AE-675A

INTRODUCTION TO FINITE ELEMENT METHODS

PROJECT REPORT

FEM ANALYSIS OF 2D TRUSS STRUCTURES

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BY -

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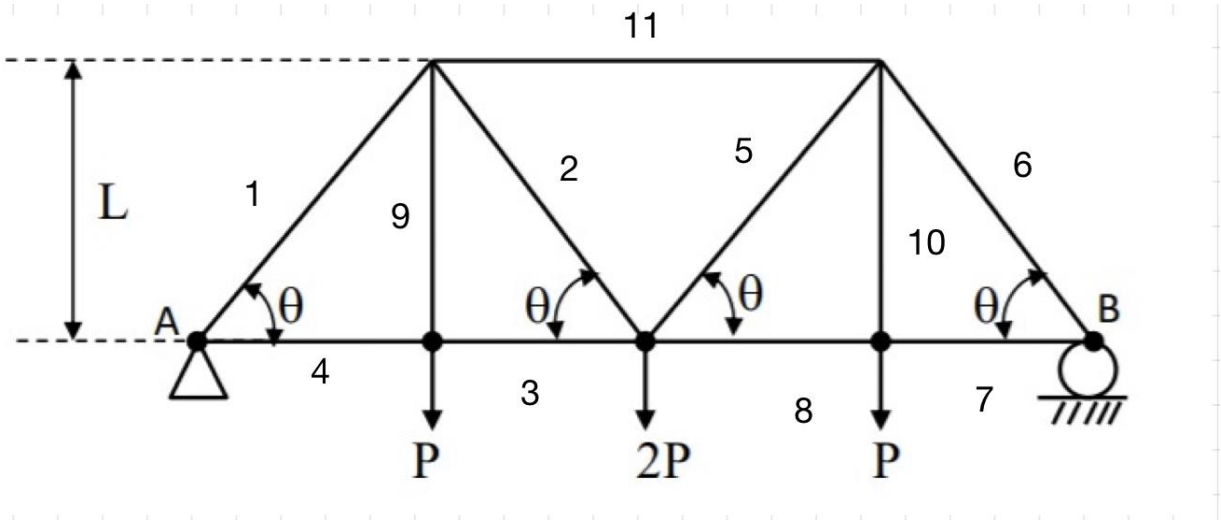
Introduction

A truss is a structural element designed to support only axial forces; therefore, it deforms only in its axial direction. The bar's cross-section can have arbitrary geometry, but its dimensions should be much smaller than the bar length. Finite element developments for truss members will be performed in this chapter. The simplest and most widely used finite element for truss structures is the well-known truss or bar finite element with two nodal points. Such kinds of finite elements are applicable for analyzing skeletal types of structural truss systems in two-dimensional and three-dimensional space. Basic concepts, procedures, and formulations can also be found in a significant number of existing books. In skeletal structures consisting of truss members, the truss elements are linked by pins or hinges without friction, so only forces are transmitted among bars, which means that no moments are shared. In the presentation of this concept, it will be assumed that truss elements have uniform cross-sections.

In the forthcoming pages we plan to explain the methodology used to find the Temperatures, displacements and stress fields in the elements of the Truss Structure given below.



An Overview of the given Truss Structure and circumstances under which it acts upon.

Here, the given Truss structure constitutes 11 elements, each element with 2 nodes named *A* and *B* as fixed/rigid hinges and rolling hinges. The structure comprises of 3 isosceles triangular assemblies with the base angles θ and altitude *L*.

The truss structure is under the action of 3 external forces as described in the figure above, with values *P;2P; P*.

At nodes *A* and *B*, due to their hinges' nature, the displacement of the respective nodes is affected in a significant way. The displacement corresponding to node *A* is restricted in both the *X* and *Y* direction due to the rigid hinge. In contrast, the displacement corresponding to node *B* is only restricted in the *Y* direction, whereas it's free to roll in the *X* direction without any external stimuli interference.

Given Data:- (Retrieved by the code given in the problem statement)

Length(L) = 1.0652 meters
Theta(θ) = 43.1160 degrees.
The Temperature at point A(T_A) = 509.5566 Kelvin
The Temperature at point B(T_B) =298 Kelvin

Area=$6*10^{-4}$ $meter^2$

Being inspired from real-world, we assume:

Youngs Modulus(E)= $210*10^9 Pa$
Coefficient of Expansion(α)=$10^{-6} Kelvin^{-1}$
Thermal Conductivity(k)= some constant (not given and isn't needed while calculations)

Methods employed in calculations

- *Gauss–Legendre quadrature rule:*

In numerical analysis, Gauss–Legendre quadrature is a form of Gaussian quadrature for approximating the definite integral of a function. For integrating over the interval [−1, 1], the rule takes the form:

$$\int_{-1}^{1} f(x)\,dx \approx \sum_{i=1}^{n} w_i f(x_i)$$

where

- n is the number of sample points used,
- w_i are quadrature weights, and
- x_i are the roots of the nth Legendre polynomial.

