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Structural Analysis of Continuous Beam Using Finite Element Method and ANSYS Software-A Review

Hemang Gadhavi[1], Vishalkumar B. Patel[2], Pratiti M. Bhatt[2], Dr. Vishal A. Arekar[2], Dr. Indrajit N. Patel[3]

PG Research Scholar, Department of Structural Engineering, Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar, Gujarat, India[1]

Assistant Professor & Departmental Coordinator, Department of Structural Engineering, Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar, Gujarat, India[2]

Principal & Professor, Department of Structural Engineering, Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar, Gujarat, India[3]

Abstract: This review paper provides an in-depth analysis of a basic finite element formulation for beam elements subjected to flexural loads. The source document employs stiffness matrices for several segments of beams to obtain rotations and moments from consistent force and displacement vectors. Highlight is given to the assembly of global stiffness matrices, imposition of boundary conditions, and computation of element responses such as bending moments and rotations. The solutions are employed in illustrating the consistency and precision of the finite element method in simulating structural systems. The review places the method in the context of overall structural analysis and its importance to engineering application and academic teaching.

Keywords: Finite Element Analysis; Stiffness Matrix; Rotation and Distribution; Structural Engineering; Element Assembly; ANSYS; FEM

I. INTRODUCTION

Finite element method (FEM) is the central computational package in structural mechanics, enabling computation of displacement, rotation, and internal stress of intricate structures [1-15]. The target paper is particularly concerned with applying finite element analysis for continuous beams loaded by flexure forces [16-24]. It employs matrix formulation to arrive at a solution for flexure in different beam components connected at node points, in terms of their stiffness matrices modelling the behaviour [25-35]. Individual beam elements are solved independently on the basis of length and stiffness properties, and local stiffness matrices are determined and assembled into a global stiffness matrix controlling the overall structural system [35-55].

The approach is accomplished by the division of a continuous beam into three elements with different lengths and applying the classical stiffness matrix formulation to each of them [55-61]. These matrices are element length normalized and modulus of elasticity times moment of inertia (EI) normalized and assembled in a global system [61-70]. The paper uses applied external moment and force vectors cautiously, determines unknown nodal rotations (θ), and back-calculates the internal bending moments by consistent force methods. The precise quantitative results demonstrate the way finite element modeling effectively represents the rotation and bending moment distribution over the beam's span under imposed loads [70-83].

Through demonstrating each phase of the finite element method—element matrix calculation through to global assembly, loading vector incorporation, and solving simultaneous equations—the work presents a root-level illustration of the effectiveness of FEM for flexural analysis. Clarity of mathematical design and procedure ensures not just it being practically viable for use in structure analysis, but it's perfect for instructional application. The findings demonstrate FEM's ability to work with statically indeterminate structures in a very easy manner and pave the way for further complex studies including dynamic loads, material nonlinearities, or multi-dimensional structural systems [55-83].

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II. LITERATURE REVIEW

Lam Thanh Quang Khai et al. [1] performed Structural Analysis of Continuous Beam Using FEM and ANSYS. Structural analysis of continuous beams is significant due to the fact that continuous beams are complex in nature, characterized by numerous spans and varied loads. Application of traditional methods like the moment distribution and slope deflection methods is restricted in terms of accuracy for complex structures. Finite Element Method (FEM) is nowadays a tool without which it's no longer possible to model by slicing beams into several small beam slices. Software tools like ANSYS make it possible by supplying an effective utility for solving beam problems that are highly complex like non-uniform load, support variations, or non-linear materials. As the existing research shows, FEM and ANSYS accurately predict deflections, internal stresses, and moments for continuous beams more precisely than with traditional methods. Integration, which is made possible by the use of the tools, offers the possibility of having flexible and safe designs, particularly in actual engineering applications. Literature today renders FEM and ANSYS as standard tools of current beam analysis with the prospect for having a better, more effective prediction of the performance of a beam under changed conditions

Bykiv et al. [2] examined the application of shape memory alloys (SMA) to improve the performance of reinforced concrete beams under bending load. In a comparison through finite element analysis (FEA), they investigate the performance of beams reinforced with SMA and steel under 3- and 4-point bending. The results indicate that SMA rods, especially NiTi alloys, improve the elasticity of beams and minimize residual deflection by 24% and 27% under 3- and 4-point bending, respectively. The research confirms the efficiency of SMA in deflection reduction and the integrity of the structure under load.

