COLLEGE OF E

(University of Mumbai)

(CGPA : 3.18)

ANSWER - BOOK

any form should not be revealed in the answer book's cover

Space for marks	Question No.	
	Q1	
	a	Mathematical modelling is an important step in the field of engineering where the domain over which the analysis has to be conducted gets complex and the designers need to resort to numerical analysis of the domain. The domain can be either, structural, thermal & electrical, the system is first expressed in form of differential equations. The equation formed gives out the charactristic response of the system / domain over which the problem is needed to be solved. This formation of the differential equation of the specific domain which mimics the behaviour of the system is called as mathematical modelling. This is an important parameter as not all systems / domain can be solved using the classical method. The differential equation formed is known as the governing differential equation or GDE.
	→	This method of mathematically modelling of the system is utilised in every engineering field (Mechanical, civil, automobile, electrical, nuclear, thermal, etc)
	Eg	In the automobile field, the safety test of the vehicle chassis needs to be conducted. In the normal way designers would required a built prototype of the chassis to conduct these test. By solving the problem numerically the simulation can be created and be done virtually

Space for marks | Question No.

thus being beneficial. The chassis is represented as a ~~par~~ differential equation. The equation formed can be of an order (0, 1, 2, 3, 4) depending upon the domain.

b Patch test - In FEA its important to finalize if the ~~model~~ equation given properly represents the model being tested on. Patch test consists of assemblying a few elements of the whole system, making sure each node connects atleast two elements and the patch test is conducted. By conducting the test over a smaller portion of the system designers can verify the credibility of the equation thus making it easier to carry out the test on large scale.

→ Convergence criteria - Numerical analysis never yeilds a ~~ct~~ correct solution, its always an approximation. The goal is to create a solution as close to real as possible. Thus in a system where the modelling is tested, assuming the discritization & formation of elements are done correctly the test is considered as converging if its getting closer to the correct solution. Otherwise its called as diverging

There are certain criterias for a solution to converge

i The auxillary equation should be on one higher order

ii All the polynomials should be a closed polynomial

iii The residual value should be equal or near to 0

iv

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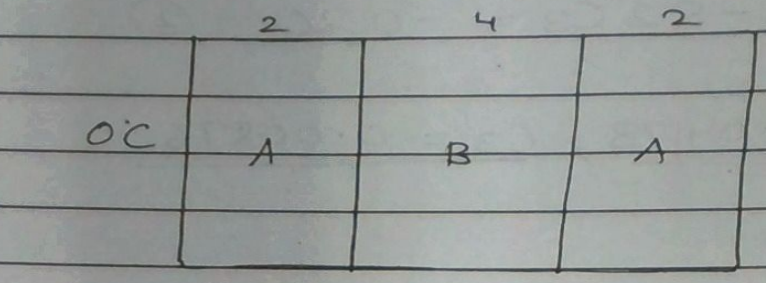
Space for marks	Question No.	
	Ci	$\frac{d^2u}{dx^2} + 8u + x = 0$ $\quad 0 < x < 1$
		$u(0) = 0$
		$u(1) = 0$
		$u(0.5) = ?$
	→	Auxillary Approximate solution
		$y = C_0 + C_1x + C_2x^2 + C_3x^3$
	→	Boundary conditions
		$0 = C_0$, $\quad 0 = C_1 + C_2 + C_3$
		$\therefore C_1 = -C_2 - C_3$
	→	$y = (-C_2 - C_3) + C_2x^2 + C_3x^3$
		$= C_2(x^2) - C_3(x^3)$
	∴	$\frac{dy}{dx} = 2xC_2 - 3C_3x^2$
		$\frac{d^2y}{dx^2} = 2C_2 - 6C_3x$
	∴	$(2C_2 - 6C_3x) + 8(2xC_2 - 3C_3x^2) + x = 0$
		$2C_2 - 6C_3x + 16xC_2 + 24C_3x^2 + x = 0$
		$C_2(2 + 16x) - C_3(6x + 24x^2) + x = 0$
	★	By galerkin method, coefficients of y
		$\int_0^1 (x^2) \cdot C_2(2+16x) - \int_0^1 (x^2) C_3(6x + 24x^2) + \int_0^1 (x^2) x\,dx$
	∴	$4.667C_2 - 6.3C_3 + 0.25 = 0$
		$4.667C_2 - 6.3C_3 = -0.25 \rightarrow ①$
		$\int_0^1 (x^3) \cdot C_2(2+16x) - \int_0^1 (x^3) C_3(6x + 24x^2) + \int_0^1 (x^2) x\,dx$
		$3.7C_2 - 5.2C_3 + 0.2$

