Development of Strain Measuring Instrument for Health Monitoring of Structural Members

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***Abstract** - A strain gauge is a device used to measure the strain of an object, Main purpose of this project is to measure or monitor the continuous deformation of RCC columns and beam during construction. A new modal of mechanical strain gauges is developed for structural/ construction engineering concept. The tensile strength of steel bar is observed in the laboratory test up to 150 kN Theoretical calculations are done by using the stress and strain formulas. The scope of project is to check behaviour of the column/ beam (or) structural members with in the elastic limit. The connecting rods are welded in the main reinforcement bar of columns and beam by spacing of gauge length 200 mm. After concreting the strain gauges are fixed by setting the strain indicator at zero using slip gauges. Then monitoring the structural members regularly and compared with the calibration reading observed at universal testing machine for strain calculations. We can monitor the building throughout its life span using mechanical strain gauges by this project concept.*

Keywords: Strain gauge, RCC column & beam, monitoring, strain

I. INTRODUCTION

Any device that is used to measure surface deformation can be known as a strain gauge. Main purpose of experiment is to measure strain readings and stress due to loading by using mechanical strain gauges. The stress-strain relation represents the overall behaviour of concrete & steel in tension and compression loads. And also, application of strain gauges in various structural member are reported in this project.

1.1 HEALTH MONITORING OF STRUCTURES

The health monitoring of engineered structures concept is widely valid to greater period of construction of various infrastructure like skyscrapers and bridges also. Especially when damages to the structural members are concerned, it is important to note that there are stages that require the knowledge of previous stages.

- Identification of damage on structures
- Location of column and beam
- Drilling the concrete (For old Structures)
- Welding the Connecting rods on main bars
- Fixing the gauge
- Monitoring the strain readings
- Comparing to laboratory calibration readings
- Validation for increasing or decreasing the floors.

1.2. MECHANICAL STRAIN GAUGE

It is a simple instrument used to measure strain on an object, as it deformed due to external applied force. It comprises of gauge points with three holes on each side of the gauge to fit the instrument to the projection of rods (connected with in the structural members).The displacement caused by the external force in the member is magnified and indicated in the dial indicator with a least count of 0.01 mm.

Change in length of test specimen is magnified using mechanical devices. Used for static strain and point of measurement is accessible for visual observation. It is employed for measuring small deformations under linear strain conditions over gauge lengths up to 200 mm approximately.

Fig -1: Mechanical Strain Gauge

2. OBJECTIVE

- To monitor the continuous deformation of existing/ during construction of new R.C.C columns and beams.

- To develop a new strain measuring instrument to monitor the movement of structural component.
- To check the existing structure about its behaviour, structural integrity with respect to load carrying capacity.
- Monitor the health of RCC column throughout its life span.

3. METHODOLOGY

- Collection of literature
- Identification of research topic
- Fabrication of mechanical strain measuring equipment
- Taking measurement on structures during new construction (Health monitoring)
- Taking Laboratory tests on specimens
- Theoretical calculation of load carrying capacity of structural member
- Validation of strain measurements with reference to load carrying capacity of structural members
- Result & Conclusion

4. LITERATURE REVIEW

4.1 OVERVIEW

- **Modelling &experimental testing of strain gauges in operational mode:**
  Brent L. Ellis & Smith (Jan 2011)

Strain gauges are resistive sensors bonded at critical locations on the surface of structural components to detect surface deformation and, thus, measure mechanical stress. However, strain gauges do not always report expected measurements, even under normal operating conditions. The primary goals of this paper were to develop predictive models for strain-gauge behaviour and experimentally test them under controlled laboratory settings. A testing station was developed that generated a mechanical motion on a beam, subjecting strain gauges to a varying strain. Predictive models of the testing station were developed and experimentally analysed. Models were also developed for two particular failure modes, namely, deboning and wire lead termination. For the cases studied, the models over predict the output of a strain gauge operating under normal conditions, which is a discrepancy that can be explained by the gauge modifying the surface properties of the test component.

- **A Study on measuring rail contact points for wheel load &lateral force by strain gauges on disk surface:**
  T.Fujioka, H.Kanchara (1999)

It is interesting and worthwhile to study on method of measuring rail/wheel contact point and contact force of running railway vehicles, since many things in real rail/wheel contact phenomenon are still unknown, in this paper, the Japanese conventional method of measuring vertical load and lateral force is introduced. The strain of the disk surface is used for measuring forces. A new method, which detects the contact point as well as vertical load and lateral force, is proposed also in this paper. The location of an area where lateral force affects little on surface strain is investigated, since the lateral distribution of strain should be measured in such an area to avoid the interference of bending by lateral force. And finally, theory for the measurement is modified for on-track testing and the best position and direction for strain gauges is proposed in accordance with the calculated and experimental results.

