An Assessment of Artificial Intelligence Capabilities in Structural Analysis: A Comparative Study of Determinate and Indeterminate Beams

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Abstract- *This paper critically evaluates the performance of several AI models in structural analysis. The capability of different AI systems, including ChatGPT, DeepSeek, Gemini, and Perplexity, was assessed using a series of beam problems with varying degrees of static indeterminacy and structural complexity. The outputs were benchmarked against classical analytical methods, namely the force method and slope-deflection method, as well as numerical results obtained from structural analysis software (SAP2000). The results indicate that AI models can produce reasonably accurate results for statically determinate beams and systems with low levels of indeterminacy. However, their accuracy decreases significantly as structural complexity increases, with notable discrepancies observed in highly indeterminate systems. The study concludes that current AI models lack the effectiveness required for reliable structural analysis of complex systems and should not be used by engineers as the obtained results are not reliable especially for complex and statically indeterminate structures.*

1.0 INTRODUCTION

Designing any structure involves several stages, including the conceptual stage, preliminary design stage, and final design stage. The final design stage requires accurate structural analysis of the structure. In this stage, the loads acting on the structure are determined, and structural analysis is performed to evaluate the different internal forces and stresses acting on the structure, such as shear forces, bending moments, axial forces, and others.

Accurate structural analysis is highly important to ensure the safe design of a structure. Furthermore, it is essential for determining the ability of the structure to withstand the imposed loads without failure or excessive deflection. Proper structural analysis requires sufficient knowledge, as it involves the idealization of member connections and support conditions [4]. Furthermore, the analysis of structures depends on the structure classification. Structures are generally classified as determinate or indeterminate structures. The analysis of determinate structures is considered relatively straightforward because it can be performed using the equations of static equilibrium, while the analysis of indeterminate structures is more complex, as it requires both equilibrium and compatibility equations [4]. It is important to note that most real-life structures are indeterminate; therefore, efficient and reliable methods for analyzing such structures are essential for structures design.

Various methods are available for the analysis of indeterminate structures, including classical manual methods such as the force method, slope-deflection method, and displacement method [4]. Although these methods can provide accurate results, they require considerable time and become increasingly complex as the degree of structural indeterminacy increases. Nowadays, structural analysis software is widely used because it is easier to use and provides fast and reliable results. This paper investigates the capability and reliability of artificial intelligence (AI) in structural analysis. The study compares the results obtained from AI for various structural analysis problems and evaluates their accuracy and effectiveness.

2.0 Structural analysis

2.1 Importance of structure analysis

Structural analysis is significantly critical for the design of any structure. Structural analysis involves the determination of loads on a structure, such as dead load, live load, wind load, etc., followed by the application of load factors as required by the strength design methods as recommended by different design codes, such as ACI, AASHTO, etc. Therefore, during the structural analysis stage, the structure should be carefully studied and all anticipated loads determined to ensure an appropriate and sufficient design of the structure.

Following load determination, the second stage of structural analysis involves calculating support reactions and internal forces, including shear forces and bending moments. These computed forces are subsequently used by the designer to establish structural dimensions, reinforcement requirements, and other critical specifications. Safe and reliable design is contingent upon a robust and accurate structural analysis.

2.2 Main concept of structural analysis

2.2.1 Superposition theory

In structural analysis, the foundational premise relies on the principle of superposition, which dictates that the total displacement or internal resultant loadings at a given point can be determined by summing the individual displacements or internal loads caused by each external force acting independently [4]. The validity of the principle of superposition requires the structure to exhibit linear-elastic material behavior and undergoes no significant geometric deformations under the applied loads. The application of this principle is important to simplify complex structural analysis and is essential in solving statically indeterminate structures when utilized in conjunction with compatibility equations. [1].