Space for marks	Question No.	
	$\therefore$	$4.667C_2 - 6.3C_3 = -0.25$ — ①
		$3.7C_2 - 5.2C_3 = -0.20$ — ②
	$\therefore$	$\underline{C_2 = -0.04173}$, $\underline{C_3 = 0.00876}$
	$\therefore$	$u = 0.5$
		$0.5 = -0.01473(x^2) - 0.00876(x^3)$
		$\underline{x = -4.513}$
	☆	By subdomain method, divinding the domain in 2
		$\int_0^{0.5} C_2(2+16x) - \int_0^{0.5} C_3(6x+24x^2) + \int_0^{0.5} x\,dx = 0$
	$=$	$3C_2 - 1.75C_3 + 0.125$
	$=$	$3C_2 - 1.75C_3 = -0.125$ — ①
		$\int_{0.5}^{1} C_2(2+16x) - \int_{0.5}^{1} C_3(6x+24x^2) + \int_{0.5}^{1} x\,dx = 0$
	$=$	$7C_2 - 9.25C_3 + 0.375$
	$=$	$7C_2 - 9.25C_3 = -0.375$
	$\therefore$	$3C_2 - 1.75C_3 = -0.125$
		$7C_2 - 9.25C_3 = -0.375$
	$\therefore$	~~$u = 0.5$~~ $C_2 = -0.032$, $C_3 = 0.0161$
		~~$0.5 =$~~
	$\therefore$	$u(0.5) =$
		$0.5 = -0.032(x^2) + 0.0161(x^3)$
		$x =$

Space for marks	Question No.
	Q2

a



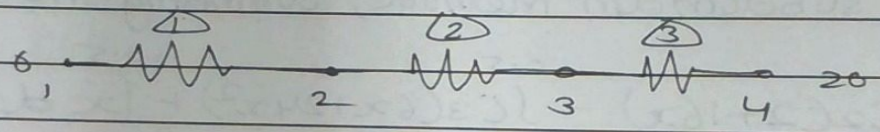
$A = 1$

$K_A = 55 \times 10$

$K_b = 0.1 \times 10$

$$\therefore \frac{K}{L}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{bmatrix} \theta_1 \\ \theta_2 \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \end{bmatrix}$$

$\therefore$



$$\therefore 10^{-3}\begin{array}{c|cc} & 1 & 2 \\ \hline 1 & 27.5 & -27.5 \\ 2 & -27.5 & 27.5 \end{array}\begin{bmatrix} 0 \\ \theta_2 \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \end{bmatrix} \longrightarrow (1)$$

$$\therefore 10^{-3}\begin{array}{c|cc} & 2 & 3 \\ \hline 2 & 0.025 & -0.025 \\ 3 & -0.025 & 0.025 \end{array}\begin{bmatrix} \theta_2 \\ \theta_3 \end{bmatrix} = \begin{bmatrix} F_2 \\ F_3 \end{bmatrix} \longrightarrow (2)$$

$$\therefore 10^{-3}\begin{array}{c|cc} & 3 & 4 \\ \hline 3 & 27.5 & -27.5 \\ 4 & -27.5 & 27.5 \end{array}\begin{bmatrix} \theta_3 \\ 20 \end{bmatrix} = \begin{bmatrix} F_3 \\ F_4 \end{bmatrix} \longrightarrow (3)$$

