Experimental Stress Analysis

By

Prof. K. Ramesh
Department of Applied Mechanics, IIT Madras.

Course Outline The course covers the basic aspects of experimental stress analysis that includes exhaustive treatment of the most versatile techniques like photoelasticity and strain gauges and also a brief introduction to the emerging techniques like digital image correlation. In addition it also provides the fundamental aspects of six different experimental techniques such as Moiré, Brittle Coatings, Holography, Speckle Methods, Thermoelastic Stress Analysis and Caustics.

Prerequisite Strength of Materials

Text/References

1. K. Ramesh, e-Book on Experimental Stress Analysis, IIT Madras, 2009. URL: http://apm.iitm.ac.in/smlab/kramesh/book_5.htm
2. K. Ramesh, Digital Photoelasticity – Advanced Techniques and Applications, Springer, 2000.
3. W.N. Sharpe (Ed.), Springer Handbook of Experimental Solid Mechanics, Springer, 2008
4. J.W. Dally and W.F. Riley, Experimental Stress Analysis, McGraw-Hill, 1991
5. L.S. Srinath, M.R. Raghavan, K. Lingaiah, G. Gargesa, B. Pant, and K. Ramachandra, Experimental Stress Analysis, Tata Mc Graw Hill, 1984.

Suggested Additional Reading

Articles from the journals: Experimental Techniques, Experimental Mechanics, Strain, Journal of Strain Analysis for Engineering Design and Optics and Lasers in Engineering etc.

Course Organisation

Modules	Title	Lectures
Module -1	Overview of Experimental Stress Analysis	10
Module -2	Transmission Photoelasticity	13
Module -3	Introduction to Three Dimensional Photoelasticity and Digital Photoelasticity	2
Module -4	Photoelastic Coatings and Brittle Coatings	5
Module -5	Strain Gauges	10
Module -6	Discussion Session	1

NPTEL

Module -1. Overview of Experimental Stress Analysis

Lecture	Concepts Covered
1 Overview of Experimental Stress Analysis	Overview of experimental stress analysis, Stress analysis – Analytical, Numerical and Experimental approaches, Specific domain of these approaches, Advantages and disadvantages.
2 Optical Methods Work as Optical Computers	Optical methods work as optical computers, Direct information provided by various experimental methods – brief description, Visual appreciation of field information – Listing of various problems of different complexity.
3 Stress, Strain and Displacement Fields	Stress, Strain and Displacement fields for various problems, Beam under pure bending, Analytical solution, Fringe contours from various experimental methods, Disc under diametral compression – Analytical solution, Fringe contours from various experimental techniques, Clamped circular plate under a central load – Analytical solution, Fringe contours from various experimental techniques.
4 Physical Principle of Strain Gauges, Photoelasticity and Moiré	Spanner tightening a nut – completeness of a numerical solution, comparison with photoelastic fringes. Physical principle behind various experimental techniques, Strain Gauges, Photoelasticity, Grids for determining plastic strains, Geometric moiré, grating details – u and v displacements, Demonstration of fringes due to translation and rotation of gratings of various types.
5 Introduction to Moiré, Brittle Coatings and Holography	Brief introduction to Moiré, Brittle coatings and Holography. Difference between normal photography and holography, Visualising the depth information, Formation of speckles due to illumination by a laser, Rainbow hologram.
6 Hologram Interferometry, Speckle Methods	Hologram interferometry, Steps in a double exposure hologram interferometry, Speckle methods, Objective speckles, Subjective speckles.
7 Introduction to Shearography, TSA, DIC and Caustics	Brief introduction to Speckle interferometry, Shearography, Thermoelastic Stress Analysis (TSA), Digital Image Correlation (DIC) and Caustics. Caustics in a tea cup, dimple formation, Class demonstration of Caustic experiment.
8 Fringe Patterns – Richness of Qualitative Information	Coherent gradient sensor, Naming of experimental methods, Fringe patterns – Richness of qualitative information, Information provided by fringe thickness, density. Optical methods for quality inspection, Comparison of various designs – Streamline fillet, Key technologies that have influenced Experimental Mechanics.
9 Multi-Scale Analysis in Experimental Mechanics	Multi-scale analysis in experimental mechanics, Trends in experimental mechanics, Discussion on selection of an experimental technique,