2.2.2 Equilibrium and stability in structure

The application of the principles of statics to a structure requires the structure to be at rest, or in a static condition, rather than in a dynamic condition [7]. The analysis of static structures, such as bridges and buildings, requires that the conditions of equilibrium be satisfied. Equilibrium in a structure is achieved when the forces and moments acting on the structure are balanced [4]. A structure is considered to be in equilibrium when the summation of all forces and moments acting on it equals zero [1]. The satisfaction of the equilibrium equations is fundamental to structural analysis, as these equations form the basis for determining support reactions and internal forces within the structure.
For a two-dimensional structure, the equations of equilibrium are as follows:

$$\sum \mathrm{Fy} = 0, \sum \mathrm{Fx} = 0, \sum \mathrm{M0} = 0$$

The structural equilibrium equations are not valid for unstable structures. A structure will always be considered stable when the structure is sufficiently restrained by its supports [4]. Structures that are partially or improperly constrained will not be stable under loading. These unstable structures will not stay at rest or in equilibrium condition, which contradicts the static principles. Therefore, for unstable structures the static and equilibrium principle is not satisfied and the sum of forces and moment acting on the structure will not be zero. An example of unstable structure is shown in figure no: 1, the structure is not appropriately restrained, and the applied external force will result in structure rotation and movement which contradicts the principle of static and result in a non-equilibrium condition.

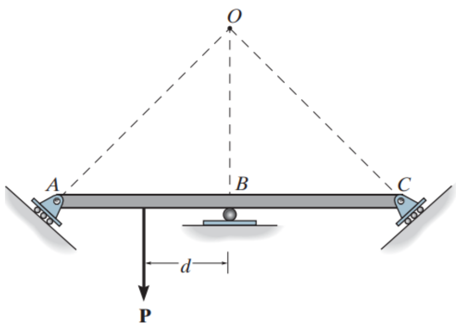

Figure 1 (Unstable structure example)

2.2.3 Compatibility of a structure

In the structural analysis of indeterminate structures, compatibility of the structure is very important and it is the key to solving indeterminate structures. Equilibrium is not sufficient to solve indeterminate structures, as the number of unknowns exceeds the number of equilibrium equations. The conditions of superposition theory necessitate that the structural material undergoes linear-elastic deformation with no significant changes in structural geometry. Therefore, the structure is assumed to maintain continuity and deform in a compatible way [5]. The compatibility of a structure is satisfied when the various parts of the structure deformation fit together without any breaks or steps [4].

An example of structure compatibility is the beam shown in figure no: 3. From compatibility, we know that the displacement at point B is zero before and after loading. The compatibility of the structure is significantly important, and it will be used for the solving of indeterminate structures.

Another example is the frame in figure no: 2, where the members of the frame are connected at joint B and the load is applied at frame span A-B. From compatibility, and by knowing that the structure will remain continuous when deformed, we know that the slope at both sides of point B is equal.

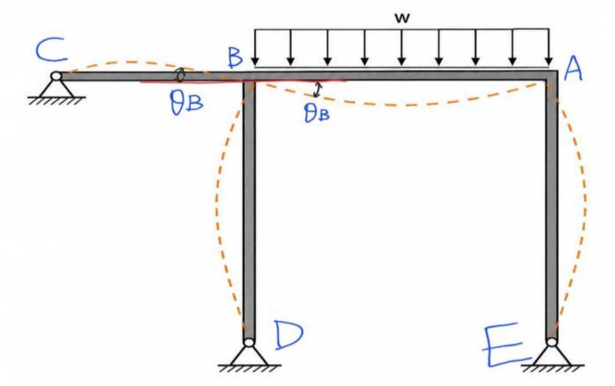

Figure 2 (Structural compatibility at a frame joint)

3.0 Structure determinacy

Structures are classified into determinate and indeterminate structures. Determinate structures can be identified as structures that require only the equilibrium equations to determine the unknown reactions [structure analysis and theory]. Determinate structures are simple structures and usually supported by a number of supports that are just sufficient to keep the structure stable and in equilibrium. The removal of one support will generally result in structural instability or failure.