- **Design of strain gauge structures (cantilever):**
  A.Husak, P.Kulha (1986)

The paper describes the design of a strain gauge on a cantilever with implanted layers. In the paper, the physical model of implanted strain gauges is characterized and basic technological steps are described. A suitable electric bridge connection of the structure for evaluation of electric parameters of strain gauges at mechanic deformation and different temperatures has been designed. On realized structures, basic parameters have been measured such as the dependence of electric parameters of strain gauges on mechanical deformation, temperature dependence at different mechanical load, temperature stability of output parameters, and temperature dependence of PN junctions in the structure. From the measured data, piezoresistive coefficients of deformation sensitivity, linearity, hysteresis, temperature coefficients of resistance, etc. have been calculated. The measured characteristics show very good linearity, small hysteresis and very good sensitivity.

- **Stress-Strain Relationship for Reinforced Concrete in Tension:**
  Domingo J. Carreira (1986)

Stress-strain relationship to represent the overall behaviour of rein-forced concrete in tension, which includes the combined effects of cracking and slippage at cracks along the reinforcement is proposed. The curve used for the compression stress-strain relationship is also used in tension with parameters that are physically significant. These parameters can be determined experimentally from reinforced concrete prismatic specimens or estimated from pro-posed empirical relationships. The effects of the testing procedures, gage length, shrinkage, reinforcement, test specimen characteristics, cracking, and concrete strength and extensibility on the stress-strain diagrams for plain and reinforced concrete in tension are discussed. The tensile strength of concrete specimens allowed to dry prior to testing is lower than that of test specimens kept saturated. Drying shrinkage provides sources of crack growth in preference to those of the tensile stresses produced by externally applied loads. The test results and their reproducibility are affected by size, shape, and reinforcement of a tensile specimen; the gage length; the strain rate; and the strain and stress measuring devices. Gage length needs to be long enough to include the effect of several primary crack systems and far enough from the specimen ends to avoid the effect of reinforcement slippage at the ends of the specimen. The gage line should be at least one development length from the ends of the specimen.

- **Strain gauge validation of FEA of mandibular implant:**
  L.F.Monaheng, P.Haupt

The approach followed was to demonstrate the correlation between an FEA modal and strain gauge measurements performed on a human mandibular implant. For the design of implant the geometrical representation of a mandible obtained from a computerized tomography scan was used. This modal was then submitted to FEA when subjected to typical static load conditions. Through this simulation the distribution of strain in the implant was determined. Using the same modal, an implant was manufactured through strain gauges were mounted on the implant locations corresponding to the areas of highest strain as determined on the FEA modal. The results obtained from both FEA and strain gauge measurements are presented in this paper and a correlation within an error margin of less than ten percentage for most of the gauge was obtained.

4.2. SUMMARY OF LITERATURE

- The strain of a structural element is often measured indirectly by determining the deformation of element around the mounting point.
- The triaxial state of stress and strain using strain gauge glued on plane surface.
- A strain gauge is known to produce applied loading to measure the force, displacement, and vibration.
- The results obtained from strain measurements are correlation within an error of <10% for most of the gauge.

5. APPARATUS

- Mechanical Strain gauges
- Dial /strain indicator
- Connecting rods
- Specimen bars

6. STRAIN FORMULA

The strain measurement based on the strength of material approach for the structural member.

- The ratio of the change in dimension to the original dimension caused by the external applied force.