NPTEL

10 Selection of an Experimental Technique	Discussion on selection of an experimental technique contd., References. Review of solid mechanics, definition of free surface, ambiguity in associating the correct value of principal stress direction to the magnitude of the principal stress, Eigen value approach or use of Mohr's circle, Shear distribution in a three point bend specimen.

Module -2. Transmission Photoelasticity

Lecture	Concepts Covered
11 Introduction to Transmission Photoelasticity	Physical principle, Historical development, Various branches of photoelasticity, Birefringence, Nature of light, Polarisation, Methods to get polarized light, Understanding polarization, Class experiment on showing crossed polarizers, Passage of light through isotropic media.
12 Ordinary and Extraordinary Rays	Snell's laws, Passage of light through crystalline media, Demonstration of birefringence effect of Calcite prism, Influence on the role of optical axis of the crystal, Light ellipse.
13 Light Ellipse, Passage of Light Through a Crystal Plate	Light ellipse (contd.) Retardation plates and wave plates, Historical development on polarization optics, Dichroism, Sheet polarisers
14 Retardation Plates, Stress-optic Law	Sheet polarisers contd., Retardation plates and wave plates, Quarter wave, Half wave and Full wave plates, Stress-optic law, Maximum stress information obtainable by photoelasticity.
15 Plane Polariscope	Plane polariscope, Logical explanation of formation of fringes, Understanding isochromatics, isoclinics. Intensity of light transmitted in a plane polariscope by trigonometric resolution.
16 Jones Calculus	Jones calculus, Rotation matrix, Retardation matrix, Representation of a retarder, Elements of the polariscope, Analysis of plane polariscope by Jones calculus, Circular polariscope, Dark and bright fields.
17 Circular Polariscope	Circular polariscope (contd.), Intensity of light transmitted by Jones calculus, Various optical arrangements possible, Demonstration of a commercial polariscope, Use of white light, Colour code, Tint of passage, Storage of photoelastic materials, Time-edge effect, Summary of photoelastic fringes.
18 Determination of Photoelastic Parameters at an Arbitrary Point	Review of colour code, Determination of photoelastic parameters at an arbitrary point, Compensation techniques, Babinet–Soleil compensator in detail, Steps in Tardy's Method of compensation.
19 Tardy's Method of Compensation	Tardy's method of compensation, Brief exposure to digital photoelasticity, Need for calibration of photoelastic materials, advantage of circular disk, Calibration of photoelastic model materials, Stress field in a circular disc under diametral compression.

20 Calibration of Photo elastic Materials	Conventional approach to calibration, Linear least squares analysis, Sampled least squares, Introduction to the use of Image processing techniques, Image sampling and quantization.
21 Fringe Thinning Methodologies	Fringe thinning methodologies, Thresholding to find fringe areas, Binary based and intensity based algorithms, Chen & Taylor algorithm for one scanning direction, Fringe skeletonisation, Global fringe thinning algorithm, Experimental evaluation, Theoretical reconstruction of fringe pattern, Opening remarks on comments on fringe ordering.
22 Fringe Ordering in Photoelasticity	Importance of accurate evaluation of material stress fringe value, Global fringe thinning – summary, Comments on fringe ordering (contd.), Features of isochromatic and isoclinic fringe field, Positive and negative isotropic points, Role of principles of solid mechanics in fringe ordering, Identification of zeroth fringe order.
23 Miscellaneous Topics in Transmission Photoelasticity	Resolving the ambiguity on the principal stress direction, Determination of the sign of the boundary stress, Compatibility conditions, Role of elastic constants on stress field, Model to prototype relations, Properties of photoelastic model materials.