Ghatole et al. [3] illustrated the application of finite element analysis (FEA) to analyze stress and deflection in stepped bars under axial loading. ANSYS and MATLAB analytical solutions were compared and were found to be equal. The authors indicate that the application of MATLAB and ANSYS saves cost in solving complex FEA problems, especially in structural analysis. The authors indicate that ANSYS provides more solutions and thus is a suitable tool for engineers to solve complex geometries that are not easy to solve manually.

Sanjie Dutt A. Kumar et al. [4] have authored a literature review of the use of the Finite Element Method (FEM) for seismic analysis of underground structure diaphragm walls. Diaphragm walls are crucial for deep urban excavations and are susceptible to seismic risk. FEM is a strong tool to simulate such seismic loads, and it offers information on soil-structure interaction. Drawbacks are high memory demand, incompatibility with real-time, and the complexity of nonlinear problems. Different FEM tools like ABAQUS, OptumG2, and PLAXIS 3D are used, each with its own advantages. Seismic risk analysis states that effective FEM modeling can increase the resistivity of diaphragm walls but future research should aim to enhance models for higher accuracy and efficiency.

Yasser E. Ibrahim et al. [5] compared the impact of train vibrations on multilevel buildings, in this instance, reinforced concrete framed buildings along train tracks. The results showed that building-train track distance had a major influence on vibration level. For instance, when the train track was 5 m away from the building, top floor maximum acceleration levels were as high as 11.78 m/s^2 and decreased with larger distances. Vertical velocities and displacements also decreased with larger distances, maximum vertical displacement being 5.99 mm at 5 m. With regard to mitigation, foam-filled and open trenches were both effective in vibration mitigation. In-filled foam trench achieved an acceleration decrease by 61.29%, and the open trench achieved the same by 57.39%. Vertical velocities and displacements also decreased significantly, foam-filled trenches being less effective than open trenches by a narrow margin. Train speed was also a consideration, as the higher the speed of the train, the higher the vibration, there being little difference at 430 km/h and 540 km/h.

Abhishek Mishra et al. [6] explained the differences and contrasts between P-delta analysis and Finite Element Method (FEM) for a G+10 multistory building frame specifically. To carry out their analysis, they employed the Zone 3 seismic analysis as per the guidelines prescribed in IS 1893:2016 to enable strict testing of structural responses against seismic loads. Throughout the research, significant parameters such as displacement, storey shear, and bending moments were compared systematically in the two analytical methods. The results presented in the paper reveal that P-delta analysis recorded a 59% increase in displacement in comparison to results obtained using FEM. Also, it was noted that P-delta analysis recorded a huge 33% higher storey shear, citing the difference in the manner in which each analytical method responds to lateral forces. Also, the analysis revealed that P-delta analysis recorded 22% higher bending moments in comparison to Finite Element Method. In addition, support reaction obtained using P-delta analysis was found to be 20% higher, primarily due to the second-order effects of this analysis method.

ZhiQiang Zhang et al. [7] ANSYS software is utilized to great benefit, simulating with great accuracy the complex thermal cycles that are necessarily involved with several welding processes, thus illustrating the wide-ranging

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potential of FEA in highly effectively simulating the complex temperature fields involved, with a high degree of success. Through the systematic combination of advanced structural analysis methods as well as FEA, the overall effectiveness of the simulations was highly enhanced, resulting in a high level of reduction of run time, averaging an impressive 3.58 minutes, and thus leading to an impressive enhancement of overall effectiveness by a high 21.81%. These groundbreaking observations go to strongly illustrate the wide-ranging potential of FEA in simplifying and streamlining complex computations in structural analysis, as well as its wide-ranging and highly diverse applications within the overall area of engineering simulations.

