INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)
Dundigal, Hyderabad -500 043

CIVIL ENGINEERING

COURSE INFORMATION SHEET

Course Title	**FINITE ELEMENT METHOD**			
Course Code	BST005			
Programme	M. Tech (Structural Engineering)			
Semester	I			
Course Type	Core			
Regulation	R16			
Course Structure	**Lectures**	**Tutorials**	**Practicals**	**Credits**
	3	-	-	3
Course Coordinator	Dr. M. Venu, Professor Department of Civil Engineering			
Course Faculty	Dr. M. Venu, Professor Department of Civil Engineering			

I. COURSE OVERVIEW:

The Finite Element Method (FEM) is widely used in industry for analysing and modelling structures and continua, whose physical behaviour is described by ordinary and partial differential equations. The FEM is particularly useful for engineering problems that are too complicated to be solved by classical analytical methods. The main objective of this course is to introduce the mathematical concepts of the Finite Element Method for obtaining an approximate solution of ordinary and partial differential equations. In this course you will attend lectures on the fundamentals of the Finite Element Method. The learning process will be enhanced by completing assignments using mathematical software. You will also be introduced to a commercial Finite Element software package – ANSYS – during lectures with computer laboratories providing opportunities to practice on, and to complete practical assignments, using ANSYS.

II. COURSE PRE-REQUISITES:

Level	Course Code	Semester	Prerequisites	Credits
UG	ACE001	III	Strength of Materials - I	4
UG	ACE004	IV	Strength of Materials – II	4
UG	ACE008	V	Structural Analysis	4
PG	BST003	I	Computer Oriented Numerical Methods	3

III. MARKS DISTRIBUTION

Subject	SEE Examination	CIA Examination	Total Marks
Finite Element Method	70 Marks	30 Marks	100

Semester End Examination (SEE):
The SEE is conducted for 70 marks of 3 hours duration. The syllabus for the theory courses is divided into FIVE units and each unit carries equal weightage in terms of marks distribution. The question paper pattern is as follows: two full questions with 'either' 'or' choice will be drawn from each unit. Each question carries 14 marks.

Continuous Internal Assessment (CIA):
CIA is conducted for a total of 30 marks, with 25 marks for Continuous Internal Examination (CIE) and 05 marks for Technical Seminar and Term Paper.

Table: Assessment pattern for Theory Course

COMPONENT	THEORY		TOTAL MARKS
Type of Assessment	CIE Exam (Sessional)	Technical Seminar and Term Paper	
Max. CIA	25	5	

Continuous Internal Examination (CIE):
The CIE exam is conducted for 25 marks of 2 hours duration consisting of two parts. Part–A shall have five compulsory questions of one mark each. In part–B, four out of five questions have to be answered where, each question carries 5 marks. Marks are awarded by taking average of marks scored in two CIE exams.

Technical Seminar and Term Paper:
Two seminar presentations are conducted during I year I semester and II semester. For seminar, a student under the supervision of a concerned faculty member, shall identify a topic in each course and prepare the term paper with overview of topic. The evaluation of Technical seminar and term paper is for maximum of 5 marks. Marks are awarded by taking average of marks scored in two Seminar Evaluations.

IV. DELIVERY / INSTRUCTIONAL METHODOLOGIES:

√	CHALK & TALK	√	QUIZ	√	ASSIGNMENTS	√	MOOCs
√	LCD / PPT	√	SEMINARS	√	MINI PROJECT	√	VIDEOS
	OPEN ENDED EXPERIMENTS						

V. ASSESSMENT METHODOLOGIES – DIRECT

√	CIE EXAMS	√	SEE EXAMS	√	ASSIGNEMNTS	√	SEMINARS
	LABORATORY PRACTICES	√	STUDENT VIVA	√	MINI PROJECT		CERTIFICATION
√	TERM PAPER						

VI. ASSESSMENT METHODOLOGIES – INDIRECT

√	ASSESSMENT OF COURSE OUTCOMES (BY FEEDBACK, ONCE)	√	STUDENT FEEDBACK ON FACULTY (TWICE)
√	ASSESSMENT OF MINI PROJECTS BY EXPERTS		

VII. COURSE OBJECTIVES:

The Course should enable the students to:

I. Equip the students with the Finite Element Analysis fundamentals.
II. Enable the students to formulate the design problems into Finite Element Method (FEM).
III. Develop the ability to generate the governing finite element equations for systems.
IV. Enable to understand the different kinds of elements used while analysing the structure.
V. Understand the use of the basic finite elements for structural applications using truss, beam, frame and plate elements.