Figure No.4 shows a simply supported beam. This type of beam is determinate, and the equilibrium equations are sufficient to find the reactions at the supports [4]. Furthermore, the supports are only sufficient to support the beam and keep it stable, and the failure of any support will result in the beam becoming unstable or failing.

Indeterminate structures can be defined as structures where the equilibrium equations alone are not sufficient to determine the unknown reactions [11]. In such structures, the number of support or internal forces exceeds the number of available equilibrium equations [4]. Solving indeterminate structures requires additional equations, which are obtained by relating the applied forces to the structural displacements and slopes. These equations are known as compatibility equations [2].

Let us consider the beam shown in Figure No.3. Here, we have three supports, while the number of valid equilibrium equations is only two. Therefore, to determine the unknown reactions, an additional equation is required, which is derived from the compatibility equations.

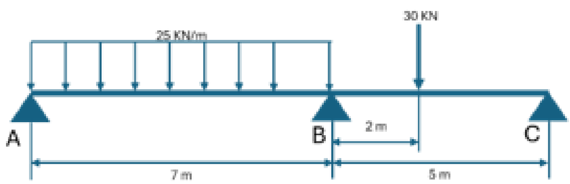

Figure 3 (Indeterminate beam example)

Unlike determinate structures, the failure of one support may not result in structural failure. Therefore, indeterminate structures are generally considered safer, as they possess higher reserve strength and better load distribution due to the availability of multiple load paths. This can improve the reliability and robustness of the structure and prevent, or significantly reduce, immediate failure resulting from the failure of a member. Therefore, the use of indeterminate structures is recommended to reduce the risk of structural failures that may occur due to member failure [3].

Indeterminate structures are also known as redundant structures. As the degree of structural redundancy increases, the ability of the structure to redistribute loads also increases. Consequently, the likelihood of structural failure due to the failure of a member decreases, as the structure possesses multiple load paths that can redistribute the loads without causing immediate collapse.

4.0 Structure analysis for determinate structures

The structural analysis of determinate structures is considered simpler compared to that of indeterminate structures. In determinate structures, the equilibrium equations are sufficient to determine the unknowns. Unlike determinate structures, indeterminate structures require compatibility equations in addition to equilibrium equations to determine the unknown reactions.

4.1 Manual analysis of determinate structures

The manual analysis of a determinate structure requires the application of simple steps, such as the idealization of the structure, determining the type of supports, and applying the equilibrium equations. The engineer should be aware of the different type of supports and their possible reactions.

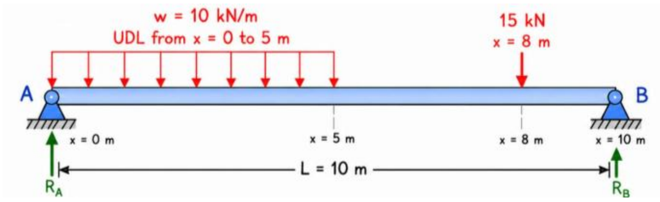

Figure 4 (Determinate beam used in the analysis)

Once the structure is idealized and the type of support, along with the associated unknowns, is determined, the equations of equilibrium can be used to determine the unknown reactions of the structure. Table No. 1 summarizes the equilibrium equations used to solve the beam presented in Figure No. 4 along with the calculated reaction at each support.

Table 1 (Determinate beam solution)

Solution for determinate beam (Figure No.4)	
ΣFy = 0	1. -10*5-15+RA+RB=0 2. -65+RA+RB=0
ΣMA = 0	1. -10*5*5/2-15*8+RB*10=0 2. -245=-10*RB-----> RB=24.5 KN 3. RA=65-24.5=40.5 KN
Final results	RA=40.50 KN RB=24.50 KN

4.2 structural analysis by software and AI models

The structural analysis of the simply supported beam presented in Figure No.4 was conducted using SAP2000 software and the following AI models: DeepSeek, Gemini, ChatGPT, and Perplexity. It is important to note that the analysis of this beam is considered simple, as it is a determinate structure. Each AI model was provided with the beam figure as input, and it was noted that Gemini, ChatGPT, and Perplexity provided the correct reactions within a short time, while DeepSeek provided incorrect results due to a mistake in reading the figure. DeepSeek neglected the point load, which resulted in incorrect reactions. However, when the AI model was asked to consider the point load, the model provided the correct reactions.