- *Isoparametric elements with quadratic shape functions:*

Here the shape functions ϕ_1, ϕ_2 and ϕ_3 are quadratic and are determined to be:

$$\phi_1 = \frac{\xi\,(\xi-1)}{2}$$
$$\phi_2 = 1-\xi^2$$
$$\phi_3 = \frac{\xi\,(\xi+1)}{2}$$

Considering the shape function matrix as[N]

$$[N] = \begin{pmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \end{pmatrix}$$

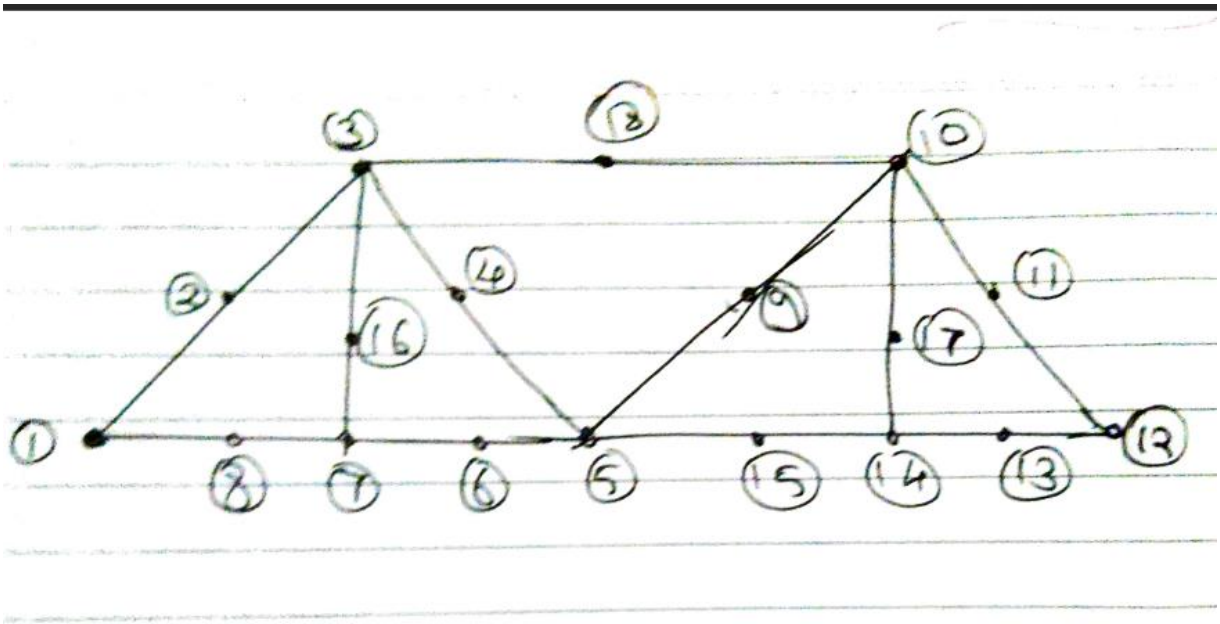
On implying the functional values, we get:

$$[N] = \begin{pmatrix} \frac{\xi\,(\xi-1)}{2} \\ 1-\xi^2 \\ \frac{\xi\,(\xi+1)}{2} \end{pmatrix}$$

In the quadratic Gauss–Legendre quadrature rule, the roots x_i are **+0.5774** and **-0.5774.**

Approach to find Temperature, Displacement, and Stress field:

- The numbering of the nodes and elements is done as shown below



Elements	Corresponding Nodes		
1	1	2	3
2	3	4	5
3	7	6	5
4	1	8	7
5	5	9	10
6	10	11	12
7	14	13	12
8	5	15	14
9	7	16	3
10	14	17	10
11	3	18	10

- **Temperature Analysis:**

Here we employ to solve the differential equation:

$$\frac{d}{dx}\left(kA\frac{dT}{dx}\right)=0$$

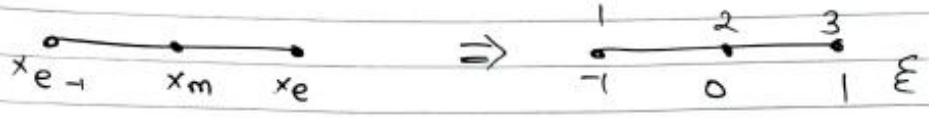
….(1)

With the boundary conditions:

$$T_A=509.5566\ K$$
$$T_B=298\ K$$

And considering/assuming the net Heat Flux for the system to be zero.

The weak form we obtain for the equation (1) is:



Quadratic Lagrange Polynomials

$$N_1 = \frac{\xi(\xi-1)}{2} \qquad N_2 = (1-\xi)(1+\xi)$$

$$N_3 = \frac{(\xi+1)(\xi)}{2}$$

$$x = N_1 x_1 + N_2 x_2 + N_3 x_3$$

$$\tilde{T}(\xi) = N_1 \hat{T}_{1e} + N_2 \hat{T}_{2e} + N_3 \hat{T}_{3e}$$

$$\tilde{\omega}(\xi) = N_1 \hat{\omega}_{1e} + N_2 \hat{\omega}_{2e} + N_3 \hat{\omega}_{3e}$$