$$\therefore 10^{-3}\begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 27.5 & -27.5 & 0 & 0 \\ 2 & -27.5 & 27.52 & -0.025 & 0 \\ 3 & 0 & -0.025 & 27.52 & -27.5 \\ 4 & 0 & 0 & -27.5 & 27.5 \end{array}\begin{bmatrix} 0 \\ \theta_2 \\ \theta_3 \\ 20 \end{bmatrix} = \begin{bmatrix} T_1 \\ 0 \\ 0 \\ T_4 \end{bmatrix}$$

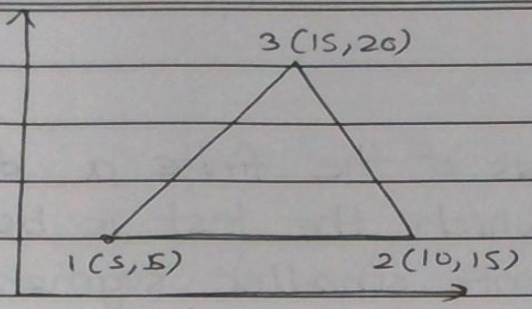
$-27.5\theta_2 = T_1$

$27.52\theta_2 - 0.025\theta_3 = 0$

$-0.025\theta_2 + 27.52\theta_3 - (27.5 \cdot 20) = 0$

$-27.5\theta_3 + (27.5 \times 20) = T_4$

Space for marks	Question No.	
	Bi	



$x_1 = 5 \quad y_1 = 5$
$x_2 = 10 \quad y_2 = 15$
$x_3 = 15 \quad y_3 = 20$

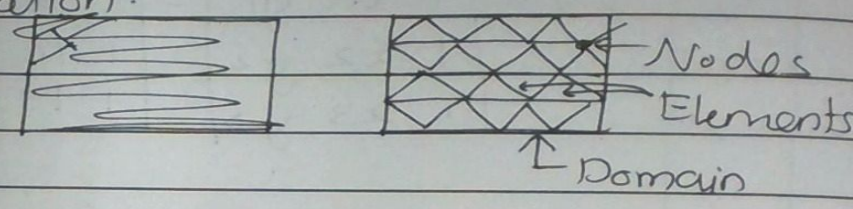
$$\Rightarrow \quad 2A = \begin{vmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ 1 & x_3 & y_3 \end{vmatrix} = \begin{vmatrix} 1 & 5 & 5 \\ 1 & 10 & 15 \\ 1 & 15 & 20 \end{vmatrix} = -25$$

$$\Rightarrow \quad a_1 = x_2y_3 - x_3y_2 = (10 \times 20) - (15 \times 15) = -25$$
$$a_2 = x_3y_1 - x_1y_3 = (15 \times 5) - (5 \times 20) = -25$$
$$a_3 = x_1y_2 - x_2y_1 = (5 \times 15) - (10 \times 5) = 25$$
$$\beta_1 = y_2 - y_3 = 15 - 20 = -5$$
$$\beta_2 = y_3 - y_1 = 20 - 5 = 15$$
$$\beta_3 = y_1 - y_2 = 5 - 15 = -10$$
$$\gamma_1 = -(x_2 - x_3) = -(10 - 15) = 5$$
$$\gamma_2 = -(x_3 - x_1) = -(15 - 5) = -10$$
$$\gamma_3 = -(x_1 - x_2) = -(5 - 10) = 5$$