VIII . COURSE LEARNING OUTCOMES:

Students, who complete the course, will have demonstrated the ability to do the following:

CBST005.01	Understand the Concepts of FEM, steps involved merits and demerits.
CBST005.02	Understand the concept of energy principles, discrimination.
CBST005.03	Solve the problems using Raleigh-Ritz method of functional approximation.
CBST005.04	Know the Stress equations, strain displacement relationships in matrix form plane stress.
CBST005.05	Understand the concept of plane strain and axisymmetric bodies of revolution with axisymmetric loading.
CBST005.06	Understand the concept of One dimensional FEM Stiffness matrix for beam and bar elements.
CBST005.07	Different types of elements for plane stress and plane strain analysis, displacement models.
CBST005.08	Know the generalized coordinates, shape functions.
CBST005.09	Concept of convergent and compatibility requirements, geometric invariance.
CBST005.10	Know the natural coordinate system, area and volume coordinates.
CBST005.11	Understand the generation of element stiffness and nodal load matrices.
CBST005.12	Concept of isoparametric formulation, different isoparametric elements for 2D analysis.
CBST005.13	Understand the formulation of 4- noded and 8-noded isoparametric quadrilateral elements.
CBST005.14	Understand the lagrange elements, serendipity elements.
CBST005.15	Concept of Axisymmetric bodies of revolution, axisymmetric modeling.
CBST005.16	Understand the strain displacement relationship, formulation of axisymmetric elements.
CBST005.17	Know the different 3-D elements strain, displacement relationship.
CBST005.18	Understand the formulation of hexahedral and isoparametric solid element.
CBST005.19	Understand the basic theory of plate bending, thin plate theory.
CBST005.20	Stress resultants, mindlin's approximations.
CBST005.21	Understand the formulation of 4-noded isoperimetric quadrilateral plate element, shell element.
CBST005.22	Introduction to nonlinear analysis: basic methods, application to special structures.

IX. HOW PROGRAM OUTCOMES ARE ASSESSED:

Program Outcomes		Level	Proficiency assessed by
PO 1	**Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.	H	Assignments
PO 2	**Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.	H	Assignments
PO 3	**Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.	S	Mini Project
PO 4	**Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid	S	Open ended experiments /

Program Outcomes		Level	Proficiency assessed by
	conclusions.		
PO 5	**Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.	S	Mini Project
PO 6	**The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.	N	---
PO 7	**Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.	N	---.
PO 8	**Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.	N	---
PO 9	**Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.	N	---
PO 10	**Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.	S	Technical Seminars / Term Paper
PO 11	**Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments	N	---
PO 12	**Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.	S	Research Projects

N= None S= Supportive H = Highly Related

X. HOW PROGRAM SPECIFIC OUTCOMES ARE ASSESSED:

Program Specific Outcomes		Level	Proficiency assessed by
PSO 1	**ENGINEERING KNOWLEDGE:** Graduates shall demonstrate sound knowledge in analysis, design, laboratory investigations and construction aspects of civil engineering infrastructure, along with good foundation in mathematics, basic sciences and technical communication.	H	Lectures, Assignments
PSO 2	**BROADNESS AND DIVERSITY:** Graduates will have a broad understanding of economical, environmental, societal, health and safety factors involved in infrastructural development, and shall demonstrate ability to function within multidisciplinary teams with competence in modern tool usage.	H	Projects
PSO 3	**SELF-LEARNING AND SERVICE:** Graduates will be motivated for continuous self-learning in engineering practice and/ or pursue research in advanced areas of civil engineering in order to offer engineering services to the society, ethically and responsibly.	S	Guest Lectures

N - None S - Supportive H - Highly Related

XI. SYLLABUS:

UNIT I: INTRODUCTION TO FEM AND PRINCIPLES OF ELASTICITY
Introduction: Concepts of FEM, steps involved merits and demerits, energy principles, discrimination, Raleigh-Ritz method of functional approximation. Principles of Elasticity: Stress equations, strain displacement relationships in matrix form plane stress, plane strain and axisymmetric bodies of revolution with axisymmetric loading.