$$\frac{d\xi}{dx} = \frac{2}{l_e}$$

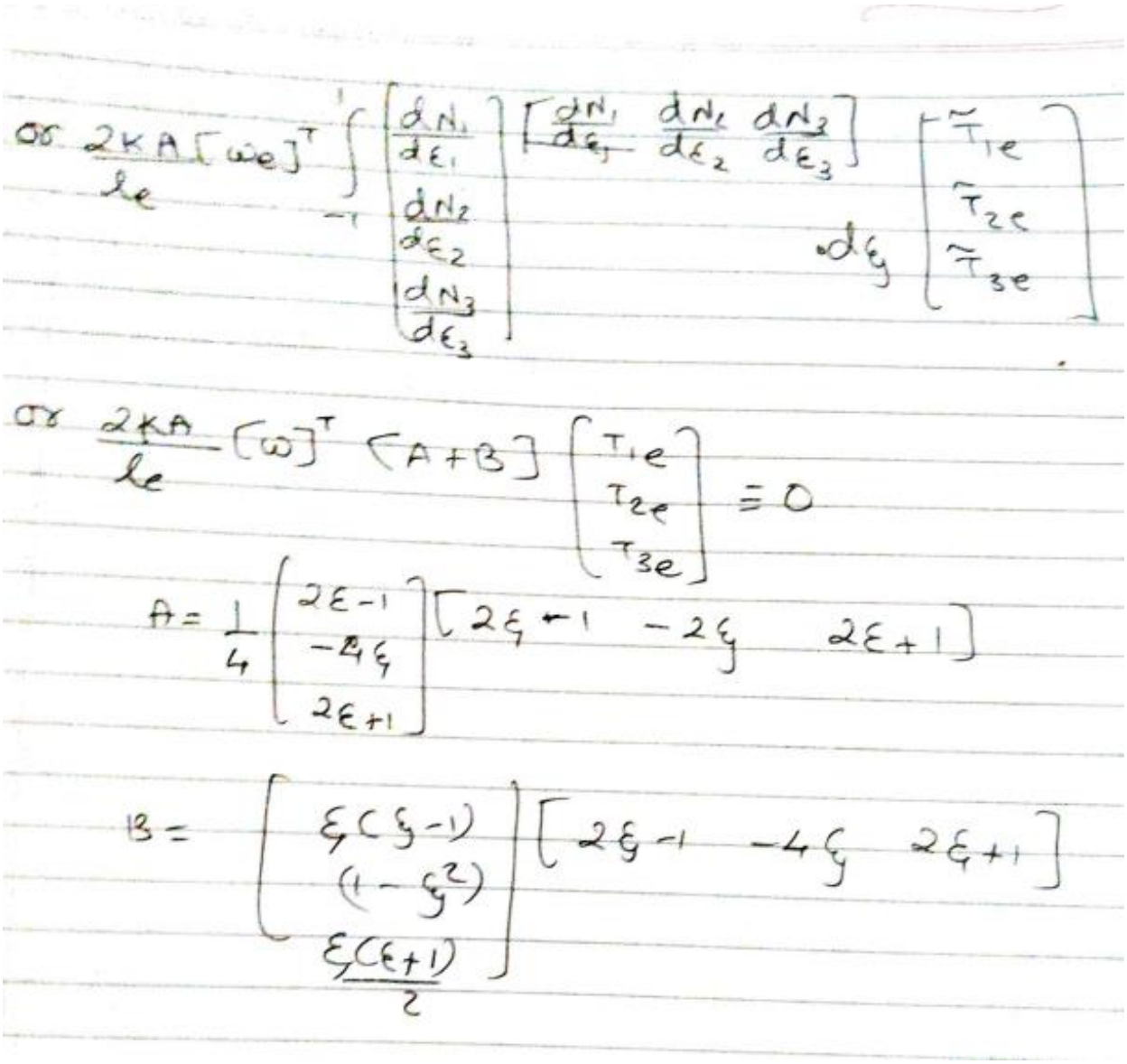
$$\frac{d}{dx}\left(KA\frac{dT}{dx}\right) = 0$$

$$\Rightarrow \int_{x_{e-1}}^{x_e} \omega \cdot \frac{d}{dx}\left(KA\frac{dT}{dx}\right) = 0$$

Transforming to ξ

$$-\int_{-1}^{1} \frac{d\tilde{\omega}}{d\xi} \cdot KA\frac{d\tilde{T}}{dx}\frac{d\xi}{dx} \cdot d\xi + \omega KA\frac{dT}{d\xi}\frac{d\xi}{dx}\Big|_{-1}^{1}$$

$$= 0$$



Now, after solving for these equations by 2-point Gauss-Legendre quadrature rule for quadratic integration and 1-point for linear integration, we get for an element

$$[\tilde{w}]^T kA\left[\frac{1}{3L}\begin{pmatrix}7 & -8 & 1\\ -8 & 16 & -8\\ 1 & -8 & 7\end{pmatrix}-\frac{1}{L}\begin{pmatrix}3 & -4 & 1\\ 0 & 0 & 0\\ 1 & -4 & 3\end{pmatrix}\right]\begin{pmatrix}T_1\\ T_2\\ T_3\end{pmatrix}=0$$

$$K_e = \left[\frac{1}{3L} \begin{pmatrix} 7 & -8 & 1 \\ -8 & 16 & -8 \\ 1 & -8 & 7 \end{pmatrix} - \frac{1}{L} \begin{pmatrix} 3 & -4 & 1 \\ 0 & 0 & 0 \\ 1 & -4 & 3 \end{pmatrix} \right]$$

- **Displacement Analysis:**

We find the displacement of each node with the help of equations:

$$\frac{d}{dx}(\sigma A) = 0 \quad \text{where} \quad \sigma = E(\varepsilon - \alpha \Delta T) \quad \text{and} \quad \varepsilon = \frac{du}{dx}.$$

……..(2)

Here we may take the *To=298K* as equivalent to room temperature, which is to be used in ΔT.
The weak form for equation (2) will be

$$\int_{-1}^{1} \frac{d\tilde{w}}{d\xi}\frac{d\xi}{d\tilde{x}} EA \frac{d\tilde{U}}{d\xi}\, d\xi - (\tilde{w} EA \frac{d\tilde{U}}{d\xi}\frac{d\xi}{d\tilde{x}})\Big|_{-1}^{1} + \int_{-1}^{1} \tilde{w} EA\alpha \frac{dT}{d\xi}\, d\xi = 0$$