Module -3. Introduction to Three Dimensional Photoelasticity and Digital Photoelasticity

Lecture	Concepts Covered
24 Three Dimensional Photoelasticity	Three dimensional photoelasticity, Stress freezing, Slicing, Application to a complex problem, Integrated photoelasticity, Principle of optical equivalence.
25 Overview of Digital Photoelasticity	Introduction to digital photoelasticity, Use of colour information for quantitative analysis, Three Fringe Photoelasticity (TFP), Refined TFP (RTFP) to solve slow time variant problems. Paradigm shift in data processing, Processing of intensity data for photoelastic data extraction, Overview of digital photoelasticity, Ten-step method, Understanding phasemaps.

Module -4. Photoelastic Coatings and Brittle Coatings

Lecture	Concepts Covered
26 Introduction to Photoelastic Coatings	Photoelastic coatings, Historical development, Optical arrangements, Photoelastic strain gauges, Strain-optic relation for coating, Evaluation of coating and specimen stresses.
27 Correction Factors for Photoelastic Coatings	Correction factors for photoelastic coatings, Correction factor for bending, Combined in-plane and bending loads, Correction factor for torsion, Correction factor for pressure vessel.

NPTEL

28 Coating Materials, Selection of Coating Thickness, Industrial Application of Photoelastic Coatings	Correction factors – Summary, Handling mismatch of Poisson's ratio, Coating materials, Properties of photoelastic coating materials, Selection of the coating thickness, Maximum fringe order obtainable, Use of photoelastic coatings to solve a range of problems of practical interest.
29 Calibration of Photoelastic Coatings, Introduction to Brittle Coatings	Demonstration of photoelastic coating test, Calibration of photoelastic coatings, Compact displacement controlled loading jig. Historical development of brittle coatings, Methodology of brittle coatings, Crack patterns produced by direct loading, Uniaxial, Biaxial and Isotropic stress fields, Steps in brittle coating tests, Coating selection, Surface preparation.
30 Analysis of Brittle Coatings	Undercoating, Application of the coating, Drying. Coating stresses, Uniaxial specimen stress, Nature of coating stress, Calibration of brittle coatings, Influence of Poisson's ratio mismatch, Crack patterns by refrigeration, Crack patterns by relaxation, Stresscoat.

Module -5. Strain Gauges

Lecture	Concepts Covered
31 Introduction to Strain Gauges	Analysis of Isoentatic data, Strain Gauges: Physical principle, Historical development, Development of SR-4 gauges, Strain sensitivity of a conductor, Gauge construction, Gauge length, Gauge length error in measurement, Thumb rule in selection of gauge length, Commonly used strain gauge materials.
32 Strain Sensitivity of a Strain Gauge, Bridge Sensitivity, Rosettes	Strain sensitivity of a strain gauge, Transverse sensitivity factor, Gauge factor, Experimental determination of gauge factor, Wheatstone bridge, Strain measurement options, Bridge sensitivity, Bridge factor, Accuracy achievable in Foil strain gauges, Linearity, Hysteresis and Zero shift, Determination of strain at a point, Three element rectangular rosette.
33 Strain Gauge Alloys, Carriers and Adhesives	Delta rosette, Metallic alloys commonly employed, Advance, Isoelastic alloy, Karma alloy, Thermally induced apparent strain, Nichrome-D, Strain gauge carriers, Types, Cements for bonding a strain gauge: Cynoacrylate, Epoxy cements and Polyester cements.
34 Performance of Strain Gauge System	Ceramic cements, High temperature strain gauge, Flame spraying Rokide process, Strain gauge linearity, Hysteresis, Drift, Stability, Heat dissipation, Allowable power density, Selection of bridge voltage, Sensitivity of gauge to temperature, Strain sensitivity of a conductor as a function of temperature.
35 Temperature Compensation, Two-wire and Three-wire Circuits	Temperature compensation, Temperature compensated gauges, Measurement techniques: Two-wire circuit, Gauge factor desensitization, Role of change in temperature, Three-wire circuit, Benefits of three-wire circuits.

