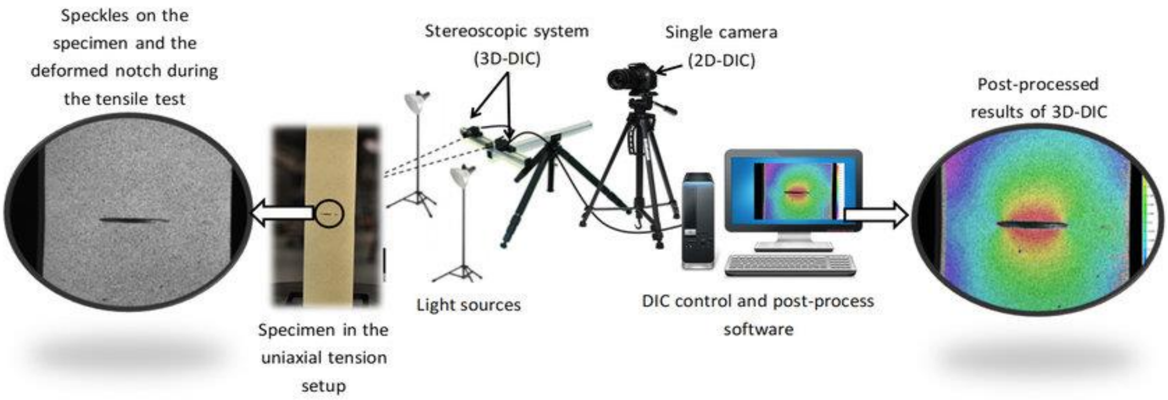

Fig 1.1 DIC and test set-up

(Source: https://www.researchgate.net/figure/DIC-and-test-set-up_fig1_325691949)

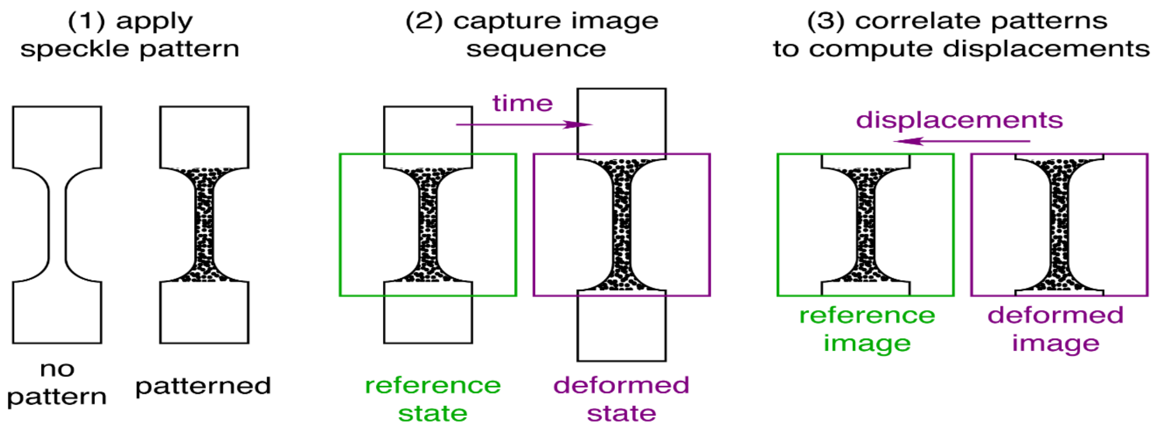

Fig 1.2 DIC tracking pattern (Source: https://digitalimagecorrelation.org/)

1.2.1 Why so much interest in DIC?

• The fundamental idea of Digital Image Correlation (DIC) compares the images taken at various degrees of distortion of a targeted framework and analyses them using correlation-based coordinating computations.

• Civil engineering projects often include large-scale foundation such as bridges, streets, and buildings. DIC empowers engineers to gather and analyse tremendous sums of information from sensors inserted in foundation, encouraging real-time checking and prescient upkeep. This proactive approach can upgrade security, decrease downtime, and draw out the life expectancy of foundation resources.

• Realistic photos can be obtained from a variety of sources, including convenient commercial cameras, fast video recorders, and traditional charge-coupled devices (CCDs).

• By analysing authentic and real-time sensor information, DIC empowers engineers to create prescient support models that expect auxiliary debasement and weakening. These models can help optimize support plans, prioritize assessment endeavours, and amplify the life expectancy of foundation resources whereas minimizing downtime and repair costs.

• Any basic contrasts can be precisely differentiated with the captured photos, and in this way, unanticipated changes that may actuate abnormalities would be easily recognized.

Overall, the integration of DIC techniques in SHM holds great promise for improving the safety, reliability, and resilience of civil infrastructure by providing actionable insights into structural health and enabling proactive maintenance strategies.

1.2.2 Applications:

- DIC enables real-time collection and analysis of sensor data from various sources, including accelerometers, strain gauges, and temperature sensors, installed on structures. Real-time monitoring allows engineers to detect anomalies, assess structural behaviour, and identify potential issues promptly.
- DIC facilitates the measurement of strain on the surface of structures
- By analysing images captured through DIC, it's possible to detect and monitor the development of cracks on the surface of structures.

- DIC enables the development of predictive maintenance models that utilize historical and real-time sensor data to forecast the future condition of structures. By predicting potential failures or deterioration trends, engineers can proactively schedule maintenance activities, optimize resource allocation, and extend the lifespan of infrastructure assets.
- DIC enables the development of decision support systems that assist engineers in making data-driven decisions regarding structural maintenance, repair, and retrofitting. By integrating sensor data, analytical models, and risk assessment tools, decision support systems can provide actionable insights, optimize maintenance strategies, and allocate resources effectively.
- DIC provides insights into how loads are distributed across a structure. Monitoring load distribution helps in identifying uneven loading patterns and potential structural weaknesses that could lead to localized failures.

1.2.3 Advantages:

- DIC allows for continuous, real-time monitoring of structures and systems, providing immediate feedback on any changes or anomalies.
- DIC is a non-contact measurement technique, eliminating the need for physical sensors to be attached to the structure
- The high-resolution imaging capability of DIC enables detailed analysis at the surface level, allowing for precise measurement and detection of deformations, cracks, and other structural changes.
- DIC systems can be tailored to specific structural monitoring needs. Developers can design and implement custom algorithms or analysis techniques suited to the characteristics of the structure being monitored, optimizing detection capabilities and reducing false alarms.
- Compared to traditional monitoring methods, DIC can be cost-effective, especially in scenarios where continuous monitoring is required.

1.2.4 Disadvantages:

- DIC relies on clear visibility of the structure's surface. Obstructions, shadows, or surface irregularities can impact the accuracy of measurements.
- DIC systems require careful calibration to ensure accurate measurements. Calibration errors or changes in camera parameters can introduce inaccuracies in the results.
- Changes in lighting conditions, such as variations in natural light or artificial lighting, may affect the performance of DIC systems and result in variations in captured images.

1.3 Requirement for DIC:

- DIC allows for the early detection of deformations, cracks, and other structural issues, reducing the risk of catastrophic failures.
- DIC's non-contact measurement capabilities make it ideal for monitoring without altering the structure's behaviour.
- As infrastructure ages, there is a growing need for continuous monitoring to ensure the safety and integrity of structures such as bridges, buildings, dams, and tunnels. DIC provides a non-intrusive and real-time approach to structural health monitoring.
- The capability of DIC for remote monitoring is particularly beneficial for civil engineering projects in challenging or hazardous environments. It reduces the need for physical presence at monitoring sites.
- DIC is valuable for large-scale infrastructure projects, where the monitoring of extensive structures such as highways, bridges, and railway networks is essential.

1.4 Organisation of Thesis:

Chapter 2 includes Literature Survey which reviews the existing body of literature relevant to the research topic. It identifies gaps in knowledge and establishes the theoretical framework for the study. Chapter 3 includes the study's data collection techniques, analytical techniques, and research methodology. Chapter 4 includes mix design and experimental analyses which describe about the M40 and I-Section specimen. Also tell about the experimental set-up for beam, I-Section and Railway track. Chapter 5 includes results and discussion that presents the findings of the research, supported by figures and graphs. It provides a detailed analysis of the data collected and evaluates the findings considering the goals and research questions. It talks about the results' ramifications and evaluates them against previous research. It also identifies the study's shortcomings and makes recommendations for future research topics. Chapter 6 includes conclusion which summarizes the main findings and contributions of the research. It provides recommendations based on the study's conclusions and makes recommendations for next research avenues.

CHAPTER 2

LITERATURE REVIEW

2.1 Background for Literature survey:

The powerful and adaptable optical technique known as Digital Image Correlation (DIC) has transformed material testing and structure health monitoring in the field of civil engineering. Over the past decades, DIC has been extensively applied to monitor reinforced concrete structures, bridges, masonry walls, and other civil infrastructure, enabling precise detection of damage mechanisms such as cracks, spalling, and deformation. These systems have demonstrated their capability to capture minute strain variations and structural responses under different environmental conditions, thereby aiding in the effective management and maintenance of civil engineering structures. Paper reviewed for literature survey is from 2022 to 2010.

2..2 Literature survey:

[1] V.V.Masthan Reddy, Dr.S.Vidhyalakshmi,Critical Evaluation of Reinforced Concrete Beams Using Digital Image Correlation Technique[2022]

DIC uses random speckle patterns to extract Moment (M) – Curvature (κ) relationships. For 2D DIC calculations, the random speckle pattern is evaluated and shows an advanced association with regular estimations. Measurements are made on random speckle pattern characteristics, and their suitability for DIC is examined. It is discovered that the extreme moment-curvature values, which were calculated using the irregular dotted design, closely match traditional calculations. It is observed that M-κ values extracted using the random speckle pattern compare favourably to M-κ values acquired the usual way. When compared to the extreme values obtained from the M-κ random speckle pattern, the extreme minute carrying capacity of RCC beams recovered from the arbitrary based speckle pattern is more stable and exhibits less scramble.

[2] K Tharun Kumar Reddy, Srikanth Koniki, Digital image correlation for structural health monitoring [2021]:

This paper presents a point-by-point audit of the utilize of advanced picture relationship on basic wellbeing observing. The schematic setup of DIC prepare. DIC is utilized to overcome the issues by the conventional strategies and densiometric strategies. For the tall degree of precision estimation values, advanced picture relationship is to be utilized. DIC gives precise full-field deformation measurement comes about. These will capture the exceptionally little strain values and finds the surface deformation at higher temperatures. It could be a exceptionally cost-effective strategy in basic health observing, which measures the full-field uprooting and strain. DIC is utilized for any estimate example and can be tried for any fabric sort examples. DIC gives the analysed comes about of stretch concentrators and strain. DIC can measure both exceptionally little and exceptionally huge sorts of deformation strains

[3] Mohammed Abbas Mousa, Mustafasanie M.Yussof,Ufuoma Joseh Udi,Fadzli Mohamed Nazri,Mohd Khairul Kamarudin,Gerard A.R Parke,Lateef N. Assi,Seyed Ali Ghahari.[2021]

This paper employs a vision-based approach for Structural Health Monitoring (SHM) of bridge systems, offering several advantages: non-contact, non-destructive, long-distance capabilities, high accuracy, immunity to electromagnetic interference, and the ability to monitor multiple targets simultaneously. This review aims to highlight the significance and safety benefits of vision-based and Digital Image Correlation (DIC)-based SHM methods for bridge infrastructure. The study considers four types of bridges: concrete, suspension, masonry, and steel. Applications of DIC in SHM have drawn more attention lately as a means of assessing the structural reactions of bridges under loading scenarios. Although there have been several non-destructive diagnostic approaches for SHM in civil infrastructure, vision-based procedures such as DIC have just been created in the past 20 years. By giving timely and accurate data, these techniques let bridge systems detect deterioration and ensure effective, long-lasting operation over the duration of the bridge's service life. The studies discussed in this article show that DIC can identify important characteristics including deformation, stresses, vibration, deflection, and rotation, as well as damage like fractures and spalling. Furthermore, the examined literature suggests that DIC is a dependable and efficient method that provides long-term monitoring solutions for various bridge systems.