Where $\tilde{w} = \phi_1 \tilde{w}_1 + \phi_2 \tilde{w}_2 + \phi_3 \tilde{w}_3$

Now, after solving for these equations by 2-point Gauss-Legendre quadrature the rule for quadratic integration and 1-point for linear integration, we get

$$[\tilde{w}]^T \left[\frac{EA}{3L_e} \begin{pmatrix} 7 & -8 & 1 \\ -8 & 16 & -8 \\ 1 & -8 & 7 \end{pmatrix} \begin{pmatrix} \tilde{U}_{e1} \\ \tilde{U}_{e2} \\ \tilde{U}_{e3} \end{pmatrix} - \begin{pmatrix} -\tilde{P}_{e1} \\ \tilde{P}_{e2} \end{pmatrix} + \frac{EA\alpha}{6} \begin{pmatrix} -3 & 4 & -1 \\ -4 & 0 & 4 \\ 1 & -4 & 3 \end{pmatrix} \right] = 0$$

The above equation is in the local coordinate of the truss member, which we want to convert to global coordinates, for which we will use the transformation matrix.

$$lmat = \begin{pmatrix} cos\theta & 0 & 0 \\ sin\theta & 0 & 0 \\ 0 & cos\theta & 0 \\ 0 & sin\theta & 0 \\ 0 & 0 & cos\theta \\ 0 & 0 & sin\theta \end{pmatrix}$$

$$K_e = \text{Elemental stiffness matrix} = \frac{EA}{3L_e} lmat \times \begin{pmatrix} 7 & -8 & 1 \\ -8 & 16 & -8 \\ 1 & -8 & 7 \end{pmatrix} \times lmat^T$$

$$T_e = \text{Elemental Matrix due to temperature term} = \frac{EA\alpha}{6} lmat \times \begin{pmatrix} -3 & 4 & -1 \\ -4 & 0 & 4 \\ 1 & -4 & 3 \end{pmatrix}$$

$$P_e = \text{Elemental Force Matrix} = lmat \times \tilde{P}_{e1}$$
$$\tilde{P}_{e2}$$

And the global matrix for Ke, Te, and Pe, which is denoted be K_G, T_G, and P_G. and then displacement matrix U can be found by the following relation

$$U = K_G^{-1}(P_G - T_G).$$

- **Stress Analysis:**

We know that in an element's local Coordinate system, stress can be written as

$$\sigma = E(\frac{d}{d\tilde{x}}(\tilde{U}) - \alpha\Delta T)$$
$$\sigma = E(\frac{d\tilde{U}}{d\xi}\frac{d\xi}{dx} - \alpha(T - 298))$$

After substituting for $\tilde{U}$ and $\frac{d\xi}{dx}$ we get the following matrix relation. (1,2, 3) being local numbers.

$$\sigma_e = E\left[\frac{2}{L_e}\begin{pmatrix}\phi_1' & \phi_2' & \phi_3'\end{pmatrix}\begin{pmatrix}U_{e1}\\U_{e2}\\U_{e3}\end{pmatrix} - \alpha\begin{pmatrix}\phi_1 & \phi_2 & \phi_3\end{pmatrix}\right)\begin{pmatrix}T_{e1}-298\\T_{e2}-298\\T_{e3}-298\end{pmatrix}$$

where,

$$\begin{pmatrix}U_{e1}\\U_{e2}\\U_{e3}\end{pmatrix} = \begin{pmatrix} cos\theta & 0 & 0 \\ sin\theta & 0 & 0 \\ 0 & cos\theta & 0 \\ 0 & sin\theta & 0 \\ 0 & 0 & cos\theta \\ 0 & 0 & sin\theta \end{pmatrix}^T \begin{pmatrix}u_{e1}\\v_{e1}\\u_{e2}\\v_{e2}\\u_{e3}\\v_{e3}\end{pmatrix}$$

Solving above, we can get the stress for an element at any xi in the local CS (along the element).

Heading To Part B

As of now, we have obtained temperatures at all the node and displacement of every node under the given circumstances.

Thus we are able to find the Temperature field, Displacement Field, and Stress Field in every element. So we head towards dividing each element into about 21 sub-nodes and finding the Temperature; Stress, and Strain, and plotting them along xi.

Heading towards Part C

Since we know Temperature at every point possible, we can find the corresponding yield stress, i.e. the breakdown status.

Now as *P* will be a variable and we shall obtain the the asked fields as a function of *P* .We shall our solve for by equating the stress field function of to the yield stress field.

And we shall obtain a matrix of *P* for all the points on the Truss structure, and among them, we may take the minimum among the *Pmax*, leading us to obtain *Pmin* required for failure.