$\varepsilon = \Delta L / L$

Where,

ε = strain

ΔL = change in length

L = original length

7. LABORATORY TESTS

7.1. ULTIMATE TEST OF SPECIMEN

OBSERVATION

- Ultimate load = 219.80 kN
- Yield load = 198 kN
- Breaking load = 165 kN
- Final neck diameter = 17 kN
- Final gauge length = 660 kN

RESULT

1) Yield stress = 6.19 N/mm^2
2) Ultimate stress = 6.87 N/mm^2
3) Nominal breaking stress = 5.155 N/mm^2
4) Actual breaking stress = 95.21 N/mm^2
5) Percentage of elongation = 10%
6) Percentage of reduction in c/s area = 5.41%

7.2. TENSILE TEST 2

FOR 20mm ROD WITH STRAIN GAUGE

Fig -2: Rod connected with Strain Gauge in UTM

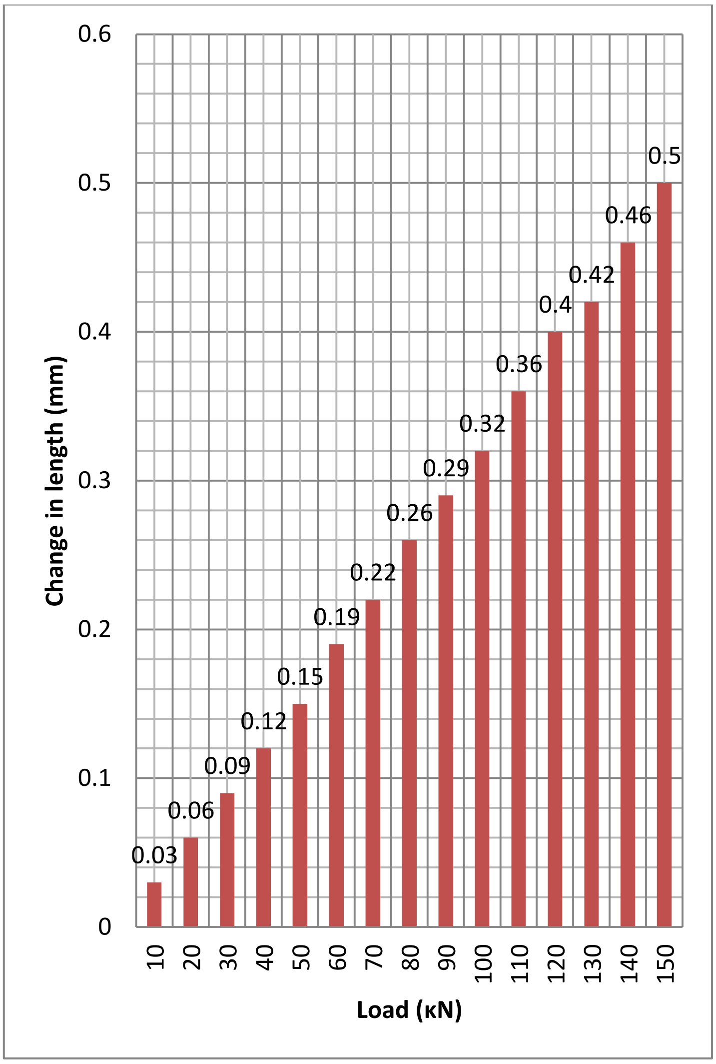
CALCULATION AND RESULTS

The average of sample / trial and gauge length are noted in **mm**.

Load (kN)	avg of sample 1,2,&3(ΔL)	Gauge length (L)	Ɛ=ΔL/L
10	0.03	200	0.00015
20	0.06	200	0.0003
30	0.09	200	0.00045
40	0.12	200	0.0006
50	0.15	200	0.00075
60	0.19	200	0.00095
70	0.22	200	0.0011
80	0.26	200	0.0013
90	0.29	200	0.00145
100	0.32	200	0.0016
110	0.36	200	0.0018
120	0.4	200	0.002
130	0.42	200	0.0021
140	0.46	200	0.0023
150	0.5	200	0.0025

Table -1: Laboratory Strain Readings of 20 mm Rod

7.3. GRAPH OF CALIBRATION STRAIN READINGS



Graph -1: Calibration Graph

8. READINGS OBSERVED AT CONSTRUCTION SITE

Table -2: Average Strain Values of Structural Members

Structural Member	Change in length, ΔL (mm)	Load(kN)	Gauge length, L(mm)	ε = ΔL /L
Column 1	0.03	10	200	0.00015
Column 2	0.045	15	200	0.000225
Beam	0.06	20	200	0.0003

Fig -3: Gauge Distance at Main Reinforcement Bar

Fig -4: Regular Monitoring using Strain Gauge

9. RESULT & CONCLUSION

The calibration readings are compared with theoretical strain values. Highest load observed in structural members are 20kN, change in length up to 0.006mm. The maximum strain value obtained is 0.0003. The range value of change in length for column and beam should be <1.5mm. Hence the structural members are safe and having required strength.

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