[4] Gonga Chen, Zhihua Wu, Chunjian Gong, Jiqiao Zhang and Xiaoli Sun, DIC Based Operational Modal Analysis of Bridges [2021]

A novel approach has been proposed to identify the natural frequencies and mode shapes of a bridge model using the Digital Image Correlation (DIC) method to track dynamic displacements. Determining a bridge's modal parameters is a critical issue in vibration-based damage detection. Because conventional acceleration sensors are only used at a limited number of measurement locations, they have difficulty adequately capturing the mode forms of bridges. The full experimental bridge model's movement is captured in this study using the DIC approach. The bridge model is a steel truss that is hammered and has its dynamic displacement captured by a digital video camera. Points of interest are then tracked using correlation analysis, and a modal analysis system receives their displacement time histories. The methodologies of Operational Modal Analysis (OMA) and Experimental Modal Analysis (EMA) are utilized to get the natural frequencies and mode shapes of the bridge model. The results obtained using the DIC method are compared with those obtained via conventional acceleration sensor-based methods, showing that the natural frequencies from both measurement techniques are very close. The DIC results are sensitive to the amplitude of the measured displacement and the shooting distance; small displacement amplitudes and long shooting distances may result in lower quality time-history curves, and low-frequency noise signals may appear in their power spectral density (PSD) curves. However, these issues can be effectively resolved using the filtering technique described in this article. Additionally, the primary frequencies obtained by EMA and OMA are very close, validating the suitability of the DIC measurement under ambient excitation. The research demonstrates the feasibility of using the DIC method to obtain the modal parameters of bridges.

[5] Jingwu Bu, Xinyu Wu and Xudong Chen, the rate effect on fracture mechanics of dam concrete based on DIC and AE techniques [2021],

To investigate the impact of loading rate on the failure behaviour of embankment concrete, various loading rates (0.1, 0.01, 0.001 mm/s) were applied to two types of full-grade notched embankment concrete cubes with edge lengths of 300 mm and 450 mm, respectively. A wedge gap test was performed. The deformation and acoustic radiation parameters of the dam concrete were measured using the Digital Image Correlation (DIC) method and the acoustic radiation method. The test results indicate that the peak load and fracture energy of the embankment concrete samples increase with the loading rate. Additionally, higher loading rates make the concrete is more fragile. Boundary effects cause the crack length to decrease as the loading rate rises, but the crack tip opening displacement (CTOD) to increase. The energy mutation region gets more pronounced as the loading rate increases, although the loading rate and maximum aggregate size both have an impact on the total acoustic emission energy. Because fewer microcracks emerge in the concrete at greater loading rates, there are fewer three-dimensional location points with both the shear signal and acoustic radiation. Important experimental information on the fracture mechanics of embankment concrete is provided by these test findings.

[6] Tambusay, A., Suryanto, and Suprobo, Digital Image Correlation for Cement-based Materials and Structural Concrete Testing [2020]:

In this paper, a generally reasonable framework is formulated and upgraded, with the point to advance a more far reaching utilize of DIC inside the respectful and structural designing field. it was chosen to utilize a customary computerized camera as the most recording instrument and an open-source picture relationship computer program known as Ncorr which runs on a broadly utilized programming stage MATLAB®.This paper will give a dialog of the capabilities of the proposed framework in two case considers:

a strengthened concrete pillar beneath four-point bowing and a dog-bone molded, pliable cement composite known as the engineered cementitious composite (ECC) [12-14]. Within the to begin with case ponder, parametric investigation was embraced to ponder the impact of key input parameters on the spatial quality and determination of the strain maps delivered by the DIC. The moment case consider was chosen to test the vigor of the proposed framework in capturing progressive arrangement and broadening of numerous micro-cracks produced amid testing.

[7] Marco Domaneschi, Gianni Niccolini, Giuseppe Lacidogna and Gian Paolo Cimellaro, Nondestructive Monitoring Techniques for C rack Detection and Localization in RC Elements [2020]:

The structural and damage analysis of a reinforced concrete (RC) beam that underwent a four-point bending test until the reinforcing steel gave way is presented in this work. NDT techniques of all kinds were used to monitor the degradation process. Distributed fiber optic sensors (FOSs) installed before concrete pouring were used to monitor strain. Acoustic emission (AE) sensors that were affixed to the surface of the material were observed the initiation and propagation of cracks. The AE activity results correlated well with the FOS strain measurements. The findings from the integrated monitoring system were confirmed by visually observing the actual crack pattern. Additionally, digital image correlation (DIC) analysis was performed at different loading stages.

[8] PanelM. Babaeeian, M. Mohammadimehr Investigation of the time elapsed effect on residual stress measurement in a composite plate by DIC method [2020]

Residual stresses are commonly found in composite panels and can adversely affect the final product. Therefore, understanding the type, location, and magnitude of these residual stresses is essential. Typically, residual stress is measured indirectly by first determining displacement and strain. Two-dimensional digital image correlation (2D DIC) is a practical and effective tool for quantitatively measuring the in-plane deformation of planar object surfaces and has become widely accepted in experimental mechanics.

In the drilling method, residual stress is measured immediately after drilling. However, there has been less emphasis on how the released stress around the hole changes over time after drilling. This study introduces a novel approach by determining the optimal measurement time post-drilling, considering holes of various diameters, and measuring displacement and strain fields at different intervals. The study investigates residual stress measurements in composite panels over time and examines the effects of hole diameter and elapsed time after drilling on the amount of residual stress released using the 2D-DIC method.

Strain estimation from displacement fields is performed using pointwise local least squares (PLS) fitting. Residual stresses are calculated by estimating strains, determining calibration constants for orthotropic materials, and considering the pre-determined properties of the composite panels. The finite element method (FEM) is utilized to determine these calibration constants, with FEM correction factors derived from comparisons between FEM results and experimental tensile tests.

[9] Paweł J. Romanowicz, Bogdan Szybiński, Mateusz Wygoda,Application of DIC Method in the Analysis of Stress Concentration and Plastic Zone Development Problems[2020]

This paper evaluates the potential and reliability of the digital image correlation (DIC) system for engineering and scientific applications. The studies involved samples made from three different materials: mild S235JR + N steel, micro-alloyed fine-grain S355MC steel, and high-strength 41Cr4 steel, each subjected to various heat treatments. The primary focus of the DIC studies was to identify zones with high stress concentrations, track the growth of plastic deformation, and predict failure zones. Experimental tests were conducted on samples with different types of notches, including circular, square, and triangular openings.

Using the DIC system alongside microstructure analyses, the research examined the effects of various factors—such as laser cutting, heat treatment, material type, notch shape, and manufacturing quality—on material behavior. For all cases studied, stress concentration factors (SCFs) were estimated using both analytical formulations and finite element analysis (FEA). It was found that theoretical models for calculating the effects of typical notches might produce inaccurate SCF values. Ultimately, selected results of total strain distributions were compared with FEA results, showing good agreement.

The authors conclude that DIC, when used with a standard digital camera, is an effective method for analyzing the evolution of plastic zones and detecting damage in both mild and high-strength steels, as well as steels that are normalized and quenched and tempered at higher temperatures.

[10] Pedro J. Sousaa,b, Francisco Barrosb , Paulo Loboc,d,Paulo J. Tavaresb , Pedro M. G. P. Moreira, Experimental measurement of bridge deflection using Digital Image Correlation[2019]:

In this study, a test was conducted where a sequence of 3,078 images was recorded at 36 frames per second, the maximum possible framerate due to equipment limitations. The images were captured during the sequential passage of two trucks, each weighing 30 tons, across the bridge. Despite less-than-ideal natural conditions during the tests, the results confirm the relevance of Digital Image Correlation (DIC) for these measurements and validate the quality of the DIC algorithms developed at INEGI.

The study successfully identified different effects caused by static loads at various positions by comparing the bridge's response to the two stops of the first truck, as well as dynamic loads by comparing those responses to the passage of the second truck. Wind gusts caused some instability in the speckle pattern, generating measurement noise, which was further exacerbated by distortions from the heat on the asphalt. Some of these issues could be mitigated by using heavier or painted targets and positioning them closer to the edge of the bridge. Despite these challenging weather conditions, the filtered results are promising.

[11] Yijie Huang, Xujia He, Qing Wang, Jianzhuang Xiao, Deformation field and crack analyses of concrete using digital image correlation method. [2019]

The creation of numerical software and a processing approach for the Digital Image Correlation (DIC) methodology is described in this work. Experimental data were used to determine and validate the displacements and strains of the interface transition zone (ITZ), cement mortar, and coarse aggregate. The axial displacements of ITZs and cement mortar were found to be greater than those of coarse aggregates prior to the emergence of macrocracks, indicating that the axial displacement was not distributed uniformly throughout the loading stage. The water-to-cement (W/C) ratio had no discernible impact on horizontal displacement. Additionally, the experimental results demonstrated that when stress reached 30%–40% of the peak stress, transverse, and shear deformation concentration areas (DCAs) occurred. The coarse aggregates, ITZs, and cement mortar were all covered by these transverse and shear DCAs. Nonetheless, the coarse aggregate was primarily encircled by the axial DCA.

Higher W/C ratios were generally associated with larger DCA sizes and numbers. distinct W/C ratios caused distinct crack propagation patterns. Regardless of the W/C ratio, microcracks in concrete are mostly initiated in the ITZs. In comparison to samples with a low W/C ratio, concrete with a high W/C ratio showed a greater number and distribution range of cracks. On the other hand, the high W/C samples had relatively minor crack sizes and widths. Concrete deterioration parameters were shown to be significantly influenced by the W/C ratio. Lastly, a comparison of the computed findings was used to assess the cracks' characteristics.

[12] M. Malesa, D. Szczepanek, M. Kujawińska, A. Świercz and P. Kołakowski, Monitoring of civil engineering structures using Digital Image Correlation technique [2019]

It is possible to quantify displacements and strains in a range of objects full-field and noncontactly using the Digital Image Correlation (DIC) technique. An application of the DIC approach for monitoring civil engineering structures is presented in this work. It explains the basic idea of an all-inclusive, automated monitoring system, of which the DIC sensor is an essential part. Additionally, the article presents new software capabilities intended to speed up the correlation analysis process and enable outside measurements. The report provides measurements made on a railway bridge in Nieporęt, Poland, as an example of an application. The experimental results are then compared with the displacements predicted by a Finite Element Method (FEM) model of the bridge.

[13] M F Bado, G Kaklauskas and J R Casas,**Performance of Distributed Optical Fiber Sensors (DOFS) and Digital Image Correlation (DIC) in the monitoring of RC structures[2019],**

Distributed fibre optic sensors (DOFS) are strain gauges that have recently gained recognition for their potential in civil engineering applications. One unique advantage is their ability to be attached to steel reinforcing bars and embedded within concrete elements (RC) to monitor mechanical strains. In this paper, we present the results of an experimental study where two RC tendons (connections) were equipped with DOFS instrumented rebars to obtain strain measurements at intervals of 7.5 mm. By observing the cracking behaviour, we gain insights into the strain distribution of the reinforcing steel within cracked concrete. These results are innovative as they provide accurate and fully distributed measurements both before and after concrete cracking, which has not been achievable until now. Additionally, internal strain measurements are combined with external digital image correlation (DIC) monitoring to capture data on surface displacements and strains of the components. This study marks the commencement of a comprehensive experimental campaign aimed at furnishing rebar strain data for multi-loaded reinforced concrete anchors with varying geometric properties such as concrete cover, rebar ratio, and rebar diameter.