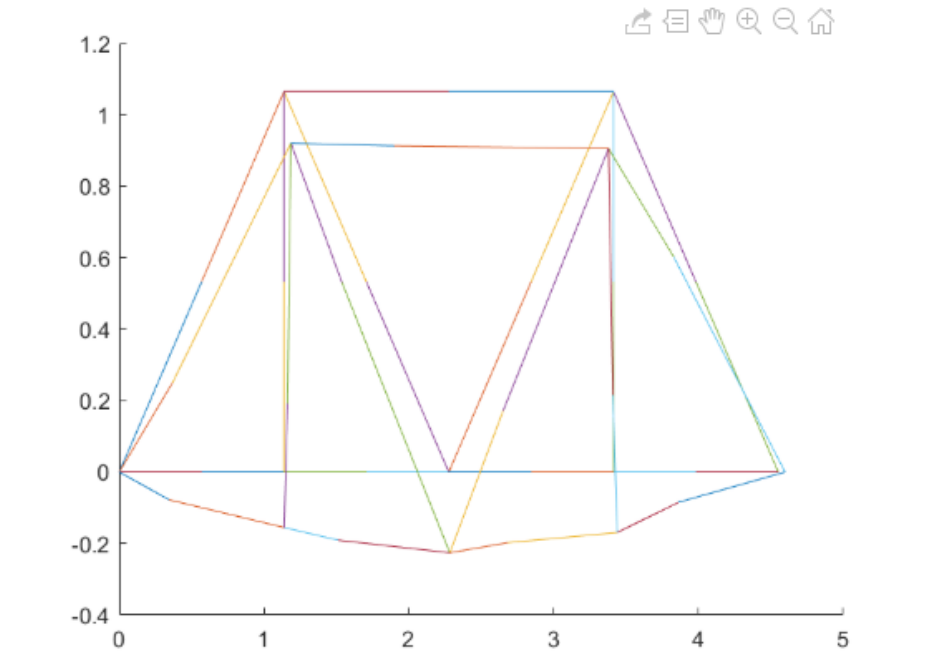
Results

We obtain Temperature at nodes as:

Nodes Temperatures

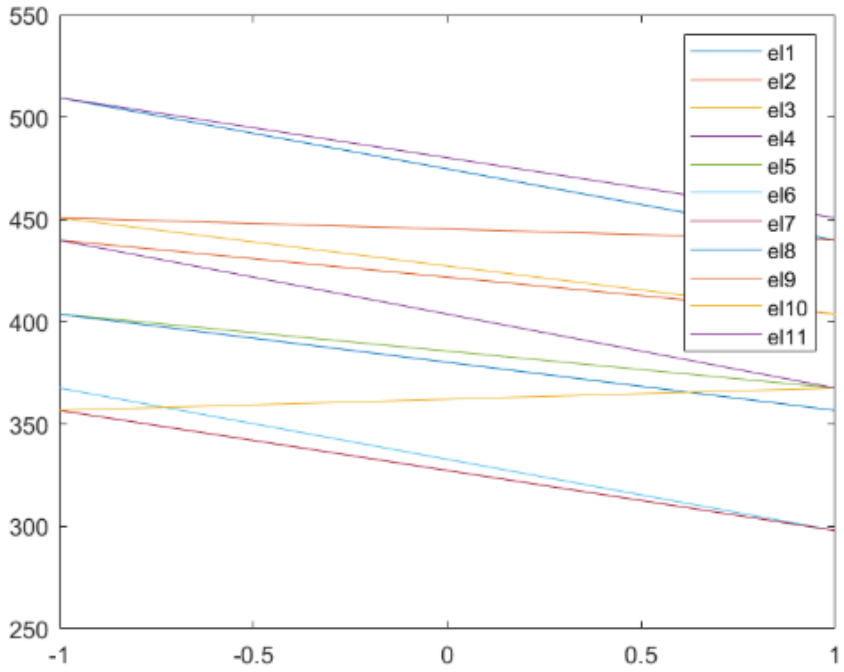
1	509.5566
2	474.7334
3	439.9101
4	421.8442
5	403.7783
6	427.3062
7	450.8340
8	480.1953
9	385.7124
10	367.6465
11	332.8233
12	298.0000
13	327.3613
14	356.7226
15	380.2505
16	445.3720
17	362.1846
18	403.7783

Displacements of the Nodes under the condition ***P=1000N***



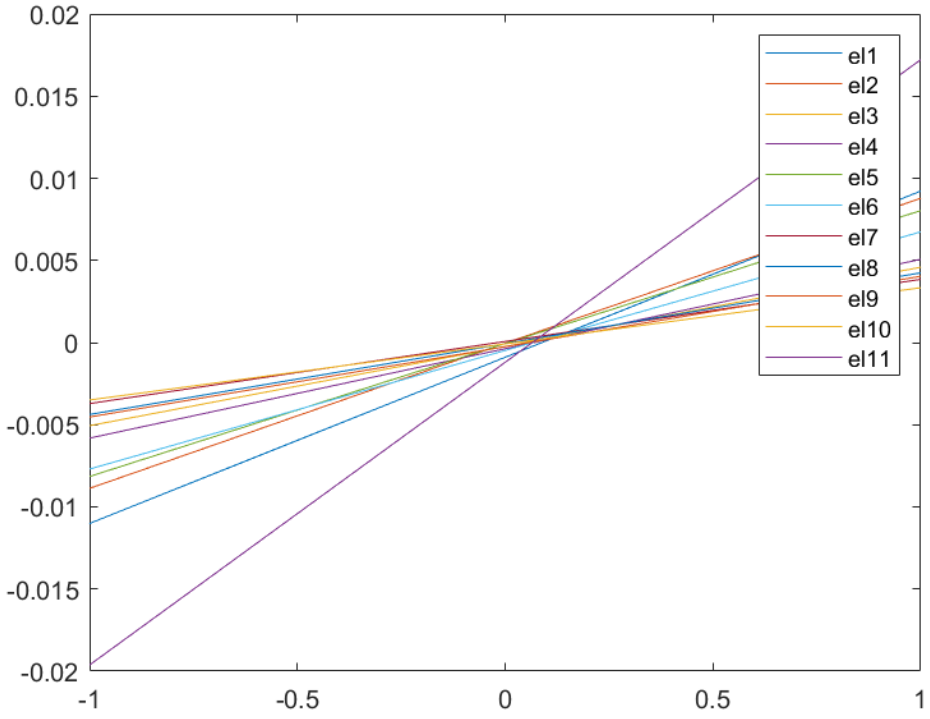
Here the Results are scaled by 100 for analysis….