UNIT II : 1D AND 2D FEM
One dimensional FEM: Stiffness matrix for beam and bar elements, shape functions foe ID elements. Two dimensional FEM: Different types of elements for plane stress and plane strain analysis, displacement models, generalized coordinates, shape functions, convergent and compatibility requirements, geometric invariance, natural coordinate system, area and volume coordinates, generation of element stiffness and nodal load matrices
UNIT III : DIFFERENT FORMULATIONS AND 3D FEM
Isoparametric formulation: Concept, different isoparametric elements for 2D analysis, formulation of 4-noded and 8-noded isoparametric quadrilateral elements, lagrange elements, serendipity elements. Axisymmetric Analysis: Bodies of revolution, axisymmetric modelling, strain displacement relationship, formulation of axisymmetric elements. Three dimensional FEM: Different 3-D elements strain, displacement relationship, formulation of hexahedral and isoparametric solid element.
UNIT IV: ANALYSIS OF PLATES
Introduction to finite element analysis of plates: Basic theory of plate bending, thin plate theory, stress resultants, mindlin's approximations, formulation of 4-noded isoperimetric quadrilateral plate element, shell element.
UNIT V: NON-LINEAR ANALYSIS
Introduction to non-linear analysis: basic methods, application to special structures.

TEXT BOOKS:

1	Finite Element Analysis by C.S. Krishnamoorthy, Tata McGraw Hill Publishing Co. Ltd (1994).
2	Concepts and applications of Finite element analysis by Cook R.D., Malkas D.S. & Plesha M.E, John Wiley & Sons (1999).

REFERENCES:

1	Finite element Methods by O.C. Zienkiewicz, Robert L. Taylor, J. Z. Zhu, Butterworth-Heinemann Ltd (2013).
2	Introduction to Finite element Method by T.C. Patil and Belugunudu.
3	Introduction to Finite element Method by J.N. Reddy.

XII. COURSE PLAN:

The course plan is meant as a guideline. There may probably be changes.

Lecture No	Topic Outcomes	Topic/s to be covered	Reference
1-2	**Know** the concept of FEM, advantages and disadvantages of FEM	Introduction, Concepts of FEM, steps involved merits and demerits	T1,T2
3-5	**Explain** Energy principles and discrimination	Energy principles, discrimination	T1, R1,R2
6-8	**Relate** Raleigh, ritz method of functional approximation	Raleigh, ritz method of functional approximation.	T2
9	**Discuss** Principle of elasticity in matrix form	Principles of Elasticity: Stress equations, strain displacement relationships in matrix form plane stress	T1,T2
10	**Explain** Axi-symmetric bodies of revolution	Axi-symmetric bodies of revolution with axi-symmetric loading.	T1,R1,R3
11	**Discuss** Stiffness matrix for beam and bar elements, shape function for 1D element	One dimensional FEM: Stiffness matrix for beam and bar elements. shape functions for ID elements	T1, R1,R2

Lecture No	Topic Outcomes	Topic/s to be covered	Reference
12-13	**Explain** Different types of elements	Different types of elements for plane stress and plane strain analysis, displacement models.	T2
14-15	**Discuss** convergent and compatibility requirements	Generalized coordinates, shape functions, convergent and compatibility requirements.	T1,T2
16-17	**Explain** Different types of coordinates	Geometric invariance, natural coordinate system, area and volume coordinates	T1
18-20	**Discuss** Generation of element stiffness	Generation of element stiffness and nodal load matrices.	T1,R1
21	**Explain** Computational of stiffness matrix for isoparametric elements	Isoparametric formulation: Concept, different iso-parametric elements for 2D analysis.	T2
22-24	**Explain** Formulation of isoparametric quadrilateral elements.	Formulation of 4-noded and 8-noded isoparametric quadrilateral elements.	T1,T2
25-26	**Discuss** Lagrange and serendipity elements.	lagrange elements, serendipity elements.	T1,T2
27-28	**Explain** the impulse momentum equation	Axi Symmetric Analysis: Bodies of revolution, axi symmetric modeling, strain displacement relationship.	T1
29	**Explain** 3D concept for FEM	Formulation of axi symmetric elements. Three dimensional FEM: Different 3-D element strain.	T2,R3
30	**Discuss** formulation of hexahedral solid elements	Displacement relationship, formulation of hexahedral and isoparametric solid element.	T1,T2
31	**Discuss** FEM analysis of plates	Introduction to finite element analysis of plates Law of conservation of Energy.	T1
32-33	**Explain** Basic theory of plates bending	Basic theory of plate bending, thin plate theory	T1,R1,R2
34-35	**Derive** Mindlin's plate element	stress resultants, mindlin's approximations	T2
36-39	**Explain** quadrilateral plate element, shell element.	Formulation of 4-noded isoperimetric quadrilateral plate element, shell element.	T2,T3
40-41	**Discuss** Nonlinear analysis	Introduction to nonlinear analysis	T2,R2
42-43	**Explain** Basic methods of nonlinear analysis	Basic methods of nonlinear analysis	T2
44-45	**Discuss** Application to special structures	Application to special structures	T1,T2