[14] Yijie Huang, Xujia He, Qing Wang and Jianzhuang Xiao, Deformation field and crack analyses of concrete using digital image correlation method [2019]

A study was conducted to investigate the deformation and cracking behavior of concrete under axial compression, utilizing the digital image correlation (DIC) method. The main focus was on analyzing the effect of the water-cement ratio (W/C), an important parameter in these experiments. A novel analysis procedure and numerical program were developed specifically for the DIC method. Through comparison with experimental data, the displacement and strain of various concrete constituents—such as coarse aggregate, cement mortar, and the interfacial transition zone (ITZ)—were accurately measured and validated. Notably, it was observed that axial displacement was unevenly distributed during loading, with the ITZ and cement mortar experiencing greater displacement than the coarse aggregate before macrocracks appeared. The impact of the W/C ratio on horizontal displacement was found to be minimal. Furthermore, regions of concentration for lateral and shear deformation (DCAs) emerged when stress reached 30-40% of its peak value. These DCAs extended through not only the cement mortar but also the ITZ and coarse aggregate. However, axial DCAs primarily surrounded the coarse aggregate. Generally, higher W/C ratios resulted in larger and more numerous DCAs. Crack propagation patterns varied with changes in the W/C ratio, with microcracks mainly occurring in the ITZ regardless of the W/C ratio. Concrete with a high W/C ratio exhibited more extensive crack networks compared to samples with a low W/C ratio, albeit with smaller crack values and widths. The study emphasized the significant influence of the W/C ratio on the damage characteristics of concrete. Additionally, crack properties were assessed through a comparative analysis of calculation results.

[15] Suryanto, B., Tambusay, A., and Suprobo, P., Crack Mapping on Shear-critical Reinforced Concrete Beams using an Open-Source Digital Image Correlation Software [2017]:

This study examines the impact of stirrup spacing on the overall strength, ductility, and failure mode of three reinforced concrete bars: two with a shear reinforcement ratio of 0.4% and 1.1%, and one without shear reinforcement. The response of two geometrically equal beams with no shear reinforcement and shear reinforcement spaced closely, as well as the response of a reinforced concrete bar deliberately intended to not comply with SNI 2847:2013 clause 11.4.5 (maximum stirrup spacing), are the main subjects of the study. The intention is to impart knowledge of the significance of stirrup spacing checks in shear design to engineers who are currently employed. A non-contact strain measurement system was utilized to see the creation and propagation of fractures throughout the loading history, from early cracking to failure, using the open-source digital image correlation (DIC) program Ncorr. This was done to aid in interpretation. The system is appealing for usage in scenarios where cost is a constraint because it is reasonably easy to set up, using only an off-the-shelf smartphone and a normal digital camera.

[16] Niranjan Desai, Small-strain measurement in bridge connections using the digital image correlation (DIC) technique [2016]

Structural health monitoring (SHM) plays a crucial role in enhancing the safety, maintainability, and reliability of vital structures, providing infrastructure owners with timely information to ensure the safety of their assets while maintaining cost-effectiveness. SHM involves implementing strategies to detect and characterize damage and undesirable behavior in engineering structures. This research project aimed to determine the minimum detectable strain using a standard SHM device based on digital image correlation (DIC). The motivation behind this investigation, which is directly relevant to industry, stemmed from the observation of damage on a real bridge that went unnoticed initially. Early detection of such damage could significantly reduce repair costs. To achieve this goal, a laboratory sample mimicking the steel beam-to-column connection of the bridge in question was subjected to incremental loading like that experienced by a real bridge. The test was conducted, and strains were measured using a DIC-based instrument and the associated software. The study aimed to establish the minimum resolution of the state-of-the-art system under controlled laboratory conditions. Despite the controlled environment, there were challenges in accurately measuring these small strains, emphasizing the need to validate existing DIC technology in real-world scenarios to detect the onset of strain-induced damage. The study concluded that it is currently impractical to measure such small strains indicative of damage to the bridge connection. Further research in this area is warranted.

[17]PanelTiago Ramos , André Furtado , Shayan Eslami , Sofia Alves , Hugo Rodrigues , António Arêde , Paulo J. Tavares , P.M.G.P. Moreira [a], 2D and 3D Digital Image Correlation in Civil Engineering – Measurements in a Masonry Wall[2015]

Reinforced concrete structures are essential components of modern buildings, often featuring RC frames reinforced with infill masonry panels. Due to their vulnerable nature, the failure and collapse of these elements have been the subject of studies aimed at conducting thorough structural analysis and design to reduce the risk to human lives during seismic events. Two studies utilized digital image correlation to validate its capability for monitoring large-scale structures and potential applications in structural health monitoring. This methodology enabled the measurement of displacements and strain fields in both in-plane and out-of-plane loading scenarios, as well as the spatial reconstruction of wall movement and the characterization of its rigid body motion. The identification of common in-plane wall defects, such as corner crushing and separation between the infill and the supporting structure, was made possible using data processing approaches.

[18] PanelTahreer M. Fayyad, Janet M. Lees, Application of Digital Image Correlation to Reinforced Concrete Fracture [2014]

Reinforced concrete structures are essential components of modern buildings, often featuring RC frames reinforced with infill masonry panels. Due to their vulnerable nature, the failure and collapse of these elements have been the subject of studies aimed at conducting thorough structural analysis and design to reduce the risk to human lives during seismic events. Two studies utilized digital image correlation to validate its capability for monitoring large-scale structures and potential applications in structural health monitoring. This technique facilitated the spatial reconstruction of wall movement, characterization of its rigid body motion, and measurement of displacements and strain fields in both in-plane and out-of-plane loading scenarios. Data processing techniques allowed for the identification of typical in-plane damages in the wall, such as corner crushing and separation between the infill and the supporting structure.

[19] N. J. McCormick 1, and J. D. Lord 1, Practical in-situ applications of DIC for large structures [2010]:

The paper discusses the recent application of Digital Image Correlation (DIC) for in-situ measurements of deformation and cracking in large civil engineering structures such as bridges and power plants. Recent research at NPL has demonstrated the potential of DIC as a novel Non-Destructive Testing (NDT) tool for assessing deformation and cracking in reinforced concrete structures. This method is particularly useful in areas where inspection is challenging or costly, and where direct access may pose safety concerns. In such cases, accurate measurements from image sets can be highly cost-effective. The study will present data from multiple preliminary studies and discuss factors influencing the accuracy of the method when used outside the laboratory. Ongoing efforts focus on understanding the effects of environmental factors on measurements and the need for camera repositioning during image capture. Strategies for mitigating these effects on accuracy will be discussed.

[20] M. Malesa, D. Szczepanek, M. KujawiEska, A. gwiercz, P. Koaakowski, Monitoring of civil engineering structures using Digital Image Correlation technique [2010]:

The use of DIC (Digital Image Correlation) based sensors for monitoring civil engineering structures is highlighted in this research, along with other important characteristics that make DIC appropriate for such applications. Its full-field, non-contact measurement capabilities, ease of adaption to different areas of interest, simple data collecting process, and comparatively inexpensive equipment are a few of these. Commercial DIC systems are available, however they are not compatible with other sensors and are not fully tuned for outdoor monitoring. The monitoring system created for the MONIT project, which makes use of modified DIC sensors with varying degrees of precision, is described in the study. The findings of local and global DIC measurements of a railway bridge in Nieporet, Poland, are compared with displacements estimated from a bridge model created using the Finite Element Method (FEM).

2.3 Summary of Literature Review:

Digital image correlation (DIC) is a powerful non-contact optical method that is widely used for structural health monitoring (SHM) and analysis of reinforced concrete (RC) structures. Various studies have demonstrated the effectiveness of his DIC in detecting deformations, strains, and cracks throughout the field under various loading conditions. Reddy and Vidhyalakshmi (2022) highlight the reliability of his DIC in extracting moment-curvature relationships from speckle patterns of RC beams, which is in good agreement with traditional methods. Reddy and Koniki (2021) reviewed the high-precision deformation measurement of DIC and its cost-effectiveness in SHM, highlighting its ability to capture minute strains and surface deformations even at high temperatures. Musa et al. (2021) and other studies have validated the non-contact and high-precision benefits of DIC in bridge monitoring, highlighting its role not only in damage detection but also in identifying structural responses to loads and environmental influences. Masu. Tambusei et al. (2020) discussed his low-cost DIC setup to visualize crack propagation in RC beams using standard cameras and open-source software. Various studies, including that of Sousaa et al. (2019) and Huang et al. (2019) verified the applicability of DIC in field conditions despite challenges such as environmental noise. There are also other studies such as Fayyad and Lees (2014) and Bado et al. (2014). (2019) demonstrated the usefulness of DIC in the analysis of fracture mechanics and interaction between concrete and reinforcement. Overall, DIC is a versatile and effective tool in civil engineering, providing detailed insight into the behaviour, deformation, and damage of structures under different conditions.

2.4 Research Gap

- Real-time image capture and seamless application in the private sector are made possible by the technical reliability of image processing, which takes into account the unpredictability of construction site and the intensity of weather.
- Improving model performance requires large amounts of accurately labelled data.
- Investigate how DIC can be effectively incorporated into advanced materials used in construction, including: Fiber-reinforced composites or intelligent materials to monitor behaviour under different charging conditions.

• Integration with other sensor technologies.

2.5 Research Objective:

- To understand digital image correlation technique for finding deflection and stresses in civil engineering structures
- To investigate lab specimen Flexural and Tensile testing to correlate and validate result obtained from DIC.
- To monitor field investigation deflection and strain at Kalka-Shimla heritage Railway line.

CHAPTER 3

METHODOLOGY

3.1 General

The task began with reviewing several journals and selecting the subject as shown in Figure 3.1. After choosing the topic, we identified the problem by reading several related research papers and review studies. Once we determined what needed to be done, we started collecting materials. After gathering the necessary materials, we conducted all the standardized tests. The testing had to be appropriate and follow proper and precise methods.

The experimental program involved casting three beams, including simple beams and reinforced beams of M40 concrete grade. For this investigation, fine aggregate corresponding to Zone II was used, along with a mild steel plate I-Section.

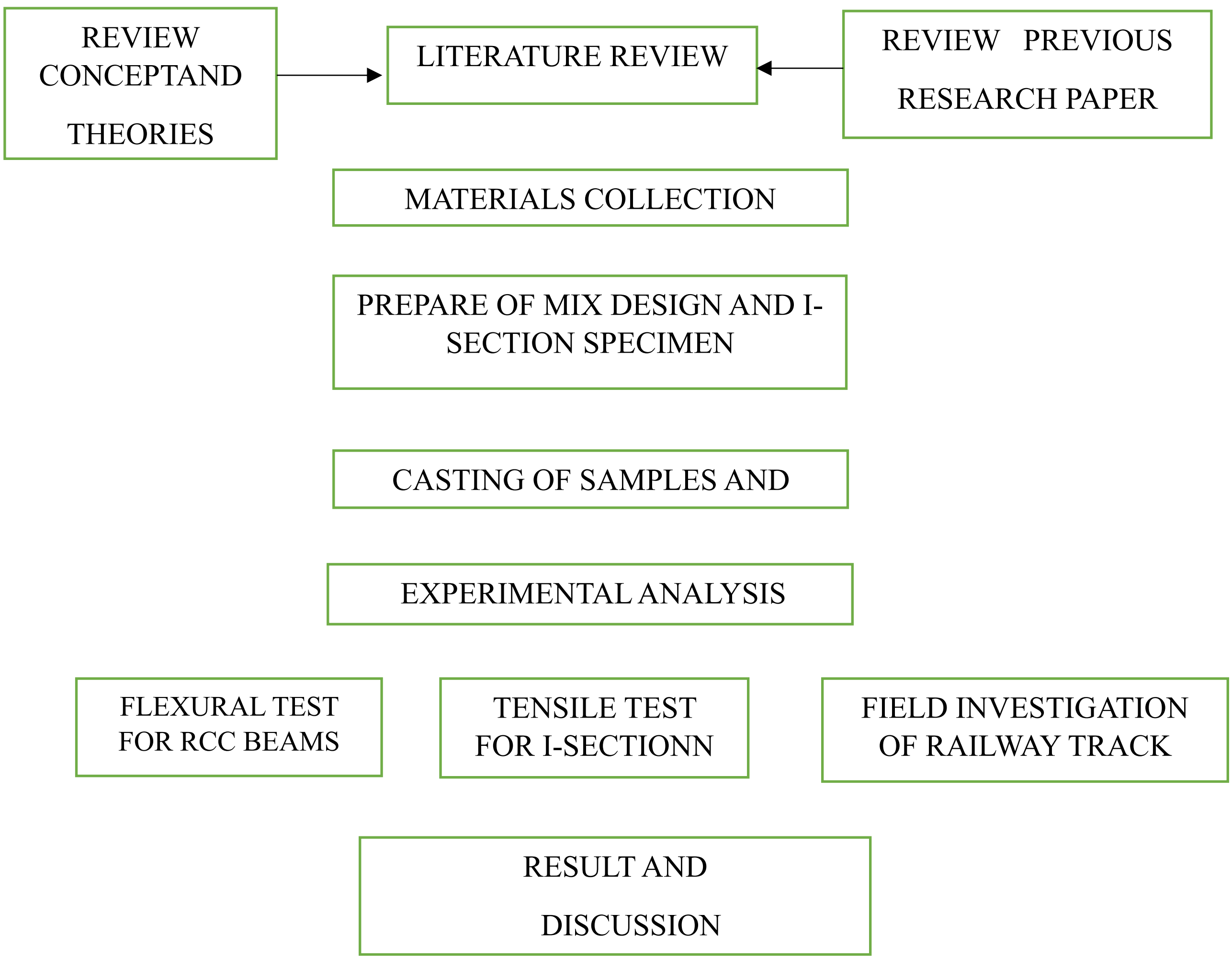

Fig.3.1 Flow Chart of Project Methodology

3.2 Material Required

The fabric required such as sand which obtained through nearby seller within the Solan, coarse aggregates cement which were to gotten from nearby merchant from Solan and the steel bars utilized are of 8mm dia that as well from Solan, acrylic paint from online store(amazon)