Shrikant Siddheshwar Pendor et al. [8] acknowledge great improvements in optimization of structural performance, cost, and material utilization. Four trusses, including Howe, Pratt, K-Type, and Warren, are modeled in this research work from STAAD.Pro software under IRS 25t Loading-2008 condition for general gauge railway. Structural parameters such as maximum shear force, axial force, deflection, and weight of steel are compared. Results indicate that the K-type truss carries the highest shear forces, Warren truss carries the highest axial forces (1235.63 kN), and Pratt truss carries the highest deflection (24.49 mm), which is a sign of instability in these structures when under dynamic loads. On the other hand, the Howe truss resists lower shear (479.81 kN), mean axial force (1211.1 kN), and lower deflection (23.399 mm), thereby being more economically and structurally viable. The cost and weight of steel as well come out the same, the lowest being that of the Warren's highest (₹33.40 lakh) of the Howe truss at ₹28.33 lakh. In contrast to other researches comparing T-beam girders, slab tracks, or prestressed trusses, the paper is unique in that it combines structural analysis and cost comparison to prove the capability of FEM in coming up with cost-efficient and cost-effective bridge designs.

V. R. Shinde et al. [9] provides a general comparative study of three steel truss bridge types—Pratt, Warren, and Howe—by modeling and simulation under STAAD Pro V8i. A bridge of 70 meters length, 7.5 meters width, and 6 meters height is studied, and variations in roof truss spacings are introduced first as equal to 0.5 meters and then further divided into ten equal spans of 7 meters. Engineering design strategy includes the calculation of forces in members, support reactions, torsional reaction, shear force, and moment for different combinations of loads, i.e., IRC Class 70R, AA, A, and B live loads. Notably, truss joints are modeled as pinned and, at key nodes, welded joints are used to simulate realistic transmission of forces in tensile and compressive loading. The comparative results indicate that the Howe truss has the largest support reaction and shear force, then the Warren truss has the largest displacement and moment, which reflects different performance tendencies under structural loading. Additionally, the Pratt truss has much larger torsional values, which reflects the effect of truss geometry on static and dynamic response. The research emphasizes the need for specially designed truss selection according to structural performance requirements like displacement, shear, torsion, and moment capacity.

Atul Sharma et al. [10] provided a comprehensive technical analysis of three steel truss bridge structures, namely K-Truss, Pratt Truss, and Warren Truss, for different spans of 40m, 50m, and 60m utilizing Midas Civil software. The analysis includes built-up steel members and follows IRC-6 (2016) loading standards for dead load, live load, and wind load analysis. Individual geometric and structural parameters are specified for each arrangement, including material parameters such as a steel density of 7850 kg/m³, yield strength of 250 MPa, and ultimate tensile strength of 410 MPa. Regional variation is included in wind pressure calculations using the 1/7th power law and employing various drag coefficients and net areas for each type of truss arrangement. The findings show that Warren Trusses have the highest axial forces, bending moments, and shear forces, which are due to the absence of vertical members. In contrast, K-Trusses have major reductions in structural stresses due to their vertical members, hence are structurally stronger when loaded. Weight analyses show that Pratt Truss is most economic at 40m spans, while Warren Trusses are best suited to 50m and 60m spans with material savings of up to 11.27% over K-Trusses. The conclusions in respect of the choice of truss type between both the mechanical performance and material economy therefore follow.