XIII. GAPS IN THE SYLLABUS - TO MEET INDUSTRY / PROFESSION REQUIREMENTS:

S NO	DESCRIPTION	PROPOSED ACTIONS	RELEVANCE WITH POs	RELEVANCE WITH PSOs
1	Experimental analysis of Structure and the behaviour under loads	Seminars / Guest Lectures / NPTEL	PO 1, PO 2, PO 3	PSO 1, PSO 2
2	Finite Element Analysis of using Software packages	Seminars / Guest Lectures / NPTEL	PO 2, PO 3	PSO 1
3	Thermal analysis of a structures using FEM	Assignments / Laboratory Practices	PO 1, PO 3, PO 4	PSO 2

XIV. MAPPING COURSE OBJECTIVES LEADING TO THE ACHIEVEMENT OF PROGRAM OUTCOMES AND PROGRAM SPECIFIC OUTCOMES:

Course Objectives	Program Outcomes												Program Specific Outcomes		
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
I	H	H			S							S	H	S	
II		H	S		S								S	H	
III	S	H	S										H		S
IV	H	S											H	S	
V	H	S											H	S	S

S= Supportive **H = Highly Related**

XV. MAPPING COURSE OUTCOMES LEADING TO THE ACHIEVEMENT OF PROGRAM OUTCOMES AND PROGRAM SPECIFIC OUTCOMES:

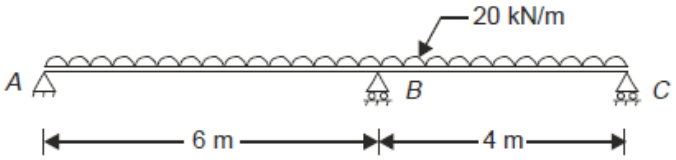
Course learning Outcomes	Program Outcomes												Program Specific Outcomes		
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CBST005.01	H	S											S		
CBST005.02	H	S											H		
CBST005.03		H			H									S	
CBST005.04			S										H		
CBST005.05		H	H										S		
CBST005.06		S			H							S	S		
CBST005.07			H	S										S	
CBST005.08		H		S									S		
CBST005.09		H													
CBST005.10				S										H	
CBST005.11	S	S		H										S	
CBST005.12					H								S		
CBST005.13	S		H								S			S	
CBST005.14					H									S	
CBST005.15		S	H						S		S		S	H	
CBST005.16		S							S					S	
CBST005.17	S	S		S										H	

CBST005.18		H												S	
CBST005.19	S												S		
CBST005.20				H										S	
CBST005.21		S													
CBST005.22	S			S											

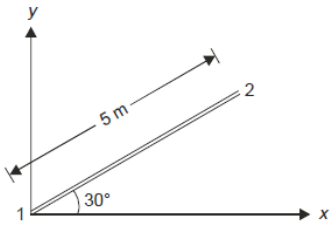
S= Supportive **H = Highly Related**

XVI. DESIGN BASED PROBLEMS (DP) / OPEN ENDED PROBLEM:

1. Analyze the beam shown in figure using FEM technique. Take E=200GPa and I=4X10^6 mm^4.



2. Assemble the stiffness matrix for a plane beam element oriented at angle of θ (theta) to the X - Axis.
3. Assemble the element stiffness matrix for the member of a plane frame as shown in figure. If it is oriented at an angle of 30^O to the X- Axis. E=200GPa, I=4X10^{-6} m^4 and A= 4X10^{-3} m^2.



Prepared By:
Dr. M. Venu, Professor
Department of Civil Engineering **HOD, CE**