Temperature Field in all the elements:



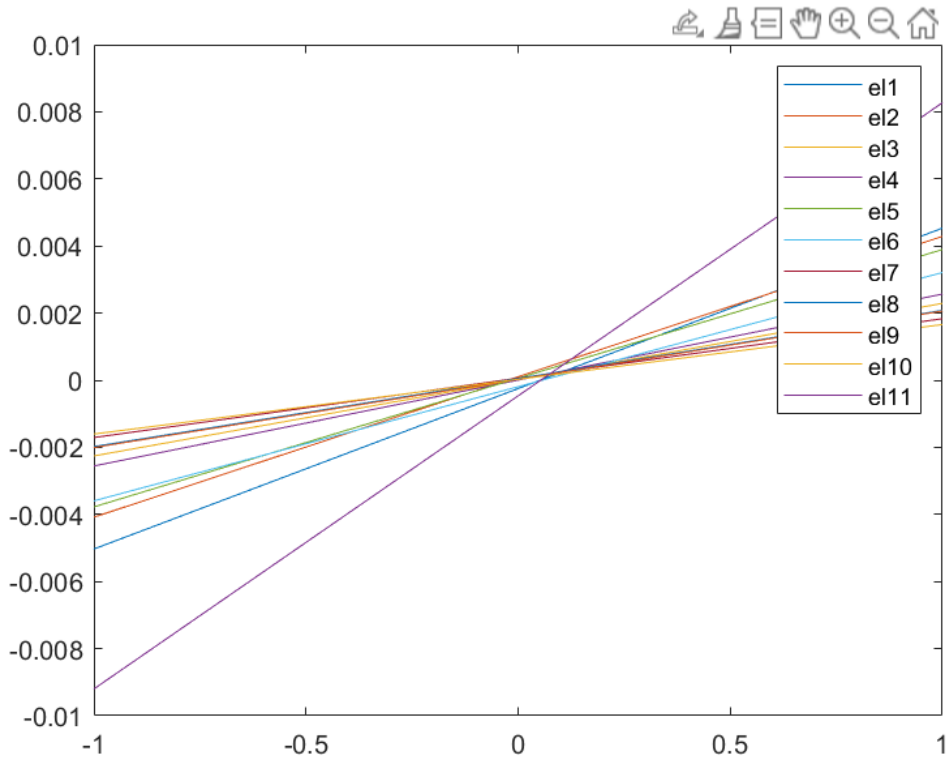
	1	2	3	4	5	6	7	8	9	10	11
1	509.5566	439.9101	450.8340	509.5566	403.7783	367.6465	356.7226	403.7783	450.8340	356.7226	439.9101
2	506.0743	438.1035	448.4812	506.6205	401.9717	364.1642	353.7865	401.4255	450.2878	357.2688	436.2969
3	502.5920	436.2969	446.1284	503.6844	400.1651	360.6819	350.8504	399.0728	449.7416	357.8150	432.6837
4	499.1097	434.4903	443.7756	500.7482	398.3586	357.1996	347.9143	396.7200	449.1954	358.3612	429.0706
5	495.6273	432.6837	441.4229	497.8121	396.5520	353.7172	344.9781	394.3672	448.6492	358.9074	425.4574
6	492.1450	430.8772	439.0701	494.8760	394.7454	350.2349	342.0420	392.0144	448.1030	359.4536	421.8442
7	488.6627	429.0706	436.7173	491.9398	392.9388	346.7526	339.1059	389.6616	447.5568	359.9998	418.2310
8	485.1804	427.2640	434.3645	489.0037	391.1322	343.2703	336.1697	387.3088	447.0106	360.5460	414.6179
9	481.6980	425.4574	432.0117	486.0676	389.3256	339.7879	333.2336	384.9561	446.4644	361.0922	411.0047
10	478.2157	423.6508	429.6589	483.1314	387.5190	336.3056	330.2975	382.6033	445.9182	361.6384	407.3915
11	474.7334	421.8442	427.3062	480.1953	385.7124	332.8233	327.3613	380.2505	445.3720	362.1846	403.7783
12	471.2510	420.0376	424.9534	477.2592	383.9058	329.3409	324.4252	377.8977	444.8259	362.7308	400.1651
13	467.7687	418.2310	422.6006	474.3231	382.0993	325.8586	321.4891	375.5449	444.2797	363.2770	396.5520
14	464.2864	416.4244	420.2478	471.3869	380.2927	322.3763	318.5529	373.1921	443.7335	363.8232	392.9388
15	460.8041	414.6179	417.8950	468.4508	378.4861	318.8940	315.6168	370.8393	443.1873	364.3694	389.3256
16	457.3217	412.8113	415.5422	465.5147	376.6795	315.4116	312.6807	368.4866	442.6411	364.9156	385.7124
17	453.8394	411.0047	413.1895	462.5785	374.8729	311.9293	309.7445	366.1338	442.0949	365.4618	382.0993
18	450.3571	409.1981	410.8367	459.6424	373.0663	308.4470	306.8084	363.7810	441.5487	366.0080	378.4861
19	446.8748	407.3915	408.4839	456.7063	371.2597	304.9647	303.8723	361.4282	441.0025	366.5542	374.8729
20	443.3924	405.5849	406.1311	453.7701	369.4531	301.4823	300.9361	359.0754	440.4563	367.1003	371.2597
21	439.9101	403.7783	403.7783	450.8340	367.6465	298.0000	298.0000	356.7226	439.9101	367.6465	367.6465