Table 3.1 Material Required and Location

Material	Location
Sand	Local Vendor
Coarse Aggregates	Local Vendor
Cement	Local Vendor
Steel Bars (8mm Dia)	Local Vendor
Acrylic Paint for Speckle Pattern	Online Vendor

3.2.1 Material Used:

Fig 3. 2 (a)PPC

Fig 3.3 (b) Coarse Aggregates

Fig 3.4(c) Fine Aggregates

Fig 3.5(d) Acrylic Paint for Speckle Pattern

Fig 3.6 (e) Steel bars of 8mm

Fig3.7 (f) I-Section Steel plate

3.3 Characteristic of Materials:

3.3.1 Cement

PPC is its pozzolanic material content, typically fly ash, which is finely divided and mixed with Portland cement clinker. Secondly, PPC exhibits slower hydration compared to Ordinary Portland Cement (OPC), resulting in reduced heat generation during the curing process, making it suitable for mass concrete applications where temperature differentials can cause cracking. Additionally, the pozzolanic reaction between the fly ash and calcium hydroxide produced during hydration results in increased strength and durability of concrete over time. Overall, the properties of PPC make it a versatile and reliable option for a wide range of construction projects, offering durability, workability, and sustainability benefits.

3.3.2 Fine Aggerates

This term refers to the larger particles that make up the bulk of concrete mixes. These particles are typically larger than 4.75 mm (0.187 inches) in diameter. Coarse aggregates are sourced naturally from quarries or are manufactured by crushing rocks or recycling concrete waste. They play a crucial role in concrete production, contributing significantly to the strength and durability of the final structure.

Fig 3.8 Fine Aggerates

3.3.3 Coarse Aggregates

This term refers to the larger particles that make up the bulk of concrete mixes. These particles are typically larger than 4.75 mm (0.187 inches) in diameter. Coarse aggregates are sourced naturally from quarries or are manufactured by crushing rocks or recycling concrete waste. They play a crucial role in concrete production, contributing significantly to the strength and durability of the final structure.

Fig 3.9 Coarse Aggerates

3.3.4 Steel bars

Steel reinforcement is the addition of steel bars to regular cement concrete to create reinforced concrete. 8 mm thick steel bars having properties such as Typically made from high-quality carbon steel. Conforms to Indian Standard specifications such as IS 1786. High tensile strength, usually around 500-600 MPa. The yield strength is generally around 415-500 MPa. The density of steel is approximately 7850 kg/m³.

3.3.5 Steel plate

Steel plate is used for I-Section which is of mild steel of thickness 0.5 cm, length 61 cm and breadth of 6.1cm. An I-section mild steel plate with a thickness of 0.5 cm exhibits a combination of physical, mechanical, and structural properties that make it suitable for various construction and engineering applications. Its material, mild steel, boasts a density of approximately 7.85 g/cm³ and typical tensile strengths ranging from 250 MPa to 550 MPa, providing adequate structural integrity while remaining relatively lightweight.

3.3.6 Speckle paint

For creating speckle pattern on the beams, we have used acrylic paint. Key property of spray acrylic paint is its excellent adhesion to a variety of surfaces, including paper, canvas, wood, metal, plastic, and more. This adhesion ensures that the paint forms a durable and long-lasting bond with the surface, preventing flaking or peeling over time. Spray acrylic paint also typically provides vibrant and opaque colours, allowing for bold and expressive artworks. This property ensures the longevity of artworks and decorative projects, making spray acrylic paint suitable for both indoor and outdoor applications. Overall, the properties of spray acrylic paint, including quick drying, excellent adhesion, vibrant colours, durability, water-resistance, and safety, make it a popular choice for a wide range of artistic and decorative purposes.

Fig 3.10 Speckle Pattern

3.3.7 DSLR [Digital Single Lens Reflex]

Here in the experiments DSLR camera Nikon D5600 is used to capture the videos for obtaining results on GOM Software. The D5600 features a 24.2-megapixel DX-format CMOS sensor without an optical low-pass filter. This sensor size is commonly referred to as APS-C. The camera setting was set up in automatic mode. It is powered by Nikon's EXPEED 4 image processor, which provides fast image processing capabilities and helps in delivering high-quality images with reduced noise. The camera has a native ISO range of 100-25,600, expandable up to ISO 51,200. This wide ISO range allows for shooting in various lighting conditions while maintaining image quality. The D5600 employs a 39-point autofocus (AF) system with nine cross-type sensors, providing accurate and fast autofocus performance, especially in good lighting conditions.

Fig 3.11 Nikon D5600 with tripod

3.4 Set-up and Instrumentation

3.4.1 Sample 1[RCC BEAMS]

The test setup and instrumentation used in the test program are shown in Figure 3.12. Each beam was initially placed into a rigid reaction frame and rested on two roller supports spanning 470 mm. The beam was then subjected to two-point loads symmetrically positioned at the centre. At each load point, a steel roller was placed on top of the beam to prevent premature failure from local concrete crushing during the test. Before testing, a speckle pattern was created on the front surface of the beam, as illustrated in Figure 3.10.

Fig 3.12 Experimental set-up side view

Fig 3.13 Experimental set-up front view

3.4.2 Flexural Strength Test

The force needed to bend a beam under three-point loading circumstances is measured by the flexural test. The information is frequently used to choose materials for components that will not flex under load. A material's flexural modulus can be used to determine how stiff it is.
Here flexural strength machine is used as the instrument and along with is digital camera is used to record the video of the experiment to get the dataset that will be required in the image processing to get the strain and deformation of the beam that is being tested.

3.4.3 Sample 2(I-Section)

The experimental setup for analysing the tensile loading of an I-section mild steel plate using Digital Image Correlation (DIC) involves several precise steps to ensure accurate and reliable data collection. Initially, an I-section mild steel plate is selected, with its dimensions and mechanical properties carefully documented. The surface of the steel plate is prepared for DIC by applying a high-contrast speckle pattern using white and black spray paint, ensuring uniform distribution to facilitate accurate strain measurement. The steel plate is then securely mounted in a tensile testing machine or UTM, aligning it precisely to avoid any slipping. High-resolution digital camera is positioned on the side of the steel plate to capture synchronized images during the tensile test. Proper lighting is arranged to illuminate the plate evenly and eliminate shadows or glare that could interfere with image quality. Before starting the tensile test, baseline images of the speckle pattern are captured. The tensile load is then applied incrementally, and images are captured at each load step to track the deformation and strain distribution across the steel plate. The DIC software is used to analyse these images, correlating the speckle pattern changes to compute displacement and strain fields

Fig 3.14 Lab testing of I-Section of Sample 2   Fig 3.15 Post testing of I-Section of Sample 2

3.4.4 Field Investigation of DIC on Shimla-Kalka Heritage line

The experimental set-up was done by choosing appropriate location along the railway line and the railway line chosen for the experiment was Shimla-Kalka Heritage Railway having single narrow-gauge track (gauge 0.762) line near Kaithlighat as the deflection would be easily processed in the GOM Software and on 60cm length of railway track speckle paint was applied. Instrumentation plays a key role in the experiment, with high-resolution digital camera strategically positioned along the railway line to capture images of the area of interest. The camera is mounted on stable tripods, ensuring precise positioning and stability. The experiment was conducted in afternoon.

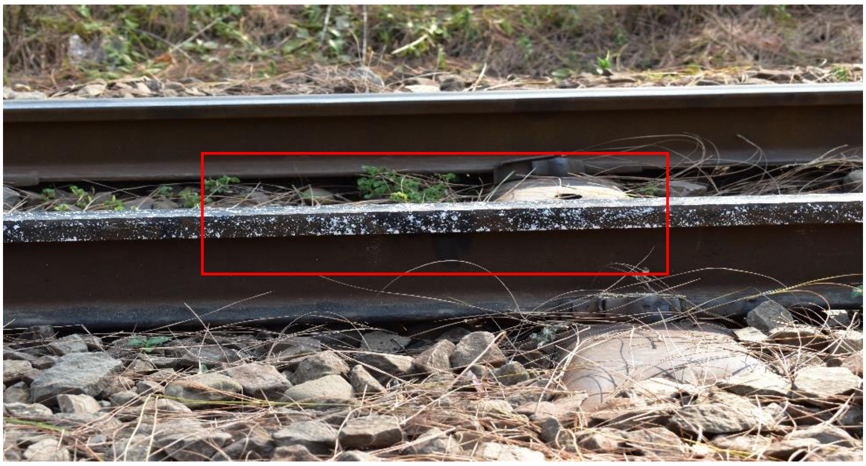

Fig 3.16 Speckle pattern on the railway line

3.5 GOM Software

A program called GOM Inspect is used to analyse 3D measurement data from coordinate measuring machines (CMM), laser or fringe projection scanners, and other measuring devices. The GOM software is employed in production, quality assurance, and product development. GOM software is used digital image processing to get the strain and deflection of the beam that is being tested. This software uses the video that is recorded with the help of digital. camera of the specimen that is being tested and then the dataset is taken to process the image and then graph is plotted

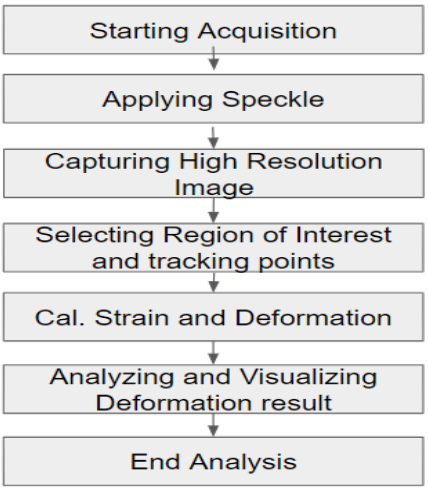

Fig 3.17 GOM Software Flow chart

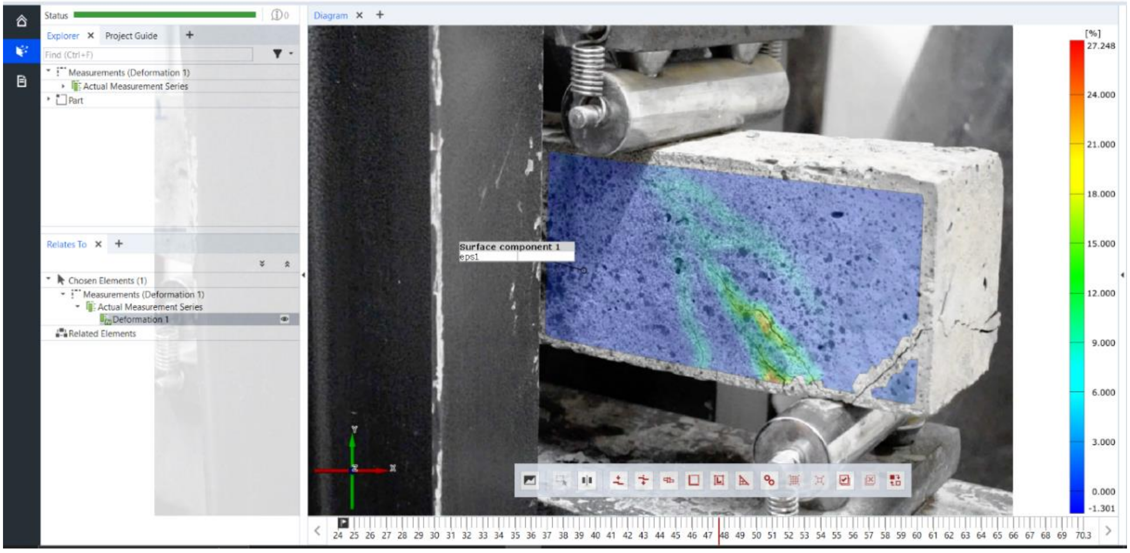

Fig 3.18 Sample 1(RCC Beam) GOM Software Interface showing deflection% through colour grading