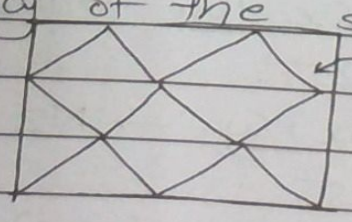
$$\therefore \quad 0.1 = \frac{-25 - 5x + 5y}{-25} \rightarrow N_1 \qquad \therefore x = 17$$
$$y = 22.5$$
$$\therefore \quad 0.2 = \frac{-25 + 15x - 10y}{-25} \rightarrow N_2 \qquad N_3 = 1.3$$
$$\therefore \quad N_3 = \frac{25 - 10x + 5y}{-25} \rightarrow N_3$$
$$N_3 = \frac{25 - 10(17) + 5(22.5)}{-25} = 1.3$$

Space for marks	Question No.
	Q3

a In the analysis of the ~~finite~~ a domain, the element over which the test is being carried are divided into smaller segments which known as elements. This process is called as discretization.

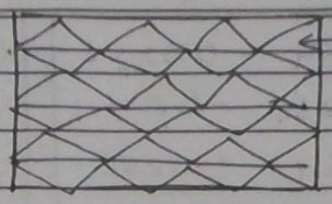


The accuracy of the calculation are dependent the resolution or the divison of the elements. the domain is divided in less elements of a l sizes it will yeild less accurate results comp to an element which is divided into higher segments and smaller elements. This the size plays a dired role in the result of the element, smaller the size, larger the elem more accurate results. An element which is divi into less number of ~~eler~~ larger elements is called as coarse element which results in lower accuracy of the salution.



Wherras if the discritization is done with higher number of element which would be of much smaller sizes it yeilds a highly accurate resul Such discretization is called as fine meshing

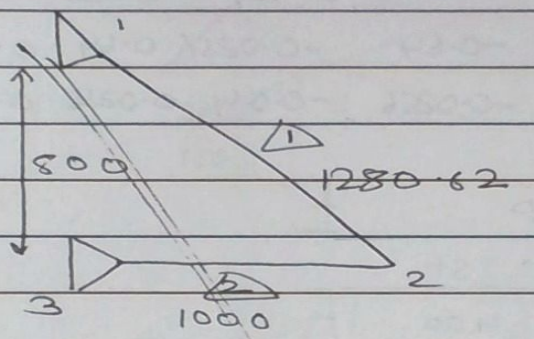
Space for marks | Question No.



Smaller elements
More no. of elements

Thus in finite element analysis element size play a direct role is the discretization process. Smaller the element, larger the element numbers, more are the results accurate.

b



∴

Element	Node i	Node j	x_i	y_i	x_j	y_j	l	m	~~l^2~~	~~m^2~~	~~lm~~
1	1	2	0	0	1000	-800	0.780	-0.624			
2	2	3	-800	1000	0	-800	-0.8	-0.2			

l^2	m^2	lm
0.6084	0.389	0.236
0.64	0.04	0.0256

$$\begin{bmatrix} l^2 & lm & -l^2 & -lm \\ lm & m^2 & -lm & -m^2 \\ -l^2 & -lm & l^2 & lm \\ -lm & -m^2 & lm & m^2 \end{bmatrix} \begin{bmatrix} U_1 \\ V_1 \\ U_2 \\ V_2 \end{bmatrix} = \begin{bmatrix} P_{1x} \\ P_{1y} \\ P_{2x} \\ P_{2y} \end{bmatrix}$$

∴

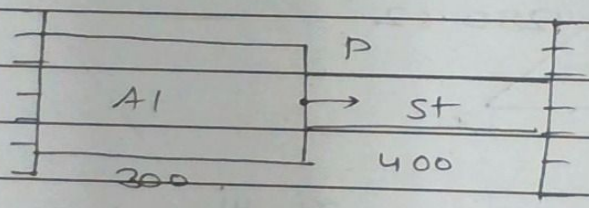
$$\begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 0.6084 & 0.236 & -0.6084 & -0.236 \\ 2 & 0.236 & 0.389 & -0.236 & -0.389 \\ 3 & -0.6084 & -0.236 & 0.6084 & 0.236 \\ 4 & -0.236 & -0.389 & 0.236 & 0.389 \end{array} \begin{bmatrix} U_1 \\ V_1 \\ U_2 \\ V_2 \end{bmatrix} = \begin{bmatrix} P_{1x} \\ P_{1y} \\ P_{2x} \\ P_{2y} \end{bmatrix} \longrightarrow \triangle$$