III. RESULTS

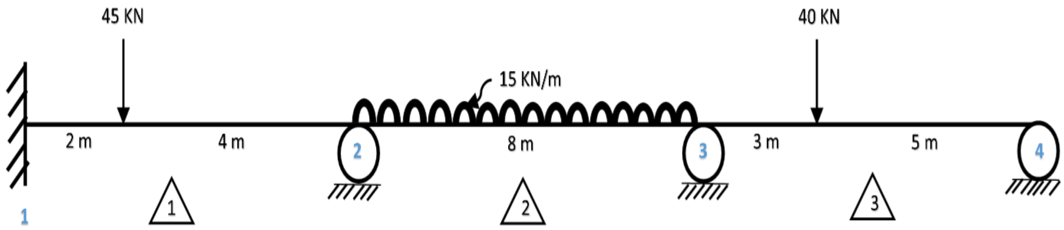

Fig.1 A three-span continuous beam

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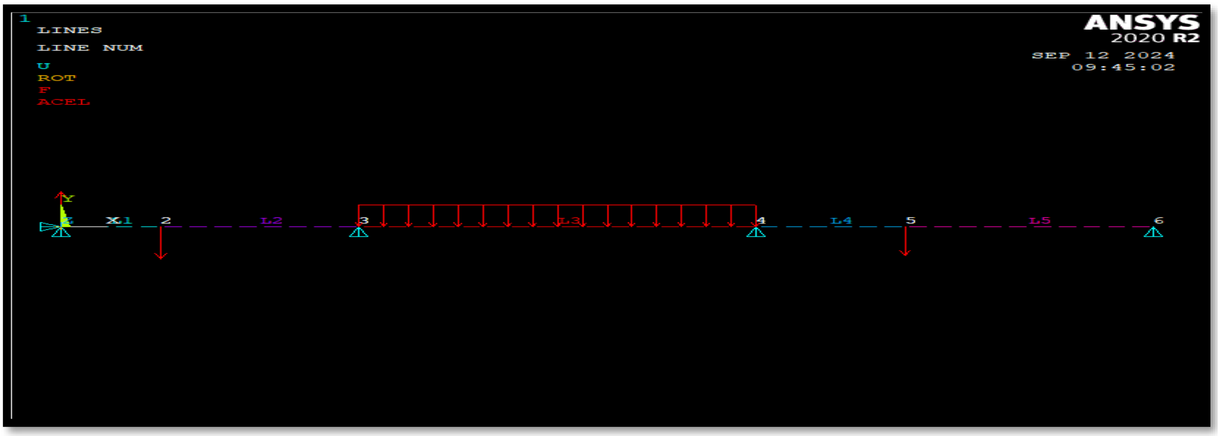

