

**DEPARTMENT OF CIVIL ENGINEERING: IIT DELHI**  
**SEMESTER II : : 2009-10**  
**CEL 722 : SOLID MECHANICS IN STRUCTURAL ENGINEERING**

**MAJOR TEST**  
**CONSTITUTIVE MODELLING**

Max. marks = 45

Time allowed = 2 hrs.

1. The deformation field for an isotropic elastic solid is given as

$$x_1 = X_1 \quad x_2 = X_2 + \beta X_3 \quad x_3 = X_3 \quad \beta = 0.1$$

- a) Obtain the Almansi Strain Tensor  $e_{ij}$  at a material point (1,1,2)
- b) Obtain the Cauchy Stress Tensor  $\sigma_{ij}$  at that point
- c) Using this example, show that the material exhibits Normal Stress Effects

5+5+5 = 15 marks

2. The Loading Function for an isotropic elasto-plastic solid undergoing small deformations is stated as:

$$f(\sigma_{ij}, k) = \sqrt{J_2} + \alpha I_1 - k = 0$$

$$\alpha = 0.4 \quad k_y < k < k_f$$

Assuming the validity of the Associative Flow Rule, show that the material exhibits Stress Induced Anisotropy under the following state of stress:

$$\sigma_{11} = \sigma_{22} = \sigma_{12} = \sigma_{23} = 0 \quad \sigma_{31} = 6 \text{ N/mm}^2 \quad \sigma_{33} = -9 \text{ N/mm}^2$$

10 marks

3. For the Kelvin-Voigt rheological element, prove the validity of the Principle of Superposition.

10 marks

4. a) For a micropolar elastic material, state the equations of motion in general. In particular, state the equations of motion explicitly for the balance of forces along and the balance of moments about the  $X_2$ -axis.
- b) State the Principle of Material Frame Indifference (PMFI) in particular reference to elastic solids.

6+4 = 10 marks