Space for marks | Question No.

$$\begin{array}{c|cccc} & 3 & 4 & 5 & 6 \\ \hline 3 & 0.64 & 0.0256 & -0.64 & -0.0256 \\ 4 & 0.0256 & 0.04 & -0.0256 & -0.04 \\ 5 & -0.64 & -0.0256 & 0.64 & 0.0256 \\ 6 & -0.0256 & -0.04 & 0.0256 & 0.04 \end{array} \begin{bmatrix} U_2 \\ V_2 \\ U_3 \\ V_3 \end{bmatrix} = \begin{bmatrix} P_{2x} \\ P_{2y} \\ P_{3x} \\ P_{3y} \end{bmatrix} \rightarrow (2)$$

$$\begin{array}{c|cccccc} & 1 & 2 & 3 & 4 & 5 & 6 \\ \hline 1 & 0.6084 & 0.236 & -0.6084 & -0.236 & 0 & 0 \\ 2 & 0.236 & 0.389 & -0.236 & -0.389 & 0 & 0 \\ 3 & -0.6084 & -0.236 & 1.248 & 0.261 & -0.64 & -0.0256 \\ 4 & -0.236 & -0.389 & 0.261 & 0.429 & -0.0256 & -0.04 \\ 5 & 0 & 0 & -0.64 & -0.0256 & 0.64 & 0.0256 \\ 6 & 0 & 0 & -0.0256 & -0.04 & 0.0256 & 0.04 \end{array}$$

bii



$$\therefore \frac{AE}{L}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{bmatrix} U_1 \\ U_2 \end{bmatrix} = \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} + EA\alpha\Delta T \begin{bmatrix} -1 \\ +1 \end{bmatrix}$$

$$\therefore 10^3 \begin{array}{c|cc} & 1 & 2 \\ \hline 1 & 560 & -560 \\ 2 & -560 & 560 \end{array} \begin{bmatrix} U_1 \\ U_2 \end{bmatrix} = \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} + 10^3 \begin{bmatrix} -110.88 \\ 110.88 \end{bmatrix} \rightarrow (1)$$

$$\therefore 10^3 \begin{array}{c|cc} & 2 & 3 \\ \hline 2 & 600 & -600 \\ 3 & -600 & 600 \end{array} \begin{bmatrix} U_2 \\ U_3 \end{bmatrix} = \begin{bmatrix} P_2 \\ P_3 \end{bmatrix} + 10^3 \begin{bmatrix} -86.40 \\ 86.40 \end{bmatrix} \rightarrow (2)$$

$$\therefore 10^3 \begin{bmatrix} 560 & -560 & 0 \\ -560 & 1160 & -600 \\ 0 & -600 & 600 \end{bmatrix} \begin{bmatrix} 0 \\ U_2 \\ 0 \end{bmatrix} = \begin{bmatrix} P_1 \\ 500 \\ P_3 \end{bmatrix} + \begin{bmatrix} -110.88 \\ 24.48 \\ 86.40 \end{bmatrix} 10^3$$

$\therefore$ $-560U_2 = P_1 - 110.88$

$1160U_2 = 500 + 24.48$

$-600U_2 = P_3 + 86.40$

Check $= -357.66 + 500 - 142.29 = 0$

$\therefore U_2 = \underline{0.4521\,mm}$

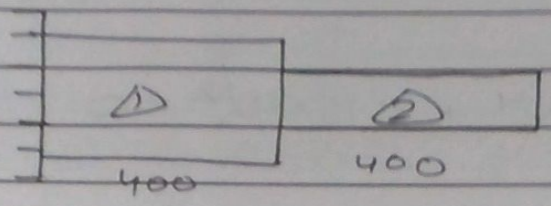
$P_1 = \underline{-142.29\ (Comp)}$

$P_3 = \underline{-357.66}$

Space for marks | Question No.