36 Strain Gauge Selection	Selection compromises, Strain gauge designation systems, Various gauge patterns for different applications, Guidelines for strain gauge selection.
37 Bonding of a Strain Gauge	Temperature effects guiding the selection of certain parameters, Importance of following a bonding procedure, Surface preparation: Strain gauge installation kit, Solvent degreasing, Surface abrading, Layout lines, Surface conditioning, Neutralizing. Strain gauge bonding: Strain gauge handling, Strain gauge alignment, Catalyst application, Bonding with adhesive.
38 Soldering, Accounting for Transverse Sensitivity Effects	Masking, Tinning, Soldering, Application of protective coating, Testing the installation, Transverse sensitivity, Actual and apparent strains, Corrections for transverse strain effects for the case of known ratio of the transverse strain to the axial strain.
39 Correction Factors for Special Applications	Corrections for transverse strain effects for a general case, T–rosette, Rectangular rosette. Effect of hydrostatic pressure, Effect of nuclear radiation, Effect of high temperature, Effect of cryogenic temperature, Effect of strain cycling, Environmental effects.
40 Special Gauges	Environmental effects contd., Torque gauge, Stress gauge, Single element strain gauge as stress gauge, Evaluation of SIF by strain gauges, Strip gauge, Single element strain gauge to evaluate SIF. Summary of the course.

Module -6. Discussion Session

41 Questions & Answers	A few questions from the whole course were discussed.

Please Note The naming of each lecture indicates only the major thrust in that lecture.

About the Author: **K. Ramesh** is currently a Professor at the Department of Applied Mechanics, IIT Madras; as it's Chairman during (2005-2009) and formerly a Professor at the Department of Mechanical Engineering, IIT Kanpur. He received his undergraduate degree from the Regional Engineering College, Trichy (now NIT, Trichy), Postgraduate degree from the Indian Institute of Science, Bangalore and the Doctoral Degree from the Indian Institute of Technology Madras. He has made significant contributions to the advancement of *Digital Photoelasticity*. This has resulted in a Monograph on *Digital Photoelasticity- advanced Techniques and Applications,* Springer and a chapter on *Photoelasticity* in the *Springer Handbook of Experimental Solid Mechanics.* Organizations such as ARDB, ISRO, DST, and NSF have funded his research. He has pioneered a new paradigm in Engineering Education by writing innovative e-Books on *Engineering Fracture Mechanics* and *Experimental Stress Analysis* published by IIT Madras. These books are first of their kind in the world and can be truly called as e-Teachers. He has over 120 publications to date of which two have been reproduced in the *Milestone Series* of SPIE, co-authored a book on *Mechanical Sciences*, Narosa Publishing House, India and has contributed a chapter on *Experimental Stress Analysis – An Overview*, in the book on *Optical Methods for Solid Mechanics*, Wiley-VCH Verlag. He has also given Video lectures of 40 hrs. each on *Experimental Stress Analysis* and *Engineering Fracture Mechanics* as part of the National Program for Technology Enhanced Learning (NPTEL), India. He has received several recognitions: Zandman Award of Society for Experimental Mechanics (SEM), U.S.A (2012), Distinguished Alumnus Award of NIT, Trichy (2008), Fellow of the Indian National Academy of Engineering (2006), President of India Cash Prize (1984). Member of the Editorial Boards of the International Journals: Strain (since 2001), Journal of Strain Analysis for Engineering Design (2009-10), Optics and Lasers in Engineering, and Steering committee member of ASEM.

For details see : http://apm.iitm.ac.in/smlab/kramesh/index.html