Fig.2 Geometric model of a beam

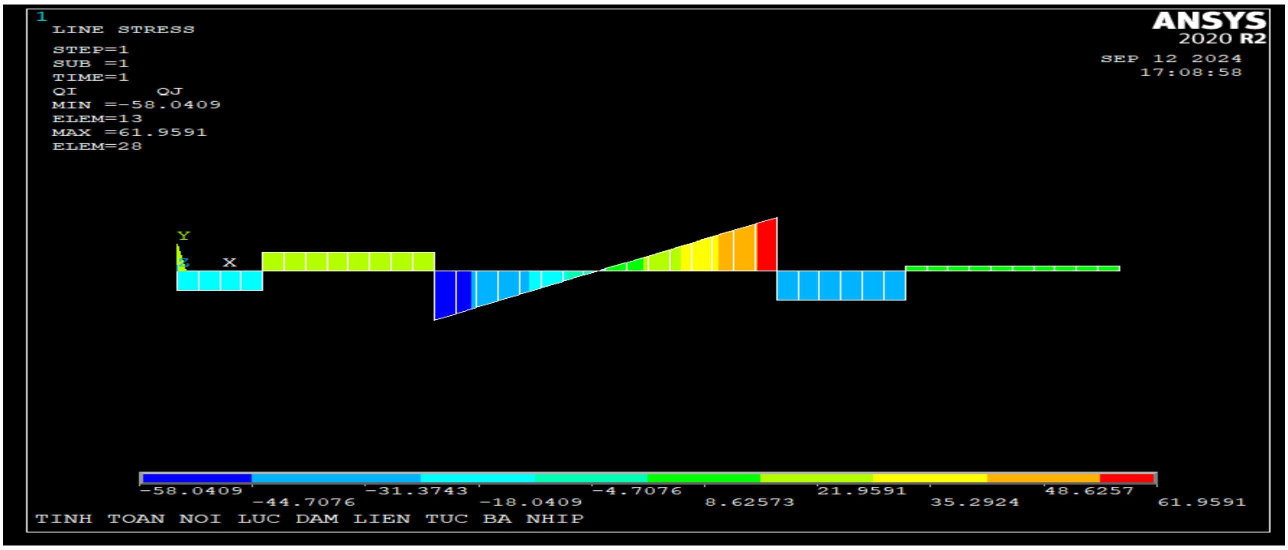

Fig.3 Shear force diagram

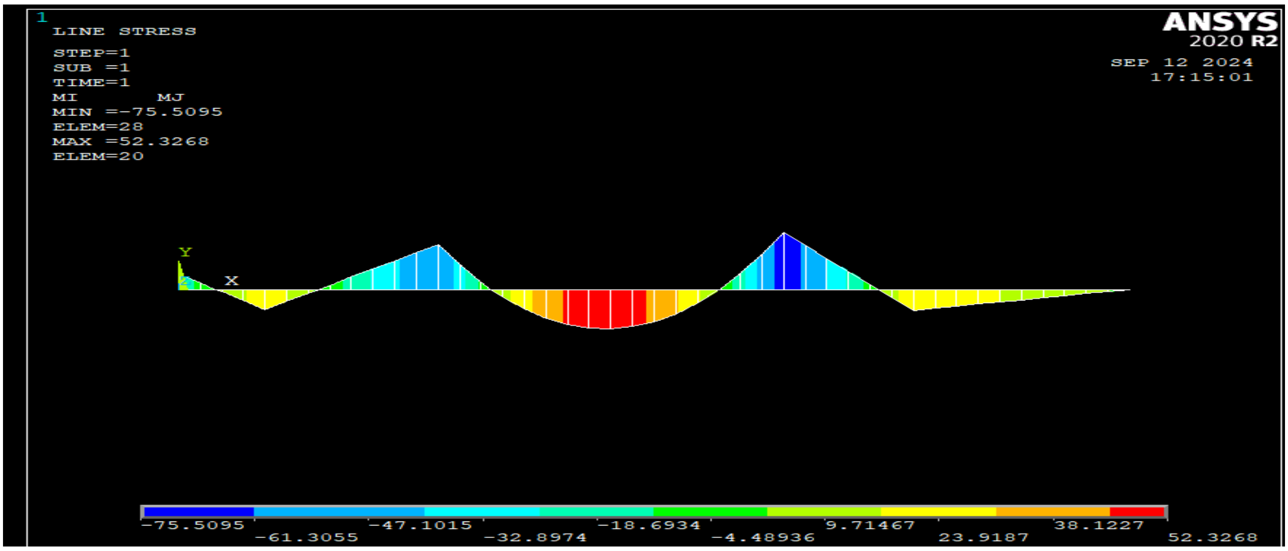

Fig.4 Bending moments diagram

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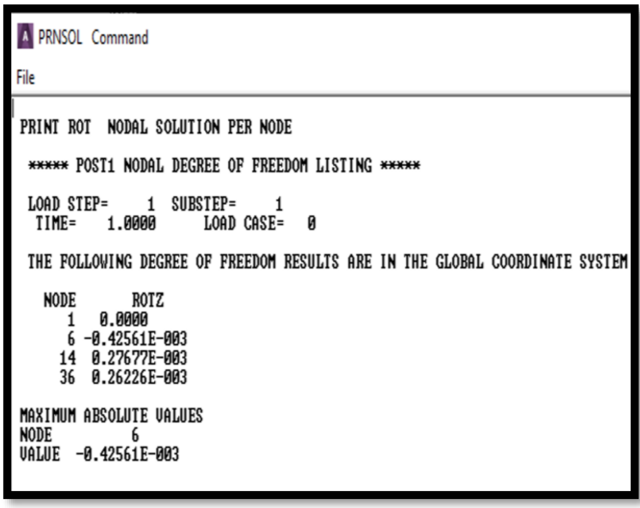