Q4

B



LMM

$E = 200 \times 10^3$

$\rho = 7600$

$A_1 = 800, \; A_2 = 400$

$$\frac{AE}{L}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} = \frac{\rho A L \omega^2}{2}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \longrightarrow \text{LMM}$$

$$\Rightarrow \quad 10^3 \begin{bmatrix} 400 & -400 \\ -400 & 400 \end{bmatrix} =$$

$$\frac{AE}{L}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{bmatrix} U_1 \\ U_2 \end{bmatrix} = \frac{\rho A L \omega^2}{2}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} U_1 \\ U_2 \end{bmatrix} \longrightarrow \text{LMM}$$

$$\therefore \quad 10^6 \begin{bmatrix} 0.4 & -0.4 \\ -0.4 & 0.4 \end{bmatrix}\begin{bmatrix} U_1 \\ U_2 \end{bmatrix} = \omega^2 \, 10^6 \begin{bmatrix} 1800 & 0 \\ 0 & 1800 \end{bmatrix}\begin{bmatrix} U_1 \\ U_2 \end{bmatrix} \longrightarrow \triangle$$

$$\therefore \quad 10^6 \begin{bmatrix} 0.2 & -0.2 \\ -0.2 & 0.2 \end{bmatrix}\begin{bmatrix} U_1 \\ U_2 \end{bmatrix} = \omega^2 \, 10^6 \begin{bmatrix} 600 & 0 \\ 0 & 600 \end{bmatrix}\begin{bmatrix} U_1 \\ U_2 \end{bmatrix} \longrightarrow \triangle$$

$$\therefore \quad 10^6 \begin{bmatrix} 0.4 & -0.4 & 0 \\ 0 & 0.6 & -0.2 \\ 0 & -0.2 & 0.2 \end{bmatrix}\begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix} = \omega^2 \, 10^6 \begin{bmatrix} 1200 & 0 & 0 \\ 0 & 1800 & 0 \\ 0 & 0 & 600 \end{bmatrix}\begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix}$$

$$\therefore \quad 10^6 \begin{bmatrix} 0.6 & -0.2 \\ -0.2 & 0.2 \end{bmatrix}\begin{bmatrix} U_2 \\ U_3 \end{bmatrix} = \omega^2 \, 10^6 \begin{bmatrix} 1800 & 0 \\ 0 & 600 \end{bmatrix}\begin{bmatrix} U_2 \\ U_3 \end{bmatrix}$$

$$\therefore \quad 10^6 \begin{bmatrix} 0.6 & -0.2 \\ -0.2 & 0.2 \end{bmatrix} - \omega^2 \, 10^6 \begin{bmatrix} 1800 & 0 \\ 0 & 600 \end{bmatrix}\begin{bmatrix} U_2 \\ U_3 \end{bmatrix} = 0$$

$$\therefore \quad \begin{bmatrix} 0.6 \times 10^6 - 1800 \times 10^6 \omega^2 & -0.2 \times 10^6 \\ -0.2 \times 10^6 & 0.2 \times 10^6 - 600 \times 10^6 \omega^2 \end{bmatrix} = 0$$

Space for marks	Question No.	
	$\therefore$	$0.12\times10^{12} - \cancel{360\times10^{12}\omega^2} + \cancel{360\times10^{12}\omega^2} + 1080000\times10^{12}\omega^4 + 0.04\times10^{12} = 0$
	$\therefore$	$1080000\times10^{12}\omega^4 + 0.16\times10^{12} = 0$