Stress Field in all the elements:



10^9 ×	1	2	3	4	5	6	7	8	9	10	11
1	-1.1010	-0.8874	-0.5060	-0.5816	-0.8151	-0.7699	-0.3713	-0.4377	-0.4531	-0.3493	-1.9622
2	-0.9998	-0.7991	-0.4578	-0.5272	-0.7342	-0.6977	-0.3335	-0.3946	-0.4103	-0.3151	-1.7780
3	-0.8987	-0.7108	-0.4095	-0.4728	-0.6533	-0.6255	-0.2957	-0.3514	-0.3675	-0.2810	-1.5938
4	-0.7975	-0.6225	-0.3613	-0.4184	-0.5724	-0.5533	-0.2579	-0.3083	-0.3246	-0.2468	-1.4096
5	-0.6964	-0.5343	-0.3131	-0.3639	-0.4914	-0.4811	-0.2201	-0.2652	-0.2818	-0.2127	-1.2254
6	-0.5952	-0.4460	-0.2648	-0.3095	-0.4105	-0.4089	-0.1823	-0.2221	-0.2390	-0.1785	-1.0412
7	-0.4941	-0.3577	-0.2166	-0.2551	-0.3296	-0.3367	-0.1445	-0.1790	-0.1962	-0.1444	-0.8569
8	-0.3929	-0.2694	-0.1684	-0.2007	-0.2487	-0.2645	-0.1067	-0.1359	-0.1533	-0.1103	-0.6727
9	-0.2918	-0.1811	-0.1201	-0.1463	-0.1677	-0.1924	-0.0689	-0.0927	-0.1105	-0.0761	-0.4885
10	-0.1906	-0.0928	-0.0719	-0.0918	-0.0868	-0.1202	-0.0311	-0.0496	-0.0677	-0.0420	-0.3043
11	-0.0895	-0.0045	-0.0237	-0.0374	-0.0059	-0.0480	0.0067	-0.0065	-0.0248	-0.0078	-0.1201
12	0.0117	0.0838	0.0246	0.0170	0.0750	0.0242	0.0445	0.0366	0.0180	0.0263	0.0641
13	0.1128	0.1721	0.0728	0.0714	0.1559	0.0964	0.0823	0.0797	0.0608	0.0605	0.2484
14	0.2139	0.2604	0.1210	0.1258	0.2369	0.1686	0.1202	0.1228	0.1036	0.0946	0.4326
15	0.3151	0.3487	0.1693	0.1803	0.3178	0.2408	0.1580	0.1659	0.1465	0.1288	0.6168
16	0.4162	0.4370	0.2175	0.2347	0.3987	0.3130	0.1958	0.2091	0.1893	0.1629	0.8010
17	0.5174	0.5253	0.2657	0.2891	0.4796	0.3852	0.2336	0.2522	0.2321	0.1971	0.9852
18	0.6185	0.6136	0.3139	0.3435	0.5606	0.4574	0.2714	0.2953	0.2749	0.2312	1.1694
19	0.7197	0.7019	0.3622	0.3979	0.6415	0.5296	0.3092	0.3384	0.3178	0.2654	1.3536
20	0.8208	0.7902	0.4104	0.4524	0.7224	0.6018	0.3470	0.3815	0.3606	0.2995	1.5379
21	0.9220	0.8785	0.4586	0.5068	0.8033	0.6740	0.3848	0.4246	0.4034	0.3337	1.7221