Fig.5 Angle displacement at points

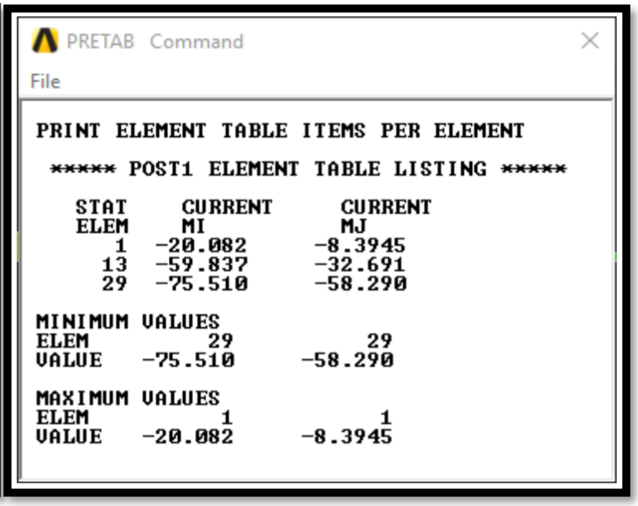

Fig.6 BM Values at the elements

IV.SUMMARY

The article illustrates a comprehensive finite element analysis (FEA) of a continuous beam system under bending. The beam is discretized into three elements of different lengths, and the stiffness matrix of each element is obtained using the conventional Euler-Bernoulli beam theory. Each local stiffness matrix takes the form $[K]=\frac{EI}{L}\begin{bmatrix}4 & 2\\ 2 & 4\end{bmatrix}$ where EI represents the flexural rigidity and L the element length. The matrices for individual elements are scaled accordingly and assembled into a global stiffness matrix that incorporates all nodes and degrees of freedom. The use of symmetry and continuity in the matrix formulation ensures consistency and stability of the global system.

To find the structural response, there are external moment and force vectors imposed at different nodes. These are in the form of fixed-end moments and nodal shear forces represented in a vector format for every element. The equations are formulated based on the equation $[K]\{\Theta\} = \{F\}$, where $\{\Theta\}$ represents the unknown nodal rotations and {F} the equivalent nodal load vector. The resulting system is solved by matrix algebra methods, providing accurate values for nodal rotations at every junction. These rotations are subsequently employed to back-calculate the internal bending moments in every beam element from the relation $\{M\} = [K_{local}]\{\Theta_{local}\} + \{M_{fixed}\}$, providing a complete picture of internal force distribution. The outcome of the analysis is in the form of calculated nodal rotation and bending moments of each of the three beam elements. The moments are negative to positive, similar to the nature of beams under various zones of loading in terms of natural responses. The verification of the correspondence of the calculated results with traditional mechanical behavior confirms the validity of the finite element model. In addition, the open and organized procedure, including matrix formulation, application of loads, and retrieval of forces, demonstrates the capability of FEM to solve complex flexural problems beyond the capability of traditional analytical procedures alone.

V.CONCLUSION

This paper demonstrates how the fundamentals of finite element analysis are useful for applying to beam structures in bending. By dividing a structure with a continuous beam into three elements, the work covers the whole process of constructing the local stiffness matrix and assembling it to produce the global system. Uniform properties of all the elements carefully define the flexural rigidity and length so that the numerical results apply to structures. The robust representation of element level matrices using EI and L, and a logical connectivity of nodes, demonstrates the capability of the matrix based modeling for structural analysis. [1-15].

Perhaps the greatest contribution of this work is the imposition of a loading condition upon the matrix system. Generation and use of nodal force vectors via fixed-end moments and shear forces enable the model to accurately treat static indeterminacy. The solution to the global system yields the nodal rotations to back calculate internal moments. The present step shows the benefit of FEM to capture local behavior of stress and deformation, which is not easy to attain with classical methods for multi-span or complicated load cases. [1-15].

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In general, the study establishes the rigorousness, precision, and versatility of the finite element procedure in predicting the response of continuous beam systems. The methodological approach, which relies upon matrix algebra and mechanics, may then be useful as an effective engineering solution as well as for the pedagogical goal of learning FEM. Although this study is currently based on linear, elastic behaviour under static loading, the same approach can be applied to nonlinear, dynamic, or multi-dimensional problems, which shows the flexibility and continuing relevance of FEM for decide to adopt a given approach, In addition to its implementation. [1-15].

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