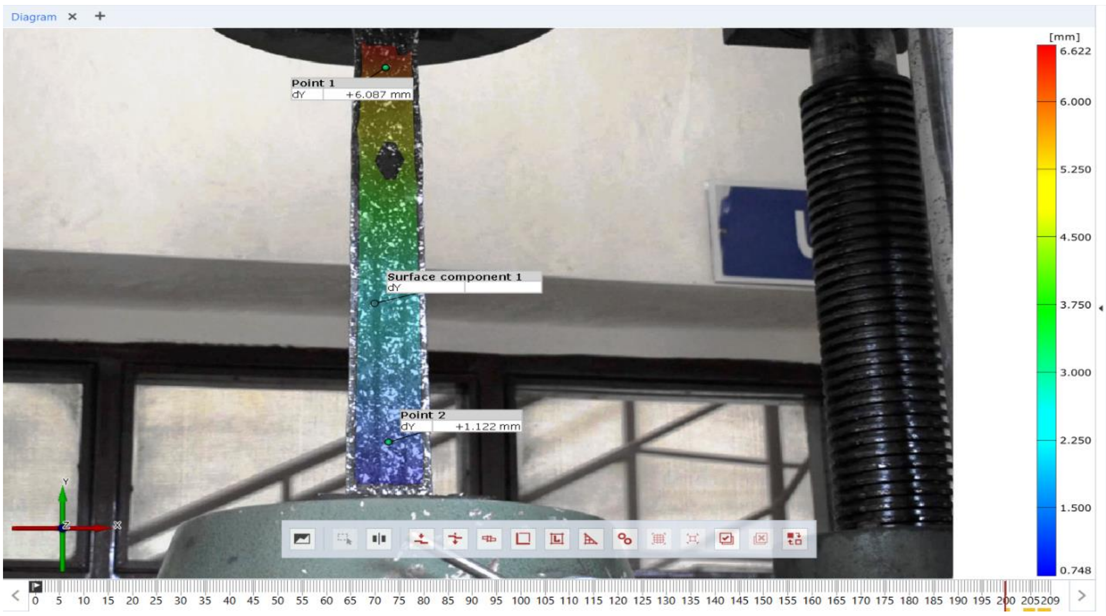

Fig 3.19 Sample 2(I-Section) GOM Software Interface showing deflection% through colour grading

Above Figure 3.18 and 3.19 how is how the GOM Software interface looks like. It features a hierarchical structure that allows users to easily organize, navigate, and access different stages of their analysis, such as calibration, image acquisition, and post-processing. It supports high-resolution displays, enabling users to zoom in, pan, and rotate images for detailed inspection. GOM Software includes robust calibration tools that ensure accurate measurements. The software provides comprehensive measurement and analysis tools, allowing users to define specific points, lines, or areas for detailed examination. It supports the calculation of displacement, strain, and other key parameters, with results displayed in a clear and interpretable format. Reports can include annotated images, graphs, and statistical data, and can be customized to meet specific needs

CHAPTER 4

MIX DESIGN AND EXERIMENTAL SET-UP

4.1 Mix Design of M40 grade concrete

4.1.1 Standard and Specifications

In this mix design and during testing, references from different codes and standards such as IS: 456-2000, IS-383:1970 is used.

4.1.2 Material Used

Detail of material used in this mix:

Cement – PPC

Fine Aggregates – Less than 4.75mm of Zone II

Coarse Aggregates – Less than 20mm

Steel bars - 8mm

4.1.3 Design Mix Proportion

The design mix proportion for M40-Grade Concrete:

Ratio of mix proportion of cement to fine aggregate to coarse aggregate is 1:1.34:2.6.

4.2 Mix Design Calculation

4.2.1 Water-Cement ratio

We take the water-cement ratio = 0.36 (As per Table 5 of IS 456: 2000)

4.2.2 Selection of Water Content

According to the codes provided in (As per table 3 IS 456:2000), the maximum water content in an aggregate of 20 mm is 186 kg (for a slump of 25 to 50 mm). Targeting a 75 mm slump, so we had to increase the water content. To get a 25mm rise in slump, we had to increase the water content by 3%, and so on.

Water content estimate: 186 + (3/100) x 186 = 192 kg.

4.2.3 Sieve Analysis for Fine and Coarse Aggregates

Sieving a known weight of the aggregate through a series of standard sieves yields the fineness modulus of the given aggregate. Each sieve's weight retention % is totalled up, and the resulting percentage is then divided by 100. When evaluating the fineness or coarseness of various aggregates, this metric comes in handy. Fine aggregates can be divided into groups according to the fineness modulus limits shown below.

2.2 to 2.6 for fine sand and 2.6 to 2.9 for medium sand

Coarse sand: 2.9 to 3.2 Sand is deemed inadequate for producing concrete that is satisfactory if its fineness modulus is higher than 3.2. The fineness modulus of coarse aggregates is usually larger than 5.

When most of an aggregate pile goes through one sieve and is held on the subsequent smaller sieve size in the standard concrete series, the pile is referred to as single-sized. The largest size that is typically found in appreciable quantities helps identify these aggregates. A heap designated as 20 mm size aggregate, for instance, indicates that it contains a significant quantity of aggregate with a maximum size of 20 mm.

A mixture of all sizes within a typical concrete series makes up graded aggregates. Well-graded aggregate is the result of proportioning these sizes to give a particular grading. When creating concrete, well-graded aggregates are desirable because the smaller particles fill up the voids left by the bigger particles, creating a tightly packed structure with less cement needed. For low-quality concreting, all-in aggregates, which combine fine and coarse materials, can be utilized directly. However, single-sized pebbles can be added to improve the quality of the concreting.

According to IS 383:1970, there are four grading zones for fine aggregates: Grading Zone I through Grading Zone IV. The fineness of each zone increases with time. Although the ratio of fine to coarse aggregate drops as fine aggregate gets finer from Zones I to IV, fine aggregates within each of these grading zones are adequate for producing concrete.

It is possible to grade coarse aggregates more differently than fine aggregates without appreciably compromising the concrete mix's workability, homogeneity, or finishing characteristics. IS-383:1970 states that single-sized or graded coarse aggregate grading limits must meet the requirements listed in Table 2 of the standard.

4.2.4 Calculating of Aggregate Content

Cement volume is equal to (cement mass / cement specific gravity) * (1/1000).
Cement volume equals (490 / 3.15) * (1/1000) = 0.156 m^3.
Water volume is calculated as (mass / specific gravity) * (1/1000).

Water volume is equal to 186 * (1/1000) = 0.186 m^3.
Volume of the entire aggregate is equal to 1 - (Volume of water + Volume of cement).
Total aggregate volume = 1-(0.156 + 0.186) = 0.658 m^3

4.2.5 Determining the Fine and Coarse Aggregate Proportions

According to IS 10262:2019, the volume of coarse aggregate suggested for 20 mm aggregate is 0.62 per unit volume of total aggregate.

4.2.6 Calculation the Volume of Coarse Aggregate

The coarse aggregate volume is equal to 0.62 * 0.658 = 0.408 m^3.
Coarse aggregate mass equals volume times specific gravity times 1000.
The coarse aggregate mass is equal to 0.408 * 2.74 * 1000 = 1118 kg.

4.2.7 Calculating the Volume of Fine Aggregate

Fine aggregate volume is equal to 0.658 - 0.408 = 0.250 m^3.
Fine aggregate mass is calculated as volume * specific gravity * 1000.
Fine aggregate mass is equal to 0.250 * 2.65 * 1000 = 663 kg.

Water content = 192kg

Total volume aggregate 0.658m^3

The coarse aggregate mass = 1118kg

Fine aggregate mass = 633kg

4.3 Experimental Set-up

4.3.1 Sample 1[RCC BEAM]

Flexural Strength of Reinforced Concrete Beam

The experimental program, which is focused on comparing the flexural conduct of RCC beams and is extracted using the DIC approach for random speckle pattern, is shown in figure 4.1. A comparative analysis is conducted between the conventionally measured moment and the distortion or curvature as ascertained by a random speckle design. While the RCC bars were being tested, the pictures were shot with appropriate equipment.
Beams where casted of measurement 500mm x 100mm x 100mm, after casting the bar they were cured in curing tank and the bars were tried for 28 days after concrete had attainted its quality. Sometime recently casting the 3d shapes, the 3d shape must be totally cleaned and oil-coated interior. Conventional water is utilized within the curing prepare. Whereas pillars amid casting are appeared in Fig. 4.2, bars some time recently putting them in curing tank are appeared in Fig. 4.**3.**

Fig 4.1 Experimental set-up

Fig 4.2 Beam during casting

Fig 4.3 Beam before curing

Fig 4.4 Speckle pattern on sample 1(RCC beam)

4.3.2 Sample 2 [I-SECTION]

Tensile Strength for I-Section mild steel plate

The figure 4.5 shows experimental program which is conducted on mild steel plate of I-Section. The tensile strength of an I-section mild steel plate is determined by both the material properties of the mild steel and the specific cross-sectional dimensions of the I-section. The ultimate tensile strength of mild steel usually ranges from 400 to 550 MPa with a yield strength around 250 MPa. To calculate the tensile strength, we consider an example I-section with a height of 61 cm, flange width of 10.5cm, flange thickness of 0.5 cm, and web thickness of 0.5 cm. The tensile force is applied on the I-section, after the load is applied displacement is caused in the web part of the section and when load of the steel plate break from the web part, data is collected and processed in GOM software to obtain the deformation and strain graph.

Fig 4.5 Experimental set-up of sample 2

4.4.3 Field Investigation Set-up:

The experimental setup shown in figure 4.6 was carried out on Shimla-Kalka Heritage Railway with single-track narrow-gauge track (0.762 gauge) near Kaithlighat. A mottled paint pattern was applied to a 60 cm long section of railway track. Equipment plays an important role in experiments. High-resolution digital cameras were strategically placed along the railway tracks to capture images of the area of interest. To ensure accuracy and stability, the camera is fixed on a robust tripod.

The experiment was conducted in the afternoon. The test was conducted on a specific part of the railway line by applying speckle pattern on the railway line and then the pattern gets changed and deformation such as displacement and strain are analysed by GOM Software.

Fig 4.6 Experimental set-up for field investigation

CHAPTER 5

RESULT AND DISCUSSION

5.1 General

This experimental program uses advanced measurement techniques such as digital image correlation (DIC) to study the structural behaviour and material properties of reinforced concrete beams (RCC), mild steel I-beams, and railway tracks. Experiments focused on evaluating the load-deflection response, crack propagation, defect detection, and strain distribution in these structural elements. The results of these tests provide valuable insight into failure mechanisms and displacement, strain distribution patterns, which can help improve structural analysis and design methods.

5.2 Results

This section presents the results and analysis of using Digital Image Correlation (DIC) to detect cracks and understand the strain distribution in Reinforced Cement Concrete (RCC) beams and I-section mild steel plates. DIC provides detailed strain maps, highlighting areas of tensile and compressive strains, and allows for early detection of crack initiation and propagation.