The use of AI models for structural analysis was relatively simple, unlike the use of structural software such as SAP2000, which requires some knowledge and experience, as it involves defining the beam, support conditions, and applied loads. Furthermore, the engineer should be aware of how to run the model and display the results.

The use of the AI models Gemini, ChatGPT, and Perplexity in solving determinate structures showed satisfactory results, as these models provided accurate solutions. However, DeepSeek showed a weakness in interpreting figures which resulted in errors in the calculated reactions. On the other hand, the use of SAP2000 provided similarly satisfactory results, which were identical to those obtained from Gemini, ChatGPT, Perplexity, and manual calculations.

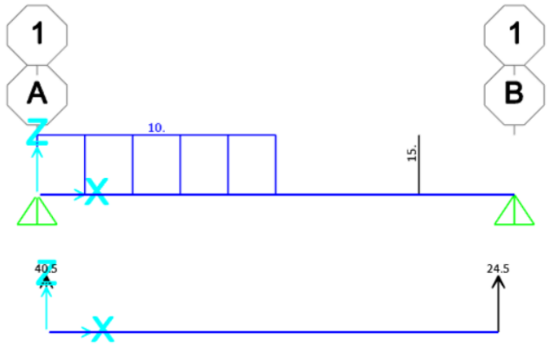

Figure 5 (SAP2000 model and output of analysis)

5.0 Structure analysis for indeterminate beams

The structural analysis of indeterminate beams is a lengthy procedure, as it requires additional equations derived from beam compatibility conditions along with equilibrium equations. This paper studies the structural analysis of indeterminate beams using various AI models and compares the results with beam analyses performed using the Force Method, the Slope-Deflection Method, and structural analysis software. The accuracy and capability of the AI models in structural analysis are assessed in terms of reliability, efficiency, and precision.

5.1 Structure analysis for indeterminate beams by force method

Force method is one of the common methods used in the analysis of indeterminate structures. In this method, the compatibility conditions (deflection constraints) of the investigated structure are satisfied through a set of partial solutions, which yield a system of equations with unknown forces. These equations, together with the equilibrium equations, are used to determine the unknown reactions and internal forces of the investigated structure [10].

Consider the structure shown in Figure No.6. This structure is indeterminate because the number of unknowns exceeds the number of available equilibrium equations. The application of the force method involves several steps to solve the structure and determine the unknowns. The force method uses the principles of superposition and displacement constraints to solve such structures [4]. Therefore, redundant support is removed to transform the structure into a determinate one. The removal of the redundant support at B results in a deflection, ΔB, due to the applied loads. To satisfy the displacement constraints and restore the structure to its original condition, the reaction force at support B causes an upward displacement, Δ'B. The sum of these displacements must be equal to zero:

$$-\Delta B + \Delta' B = 0$$

Since the reaction at support B is unknown and the material is assumed to behave in a linear-elastic manner, a unit load of 1 kN is applied at support B to determine the flexibility coefficient, fbb, which represents the deflection caused by the unit load. As the material remains within the linear-elastic range, Δ'B = By·fbb [4]. The application of this principle enables the determination of the unknown reaction By, after which the equilibrium equations can be used to determine the remaining unknowns.