Space for marks	Question No.
	Q4

a $x_1 = 20 \quad y_1 = 30$

$x_2 = 80 \quad y_2 = 30$

$x_3 = 50 \quad y_3 = 120$

$$\therefore \quad 2A = \begin{vmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ 1 & x_3 & y_3 \end{vmatrix} = \begin{vmatrix} 1 & 20 & 30 \\ 1 & 80 & 30 \\ 1 & 50 & 120 \end{vmatrix} = 5400$$

$$\therefore \quad \beta_1 = y_2 - y_3 = 30 - 120 = -90$$
$$\beta_2 = y_3 - y_1 = 120 - 30 = 90$$
$$\beta_3 = y_1 - y_2 = 30 - 30 = 0$$
$$\gamma_1 = -(x_2 - x_3) = -(80 - 20) = -60$$
$$\gamma_2 = -(x_3 - x_1) = -(50 - 20) = -30$$
$$\gamma_3 = -(x_1 - x_2) = -(20 - 80) = 60$$

$$\therefore \quad \underline{B} = \begin{bmatrix} \beta_1 & 0 & \beta_2 & 0 & \beta_3 & 0 \\ 0 & \gamma_1 & 0 & \gamma_2 & 0 & \gamma_3 \\ \gamma_1 & \beta_1 & \gamma_2 & \beta_2 & \gamma_3 & \beta_3 \end{bmatrix} \frac{1}{2A}$$

$$= \frac{1}{5400} \begin{bmatrix} -90 & 0 & 90 & 0 & 0 & 0 \\ 0 & -60 & 0 & -30 & 0 & 60 \\ -60 & -90 & -30 & 90 & 60 & 0 \end{bmatrix}$$

$$= \begin{bmatrix} -0.0167 & 0 & 0.0167 & 0 & 0 & 0 \\ 0 & -0.011 & 0 & -0.005 & 0 & 0.011 \\ -0.011 & -0.0167 & -0.005 & 0.0167 & 0.011 & 0 \end{bmatrix}$$

$$\therefore \quad E.A = 10 \times \frac{1}{2700} = \underline{\underline{0.0037}}$$

Space for marks	Question No.

$$B^T = \begin{bmatrix} -0.0167 & 0 & -0.011 \\ 0 & -0.011 & -0.0167 \\ 0.0167 & 0 & -0.005 \\ 0 & -0.005 & 0.167 \\ 0 & 0 & 0.011 \\ 0 & 0.011 & 0 \end{bmatrix}$$

$\therefore$ $K = B \cdot D B^T t A$

~~K = 0.0037~~

$$D = \frac{E}{1-\nu^2} \begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & 1-\nu/2 \end{bmatrix}$$

$$= \frac{210\times10^3}{1-0.25^2} \begin{bmatrix} 1 & 0.25 & 0 \\ 0.25 & 1 & 0 \\ 0 & 0 & 0.375 \end{bmatrix}$$

$\Rightarrow$ $K = B \cdot D B^T t A$

$$= 0.0037 \times 224000 \begin{bmatrix} -0.0167 & 0 & -0.011 \\ 0 & -0.011 & -0.167 \\ 0.167 & 0 & -0.005 \\ 0 & -0.005 & 0.167 \\ 0 & 0 & 0.011 \\ 0 & 0.011 & 0 \end{bmatrix} \begin{bmatrix} 1 & 0.25 \\ 0.25 & 1 \\ 0 & 0 \end{bmatrix}$$

Space for marks	Question No.

$$828.8 \begin{bmatrix} -0.0167 & 0.0041 & 0.0041 \\ -0.0027 & -0.011 & -0.0626 \\ 0.167 & 0.0417 & -0.0018 \\ 0.00125 & 0.005 & 0.0618 \\ 0 & 0 & 0.00412 \\ 0.00275 & 0.011 & 0 \end{bmatrix}$$

$$8.28.8 \begin{bmatrix} -0.0167 & 0.0041 & 0.0041 \\ & & \\ & & \\ & & \\ & & \\ & & \end{bmatrix}$$

$$\times \begin{bmatrix} \\ \\ \\ \\ \\ \end{bmatrix}$$

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