5.3 RCC Beam Results

Each beam's load-deflection responses are displayed, and it is clear that all beams have comparable beginning stiffness up to flexural crack development, at which time the response begins to stray from linearity. Stiffness diminishes with increasing deflection. Test results showed a sharp decline in load, which suggested a brittle failure that had no more ductility or residual strength beyond the peak load. This breakdown happened right after the beam split into two separate sections due to the start of a diagonal crack. The diagonal crack quickly spread to the loading plate, down to the top layer of the tension reinforcement, and continued as a horizontal crack toward the end of the beam, which is what caused the abrupt failure.

5.3.1 Flexural Strength Performed on RCC beam

Fig 5.1 Before testing

Fig 5.2 After testing

5.3.2 Crack Progression

An example of the longitudinal strain fields obtained from the beam using the proposed DIC (Digital Image Correlation) system is presented, with a consistent colour range across all plots to enable direct comparison, to provide a clearer understanding of the behaviour of the beam during testing (as shown in Figure 5.2). Six loading phases were chosen, including the peak load, two load levels during the post-yielding response, and three load levels during the post-cracking response prior to the tensile reinforcement yielding. Figures 5.3 and 5.4 show the longitudinal strain fields of Beam B2, which can be used to monitor the formation of cracks at different loading stages.

Flexural cracking is first seen in the longitudinal strain field, for example, near the bottom of the web region where vertical strips of high strain are separated between 0.5d and 0.75d. Alongside the flexural fractures over the centre span, pre-existing diagonal cracks continue to open as the load increases. Premature shear failure finally happens because of insufficient anchorage of the stirrups close to the load point into the upper half of the diagonal crack region. All things considered; the outcomes amply illustrate the system's potential for crack mapping.

5.3.3 Visualization of Defect Detection Results on RCC beam

Heatmaps overlaid on the original images to visually highlight regions identified as defects by the image processing algorithms.Color-coded overlays indicating the severity or type of defect detected, providing a clear visual representation of the detected anomalies. Heatmaps generated from defect probability maps, showcasing the likelihood of defects across the surface RCC Beam samples. Gradient colour scales representing the intensity of defect presence, with warmer colours indicating higher probabilities of defect occurrence.

Compressive strains near supports and load application points can lead to shear cracks.

Compressive strains are observed at the top of the beams where the material is being compressed. DIC strain maps provide a clear view of these compressive regions, showing how the compressive forces are distributed along the length of the beam.

DIC is highly effective in detecting early crack formation and propagation. The strain maps reveal strain concentrations at the tips of developing cracks, allowing for early detection and preventive measures.

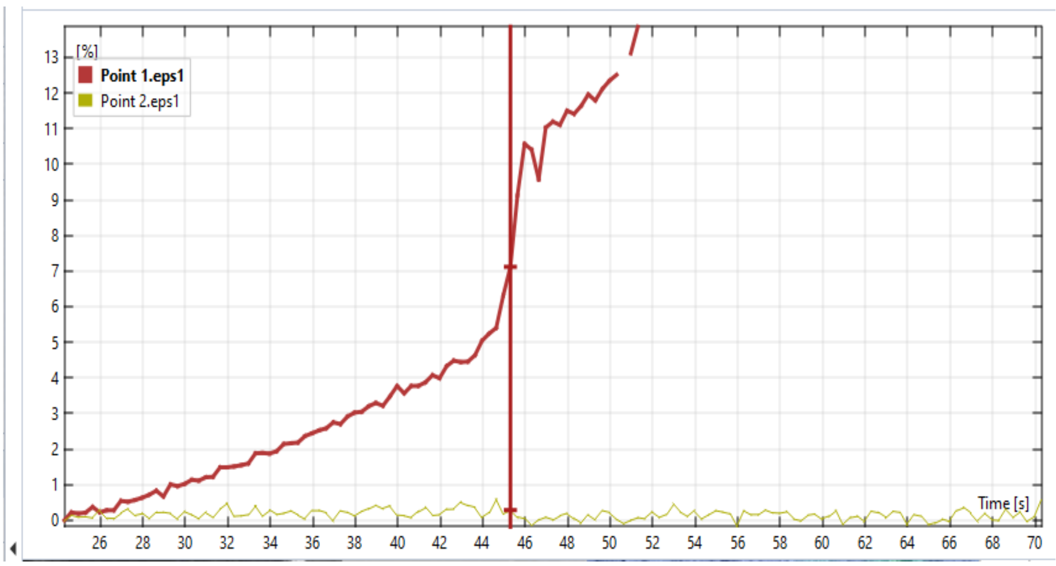

Fig 5.3 Graph represent major Strain of Sample 1

The figure 5.3 shows graph with two lines, "Point 1 exp1" and "Point 2 exp1". These likely represent the stress or strain measurements taken at two different points on the material under test during the experiment.

X-Axis (Time): The horizontal axis represents time, indicating the progression of the test.

Y-Axis (Surface Component 1): The vertical axis represents the magnitude of deformation (probably strain) measured as a percentage.

Red Curve: The red curve (Point 1 exp1) shows a sharp increase at this point at 51.2 sec, which indicates a significant change in the material's response which is 12.5%, likely corresponding to yielding or fracture point of the material, when load of 54 kN is applied.

Yellow Curve: The yellow curve (Point 2 exp1) remains relatively flat, suggesting that the deformation or stress at this point is minimal which is about 0.2%-0.7% or not significantly changing during the same period.

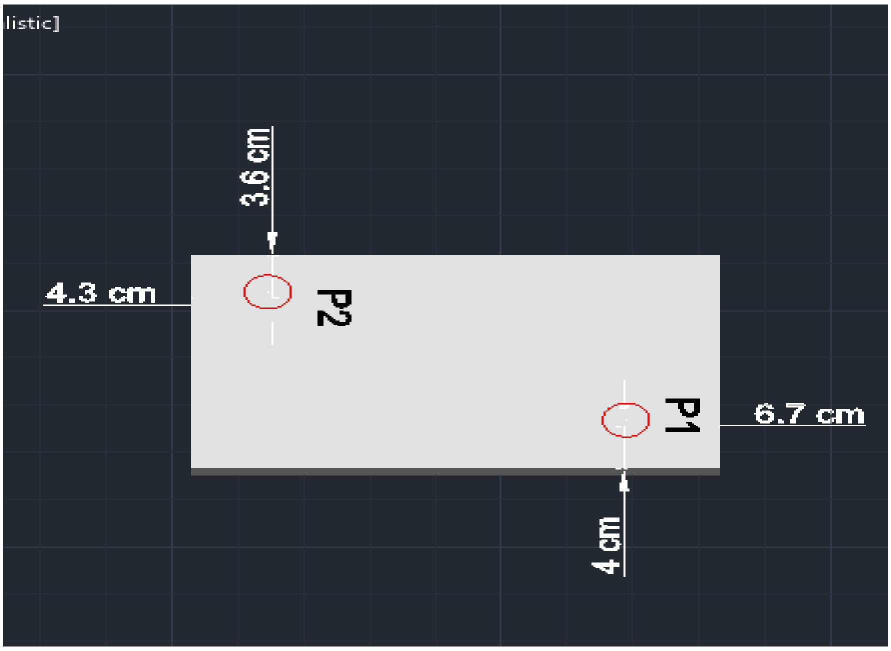

Fig 5.4 AutoCAD drawing of sample 1

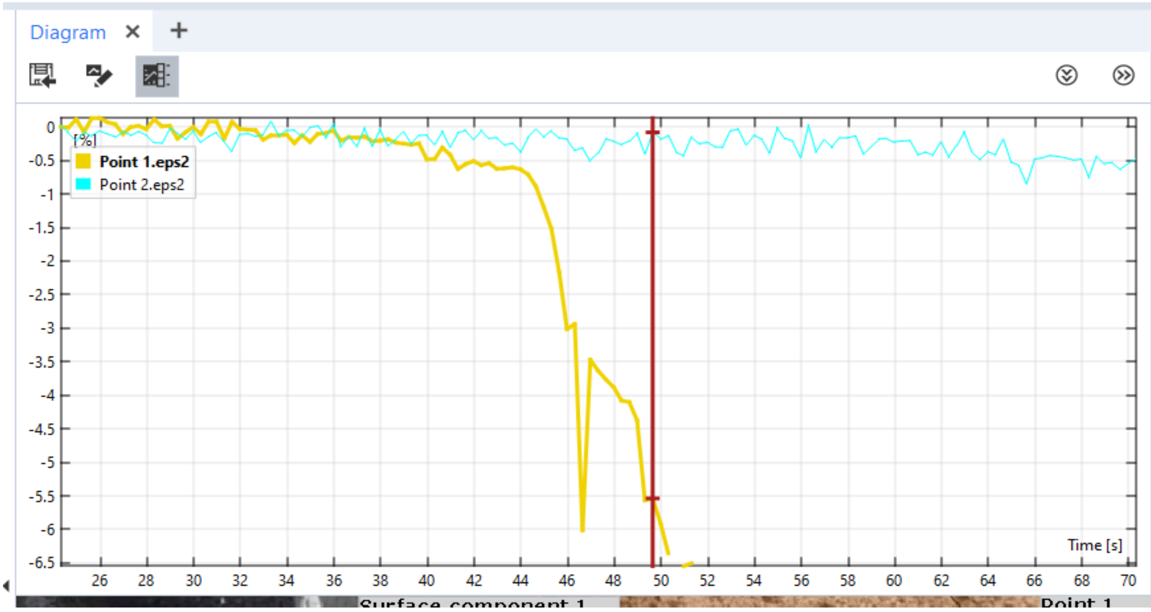

Fig 5.5 Graph represents minor strain of Sample 1

The figure 5.4 shows graph with two lines, "Point 1 exp1" and "Point 2 exp1". These likely represent the stress or strain measurements taken at two different points on the material under test during the experiment.

X-Axis (Time): The horizontal axis represents the duration of the test.

Y-Axis (Surface Component 1): The vertical axis shows deformation measurements, likely strain, in percentage.

Yellow Curve (Point 1 exp2): This curve initially remains relatively stable at 43.75 sec with minor strain ranging from 0% to -0.55% but then drops sharply at 44 sec with minor strain ranging from -0.56 to -6, indicating a significant negative deformation (likely compressive strain or a structural failure).

Blue Curve (Point 2 exp2): This curve fluctuates slightly between 0% to -0.5% but generally stays near zero, suggesting that the deformation at this point remains minimal throughout the test.

Point 1: The location on the material where the significant drop in the yellow curve is measured, likely correlating with a region of high compressive strain or structural failure.

Point 2: A location where minimal deformation is measured, correlating with the stable blue curve.

The sharp drop in the yellow curve (Point 1 exp2) suggests a catastrophic failure or significant compression at that specific point on the material when load of 54 kN is applied. The presence of visible cracks in the material reinforces the indication that the material has failed under the applied stress.

5.4 I-Section Mild Steel Plate

5.4.1 Tensile Strength Performed on I-section Steel plate

Strain maps generated by DIC highlight areas of high stress concentration, particularly at the junctions between the flange and the web of the I-beam. These areas are prone to higher tensile strains due to geometric discontinuities.

High-resolution images of the I-section mild steel samples were captured using a digital camera setup under controlled lighting conditions. The images depicted various surface defects such as cracks, corrosion, and surface irregularities. The acquired images underwent pre-processing techniques to enhance contrast, reduce noise, and improve image quality. This step was essential for enhancing the effectiveness of subsequent image processing algorithms. Segmentation algorithms were applied to isolate regions of interest corresponding to potential defects in the mild steel samples. The results of defect detection and characterization were visualized through images and graphical representations. Heatmaps highlighting detected defects, along with statistical summaries of defect attributes, were presented to facilitate interpretation and analysis.