Strain Field All the elements



	1	2	3	4	5	6	7	8	9	10	11
1	-0.0050	-0.0041	-0.0023	-0.0026	-0.0038	-0.0036	-0.0017	-0.0020	-0.0020	-0.0016	-0.0092
2	-0.0046	-0.0037	-0.0020	-0.0023	-0.0034	-0.0033	-0.0015	-0.0018	-0.0018	-0.0014	-0.0083
3	-0.0041	-0.0032	-0.0018	-0.0020	-0.0030	-0.0029	-0.0014	-0.0016	-0.0016	-0.0013	-0.0075
4	-0.0036	-0.0028	-0.0016	-0.0018	-0.0026	-0.0026	-0.0012	-0.0014	-0.0014	-0.0011	-0.0066
5	-0.0031	-0.0024	-0.0013	-0.0015	-0.0022	-0.0022	-0.0010	-0.0012	-0.0012	-0.0010	-0.0057
6	-0.0026	-0.0020	-0.0011	-0.0013	-0.0019	-0.0019	-0.0008	-0.0010	-0.0010	-0.0008	-0.0048
7	-0.0022	-0.0016	-0.0009	-0.0010	-0.0015	-0.0016	-0.0006	-0.0008	-0.0008	-0.0006	-0.0040
8	-0.0017	-0.0012	-0.0007	-0.0008	-0.0011	-0.0012	-0.0005	-0.0006	-0.0006	-0.0005	-0.0031
9	-0.0012	-0.0007	-0.0004	-0.0005	-0.0007	-0.0009	-0.0003	-0.0004	-0.0004	-0.0003	-0.0022
10	-0.0007	-0.0003	-0.0002	-0.0003	-0.0003	-0.0005	-0.0001	-0.0002	-0.0002	-0.0001	-0.0013
11	-0.0002	0.0001	0.0000	0.0000	0.0001	-0.0002	0.0001	0.0001	0.0000	0.0000	-0.0005
12	0.0002	0.0005	0.0002	0.0003	0.0004	0.0001	0.0002	0.0003	0.0002	0.0002	0.0004
13	0.0007	0.0009	0.0005	0.0005	0.0008	0.0005	0.0004	0.0005	0.0004	0.0004	0.0013
14	0.0012	0.0014	0.0007	0.0008	0.0012	0.0008	0.0006	0.0007	0.0006	0.0005	0.0022
15	0.0017	0.0018	0.0009	0.0010	0.0016	0.0012	0.0008	0.0009	0.0008	0.0007	0.0030
16	0.0021	0.0022	0.0012	0.0013	0.0020	0.0015	0.0009	0.0011	0.0010	0.0008	0.0039
17	0.0026	0.0026	0.0014	0.0015	0.0024	0.0018	0.0011	0.0013	0.0012	0.0010	0.0048
18	0.0031	0.0030	0.0016	0.0018	0.0027	0.0022	0.0013	0.0015	0.0015	0.0012	0.0056
19	0.0036	0.0035	0.0018	0.0021	0.0031	0.0025	0.0015	0.0017	0.0017	0.0013	0.0065
20	0.0041	0.0039	0.0021	0.0023	0.0035	0.0029	0.0017	0.0019	0.0019	0.0015	0.0074
21	0.0045	0.0043	0.0023	0.0026	0.0039	0.0032	0.0018	0.0021	0.0021	0.0017	0.0083

Yield Stress Field

	1	2	3	4	5	6	7	8	9	10	11
1	221.6262	231.0347	229.4838	221.6262	235.8131	240.5914	242.1424	235.8131	229.4838	242.1424	231.0347
2	222.0966	231.2737	229.8003	222.0190	236.0520	241.0618	242.5352	236.1295	229.5613	242.0648	231.5126
3	222.5670	231.5126	230.1167	222.4119	236.2909	241.5323	242.9281	236.4460	229.6389	241.9873	231.9904
4	223.0374	231.7515	230.4332	222.8048	236.5298	242.0027	243.3210	236.7625	229.7164	241.9097	232.4682
5	223.5079	231.9904	230.7497	223.1977	236.7687	242.4731	243.7139	237.0789	229.7940	241.8322	232.9461
6	223.9783	232.2293	231.0661	223.5906	237.0077	242.9436	244.1068	237.3954	229.8715	241.7546	233.4239
7	224.4487	232.4682	231.3826	223.9834	237.2466	243.4140	244.4997	237.7119	229.9491	241.6771	233.9017
8	224.9192	232.7072	231.6990	224.3763	237.4855	243.8844	244.8925	238.0283	230.0266	241.5995	234.3796
9	225.3896	232.9461	232.0155	224.7692	237.7244	244.3548	245.2854	238.3448	230.1042	241.5220	234.8574
10	225.8600	233.1850	232.3320	225.1621	237.9633	244.8253	245.6783	238.6613	230.1817	241.4444	235.3352
11	226.3305	233.4239	232.6484	225.5550	238.2022	245.2957	246.0712	238.9777	230.2593	241.3669	235.8131
12	226.8009	233.6628	232.9649	225.9479	238.4412	245.7661	246.4641	239.2942	230.3368	241.2893	236.2909
13	227.2713	233.9017	233.2814	226.3407	238.6801	246.2366	246.8569	239.6106	230.4144	241.2118	236.7687
14	227.7417	234.1407	233.5978	226.7336	238.9190	246.7070	247.2498	239.9271	230.4919	241.1342	237.2466
15	228.2122	234.3796	233.9143	227.1265	239.1579	247.1774	247.6427	240.2436	230.5695	241.0567	237.7244
16	228.6826	234.6185	234.2308	227.5194	239.3968	247.6479	248.0356	240.5600	230.6470	240.9791	238.2022
17	229.1530	234.8574	234.5472	227.9123	239.6357	248.1183	248.4285	240.8765	230.7246	240.9016	238.6801
18	229.6235	235.0963	234.8637	228.3052	239.8747	248.5887	248.8214	241.1930	230.8021	240.8241	239.1579
19	230.0939	235.3352	235.1802	228.6980	240.1136	249.0591	249.2142	241.5094	230.8797	240.7465	239.6357
20	230.5643	235.5742	235.4966	229.0909	240.3525	249.5296	249.6071	241.8259	230.9572	240.6690	240.1136
21	231.0347	235.8131	235.8131	229.4838	240.5914	250.0000	250.0000	242.1424	231.0347	240.5914	240.5914

Minimum P required for the breakdown of the complete structure = ***7.186228*10^{5}Newtons***

And the Breakdown point is ***xi=-0.7 of element 11***

Just for reference

- I shall be attaching three mlx files named Part A, Part B, and Part C, where I have done complete analysis for Temperature, stress, and displacement along with the demonstration of all the asked fields in PartA.mlx and have calculated the Pmin for the breakdown in Part C.
- The Mesh refining was partially coded and wasn't able to d=finish time; if you may, I would be willing to explain the complete process in the viva, thus embedded in PartB as function partb().