5.4.2 Crack Detection

This section focuses on the use of DIC to detect cracks in I-section mild steel plates. DIC operates by capturing images of a speckle pattern applied to the surface of the steel plate at various load stages. By analysing the displacement of the speckles between images, DIC

software generates detailed strain maps that reveal areas of high stress and strain where cracks are likely to initiate and propagate. Images are captured at each load increment to document the deformation and strain distribution. The images are DIC software is utilized to generate full-field strain maps after processing, highlighting areas of high stress concentration and potential crack initiation. The strain maps generated by DIC highlight areas of high stress concentration, particularly at the junctions between the flange and web of the I-beam. These regions are critical as they experience higher stresses due to geometric discontinuities. The strain maps show significant strain gradients, indicating potential sites for crack initiation

5.4.3 Visualization of Defect Detection Results

Heatmaps overlaid on the original images to visually highlight regions identified as defects by the image processing algorithms.Color-coded overlays indicating the severity or type of defect detected, providing a clear visual representation of the detected anomalies. Heatmaps generated from defect probability maps, showcasing the likelihood of defects across the surface of I-Section samples. Gradient colour scales representing the intensity of defect presence, with warmer colours indicating higher probabilities of defect occurrence

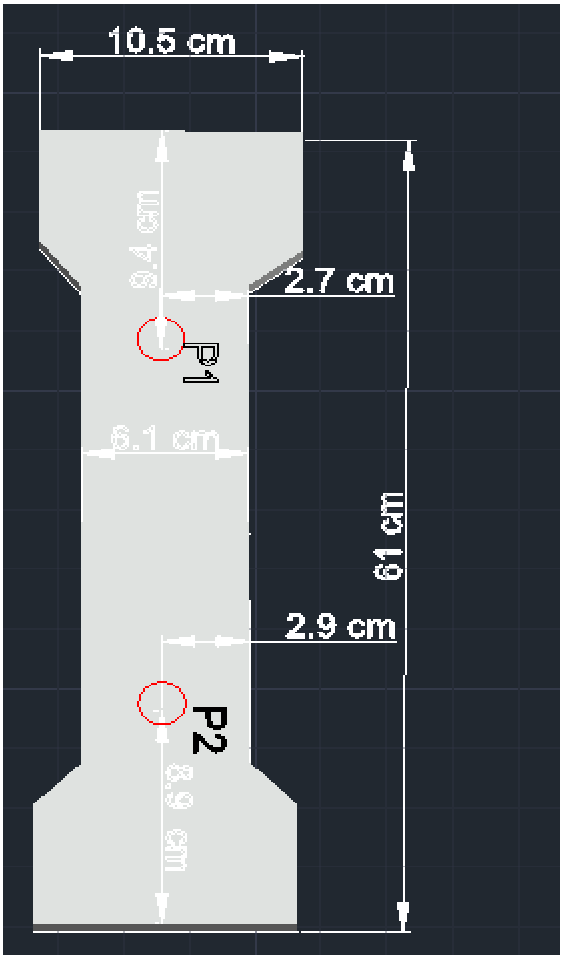

Fig 5.6 AutoCAD drawing for Sample 2 (top view)

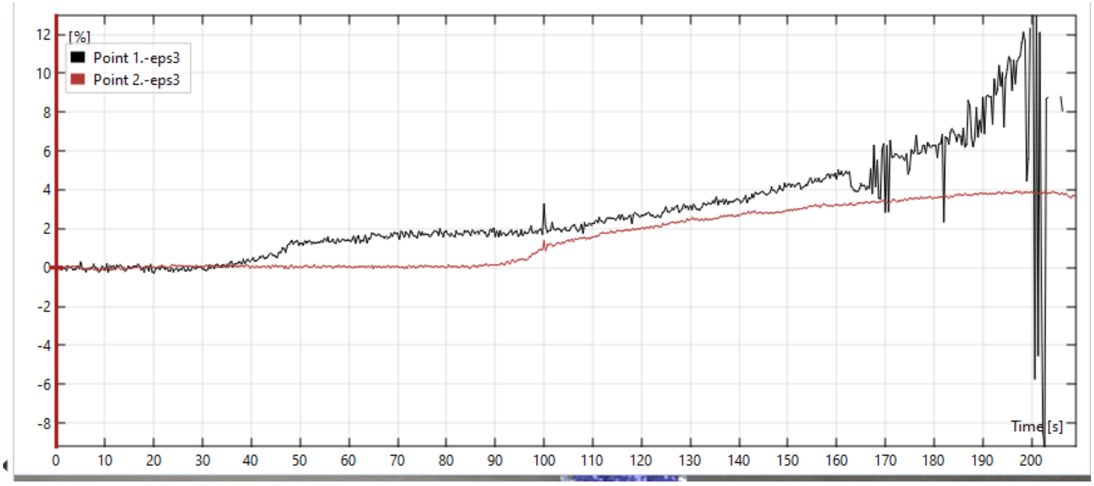

Fig 5.7 Thickness reduction graph of sample 2

The above figure 5.5 shows the thickness reduction graph of I-Section (Sample 2)

X-Axis (Time): The horizontal axis represents the time duration of the experiment.

Y-Axis (% Deformation): The vertical axis shows the percentage of deformation, which is a measure of strain on the material.

Black Curve (Point 1 - exp3): This curve shows a gradual increase in deformation over time from 0 sec to 200 sec with several fluctuations and a sharp rise towards the end at 200 sec, indicating significant deformation of 12% and failure at the end of the test,when load of 121 Kn is applied

Red Curve (Point 2 - exp3): This curve remains relatively flat with a slight increase from 0 sec – 200 sec , indicating minimal deformation of 2%- 4% at the second point throughout the test,when load of 121 kN is applied.

Point 1: This point corresponds to the black curve in the graph. The sharp rise towards the end suggests that this is where significant deformation or failure occurred.

Point 2: This point corresponds to the red curve, showing minimal deformation, indicating a region of the material that experienced less strain.

The black curve's gradual rise followed by a sharp increase suggests that the material experienced initial elastic deformation followed by plastic deformation or failure.The flat nature of the red curve indicates that deformation at Point 2 was negligible, suggesting it might be located in a less stressed region of the material.

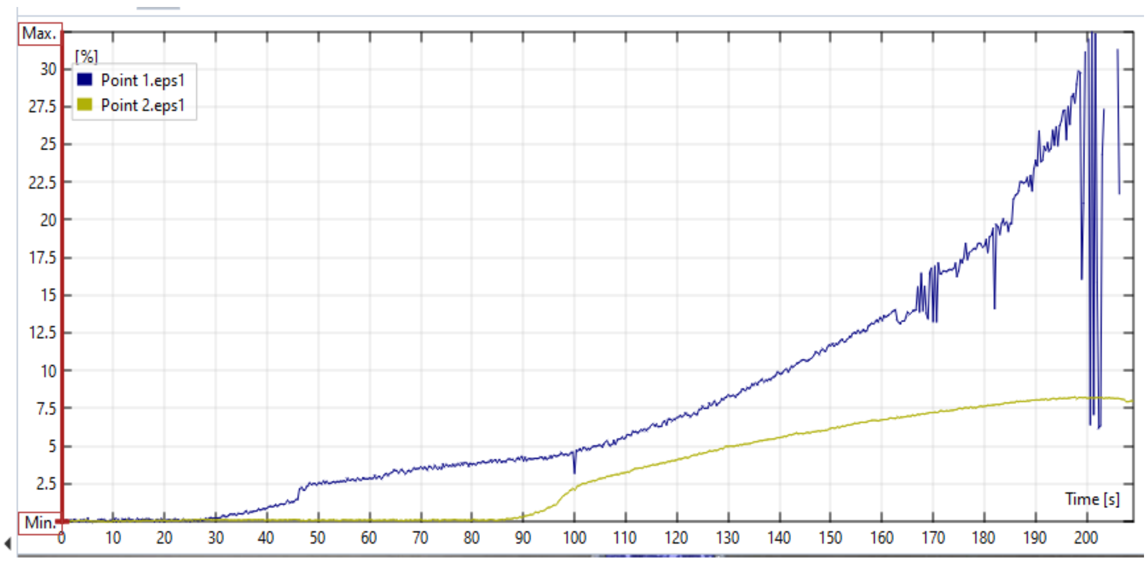

Fig 5.8 Major Strain graph of sample 2

The figure 5.6 appears to depict a stress-strain curve from a mechanical testing experiment, likely a tensile test

Horizontal Axis (Time [s]): The horizontal axis represents time in seconds, indicating the duration of the tensile test.

Vertical Axis (Stress [%]): The vertical axis represents stress in percentage, which is likely the engineering stress or load applied to the material as a function of time.

Point 1.ep1: This curve (likely in blue) shows the primary stress response of the material over time. It starts with a linear region where stress increases gradually with time from 0 sec to 162 sec, indicating elastic deformation of 13.5%. As time progresses, the curve shows non-linear behaviour from 162 sec- 199 sec, indicating plastic deformation of 28%. The sharp rise towards the end from 200 sec-205 sec could signify necking followed by fracture.

Point 2.eps1: This curve (likely in yellow) might represent another parameter related to the material's behaviour which is strain remaining linear throughout the time, having strain from 0%-7.5%.

The initial linear portion of the curve represents the elastic region where stress and strain are proportional. The point where the curve starts deviating from linearity, indicating the yield point where permanent deformation begins. The non-linear portion following the yield point represents plastic deformation. Tensile Strength: The peak of the curve signifies the maximum stress the material can withstand before failure. The sudden drop after the peak indicates the fracture point where the material fails.

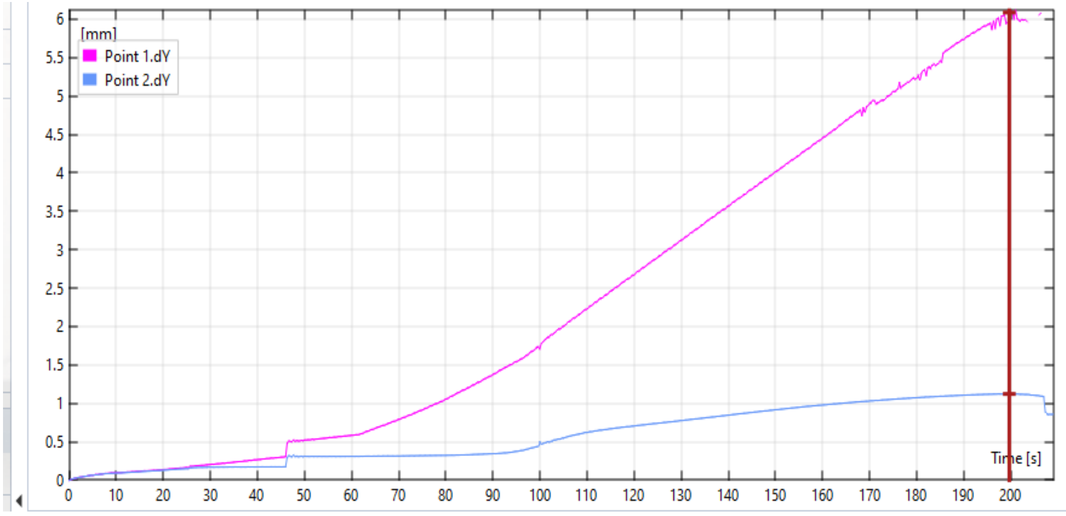

Fig 5.9 Displacement graph along y-axis

The figure 5.7 shows graph which depicts the deformation behaviour of a material during a tensile test, focusing on the displacement of two specific points on the specimen.

Horizontal Axis (Time [s]): The horizontal axis represents time in seconds, indicating the duration of the tensile test.

Vertical Axis (Displacement [mm]): The vertical axis represents displacement in millimetres, showing how much the points on the specimen have moved during the test.

Point 1. dy: This curve (likely in magenta) shows the displacement of a specific point on the specimen over time. It starts with a gradual increase from 46 sec-167 sec indicating initial elastic deformation of 0.5%-4.85%, and then shows a more rapid increase from 167sec to 198 sec, as plastic deformation of 4.9%-5.8%. The sharp rise towards the end at 200 sec indicates significant deformation of 6% leading to the ultimate failure of the specimen.

Point 2. dy: This curve (likely in blue) shows the displacement of another point on the specimen. It increases more slowly from 0 sec – 200 sec, indicating that this point is experiencing less deformation i.e, 0%-1.2% compared to Point 1.

The initial part of the curve shows a gradual increase in displacement, indicating elastic deformation where the material stretches but can still return to its original shape.

The part of the curve where the displacement increases more rapidly indicates plastic deformation, where the material deforms permanently. The sudden drop or levelling off at the end of the magenta curve indicates the point at which the material has failed or fractured.

5.4.5 Validation of sample 2 results

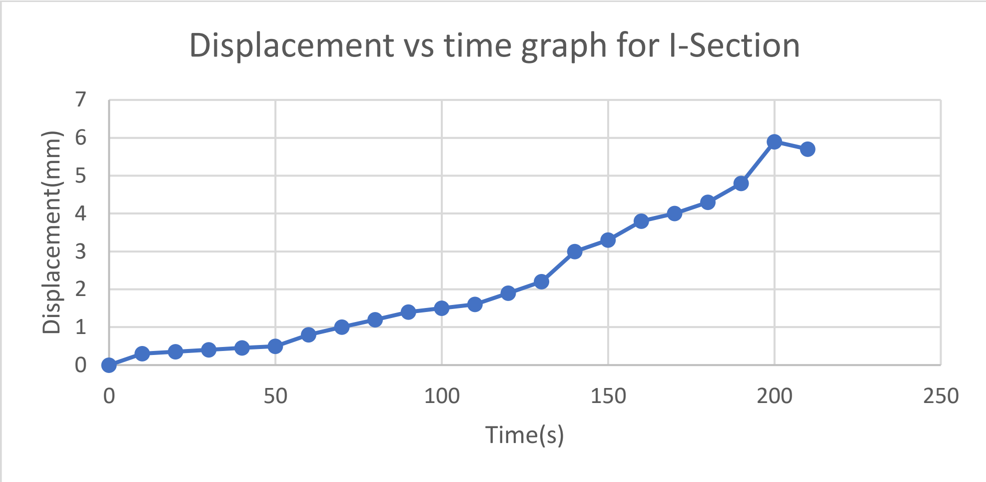

Fig 5.10 UTM machine Graph for displacement vs load of Sample 2 (point 1)

Above graph in figure 5.8 validates the result for point 1 that is obtain from GOM Software.

%error = [(Estimated No-Actual No)/Actual no]X100

Estimated value = 6mm

Actual value = 5.8

Therefore, %error (0.2x100)/100

%error = 3.33%

When validating GOM Software results with standard results obtained from a Universal Testing Machine (UTM), it was found that the results were consistent, showing a minimal percentage error. Specifically, the error margin was only 3.33%.

5.5 Field Investigation of Shimla-Kalka Heritage Railway line

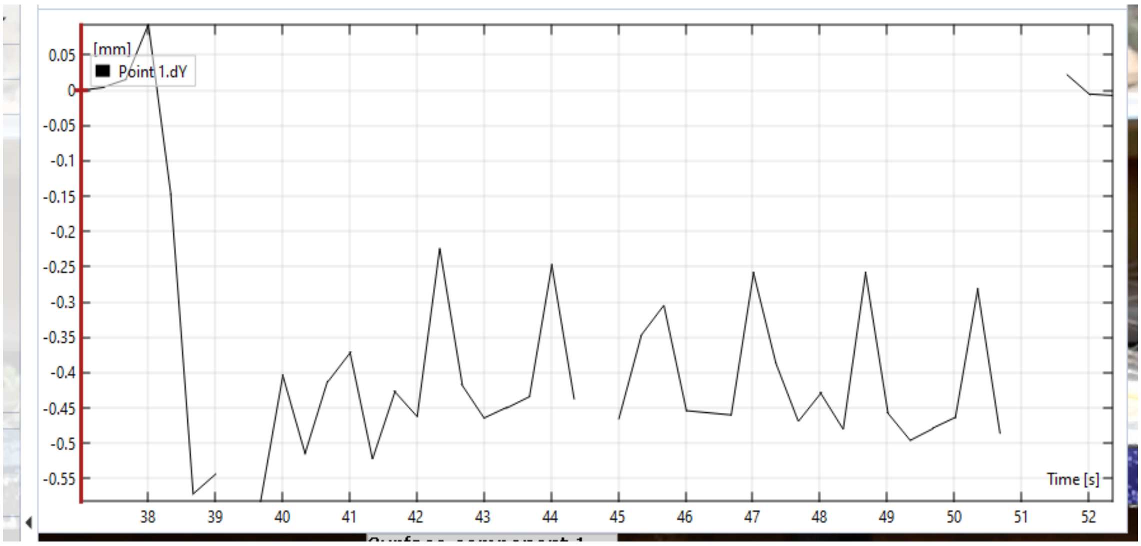

Fig 5.11 Displacement along y-axis of field experiment

The graph in figure 5.9 shows the image appears to depict the vertical displacement (dy) of a surface component over a short period of time

Horizontal Axis (Time [s]): The horizontal axis represents time in seconds, indicating the duration of the observation or test.

Vertical Axis (Displacement [mm]): The vertical axis represents the vertical displacement in millimetres, showing how much the surface component has moved up or down during the test.

The curve labelled "Point 1.dy" shows the vertical displacement of a specific point on the surface component over time. The data reveals a series of peaks and troughs, indicating periodic or oscillatory motion, indicating the -0.3% displacement caused.

The initial steep drop in the curve indicates a sudden displacement downward, which could be due to an initial impact or load being applied. The subsequent pattern of peaks and troughs indicates cyclic motion, suggesting that the surface component is experiencing oscillations or vibrations. Each peak represents each trough denotes a maximum displacement downhill and each peak, a maximum upward displacement. Toward the graph's conclusion, the oscillations appear to stabilize or decrease in amplitude, indicating that the motion might be dampening over time.

Here each peak also represent loading that is count for number of bogies in train having weight of 5.125 ton as per Indian railway. So here there are seven peaks representing seven bogies of the train.

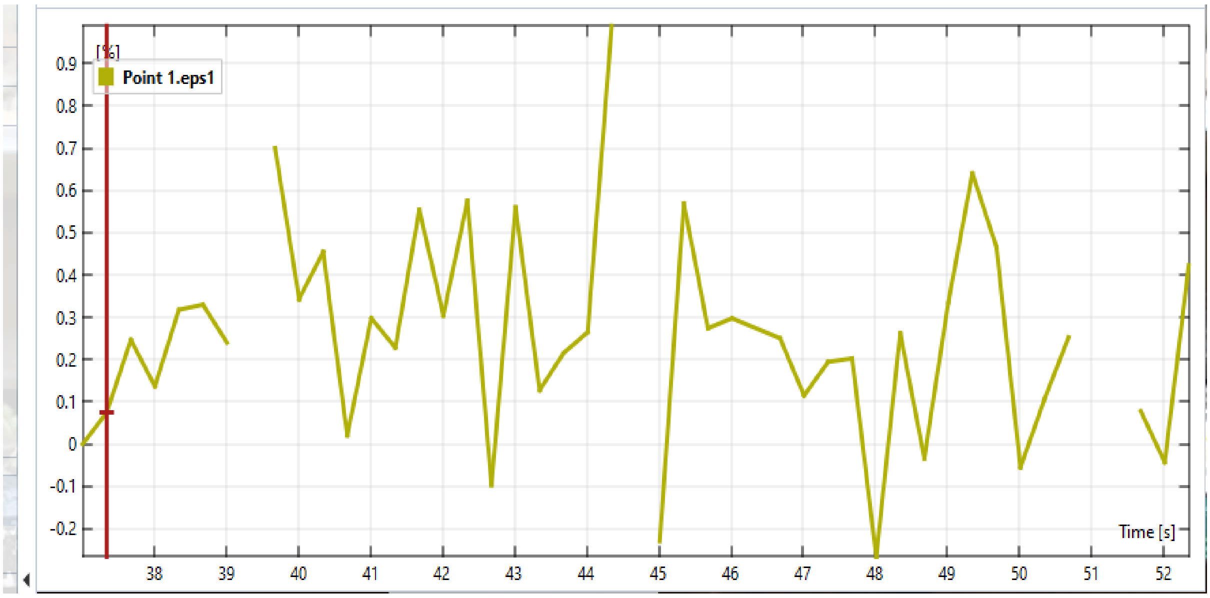

Fig 5.12 Graph of Major Starin of field experiment

The graph in figure 5.10 depicts the image appears to represent some form of measurement over time or distance

The x-axis is labelled "Time [s]" indicating that the data points on the graph are measured over a period in seconds.

The y-axis is labelled with "Surface component 1 eps1" with values ranging approximately from -0.3 to 0.6, suggesting that it might represent a specific parameter of the rail surface, possibly strain, displacement, or another form of deformation or measurement.

The yellow line indicates the recorded data points for "Point 1eps1". This could represent the deformation, strain, or another relevant metric at a specific point on the rail.

The fluctuating nature of the graph indicates variability in the measured parameter over the time of approximately 37 to 52 seconds.

CHAPTER 6

CONCLUSION

6.1 General

This study demonstrates the effectiveness of Digital Image Correlation (DIC) in detecting defects and analysing strain distribution in various materials and structures. For RCC beams, the use of heatmaps and color-coded overlays provides clear visualization of defect regions and the intensity of defect presence, while DIC strain maps reveal the distribution of compressive strains, crucial for identifying shear cracks. In I-section mild steel plates, strain maps highlight areas of high stress concentration, particularly at junctions, which are critical for understanding potential crack initiation. High-resolution imaging and segmentation algorithms enhance defect detection, offering detailed insights into surface defects such as cracks and corrosion. Additionally, the application of DIC in monitoring the deflection and strain of the Kalka-Shimla heritage railway track before and after train movement showcases the practical utility of these techniques in real-world scenarios. Overall, the integration of DIC and visualization tools proves invaluable for early defect detection, structural monitoring, and preventive maintenance, thereby enhancing the safety and longevity of infrastructure components. After comparing the outcomes from software and traditional techniques, the following conclusions can be made:

- A straightforward, inexpensive DIC system is presented and demonstrated to offer a thorough understanding of the concrete deformation process in an I-Section and reinforced concrete beam.
- The DIC values come closer to conventional measures the more random the speckle pattern is.

- DIC Method allows real time monitoring of the structure as compared to conventional method.

6.2 Limitations

Structural monitoring uses Digital Image Correlation (DIC), a potent optical technique.

to measure deformation, strain, and displacement on the surface of structures. While DIC offers several advantages such as non-contact measurement, high spatial resolution, and full-field data acquisition, it also has several limitations:

- Surface Preparation: DIC requires a speckle pattern on the surface being monitored. Preparing this pattern can be time-consuming and may not be feasible in all environments, particularly for large structures or those with irregular surfaces.

- Environmental Sensitivity: DIC is highly sensitive to environmental conditions. Factors such as lighting changes, temperature fluctuations, and vibrations can affect the accuracy and reliability of measurements. Outdoor applications can be particularly challenging due to varying light and weather conditions.

- Field of View and Resolution Trade-off: There is an inherent trade-off between the field of view and the spatial resolution in DIC. Capturing large areas requires lower magnification, which reduces the resolution of the measurements. Conversely, achieving high resolution limits the area that can be observed.

- Complexity of Setup: The DIC setup can be complex and requires precise calibration. Ensuring the correct alignment and calibration of cameras and lenses is critical for accurate measurements, which can be challenging and time-consuming.

- Data Processing and Computational Load: DIC generates large amounts of data, especially when monitoring large structures or performing high-speed measurements. Processing this data requires significant computational resources and sophisticated software, which can be a limitation for real-time monitoring.

6.3 Future Scope:

- Advancements in processing speed and algorithms may enable real-time DIC monitoring of civil structures

- The future of DIC in civil structure monitoring may involve the use of higher resolution imaging systems. This can provide more detailed information about structural deformations and behaviour, allowing for more accurate analysis and assessment.
- DIC can be integrated with Internet of Things devices and sensor networks to create a comprehensive structural health monitoring system
- DIC, when combined with predictive modelling and simulation, could be used to predict the long-term performance of civil structures. This would assist in making informed decisions about maintenance, repair, or retrofitting strategies.
- Future DIC applications may involve multi-modal imaging, combining different imaging techniques (such as infrared or 3D imaging) to gather more comprehensive data about a structure's behaviour under varying conditions

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