$$-\Delta B + fbb * By = 0$$

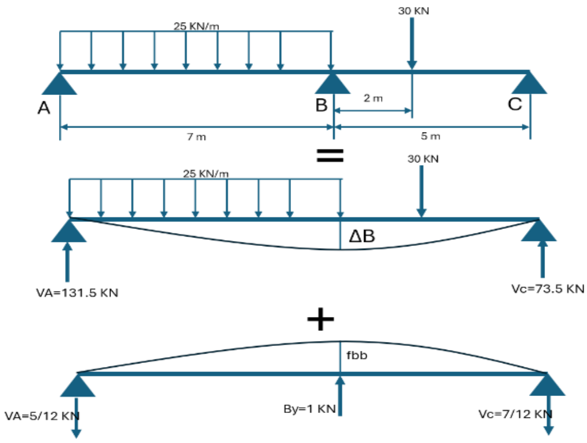

Figure 6 (Force method concept for indeterminate beams)

For this study, four beams shown in Figure No.7 are analyzed using the force method. The beam analysis follows the standard force method procedure. For example, the redundant support B is removed for Beam No. 01, while for Beams No. 02 and 03, supports B and C are removed because the removal of a single support is insufficient to transform the structure into a determinate system. Similarly, for Beam No. 04, supports B, C, and D are removed.

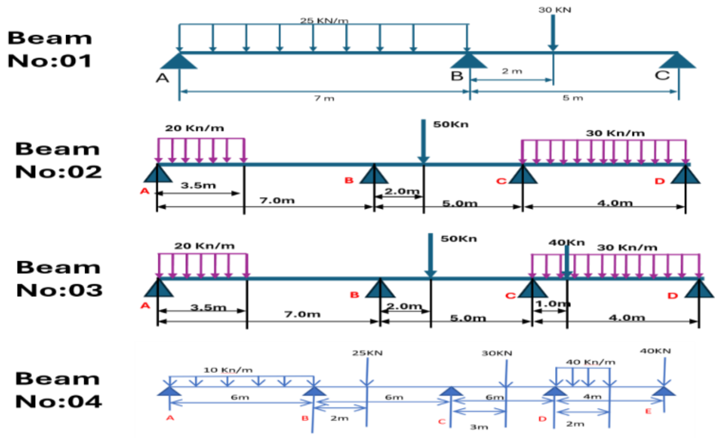

Figure 7 (Beams analyzed in this study)

Table No.2 presents the solutions for the beams shown in Figure No.7 using the force method. It can be observed that as the number of redundant supports increases, the number of required compatibility equations also increases. For Beam No. 01, one support was removed, and a single compatibility equation was sufficient to determine the unknown reaction at support B. For Beams No. 02 and 03, two redundant supports were removed to solve the beams. Consequently, two compatibility equations were required to determine the reactions at supports B and C. Similarly, for Beam No. 04, three supports were removed, and three compatibility equations were required to determine the unknown reactions at supports B, C, and D. It is evident that as the degree of structural indeterminacy increases, the number of compatibility equations also increases, making the solution process longer and more complex.

Table 2 (Force method results)

Beam no	Removed redundant support	Deflection of removed supports under loads	Deflection under the unit load	Compatibility Equations and Reactions
1	B	−Beam deflection (For X=0 at A) $EI*v = 131.5*X^3/6 - 25*X^4/24 + 25*(x-7)^4/24 - 30*(x-9)^3/6 - 1399*X$ 2- $\Delta B = V(X=7) = -4776.6/EI$	1- $EI*v = -5*X^3/72 + (X-7)^3/6 + 8.2*X$ 2- $fbb = V(X=7) = 33.6/EI$	1-$By*fbb + \Delta B = 0$ 2- $By*33.6/EI - 4776.6/EI = 0$ 3- By=141 KN (solving equation no:02) 4-Ay=72.7 KN, from equilibrium 5-Cy=-8.7 KN, from equilibrium
2	B, C	−Beam deflection (For X=0 at A) $EI*V = 99.2*X^3/6 - 20*X^4/24 + 20*(X-3.5)^4/24 - 50*(X-9)^3/6 - 30*(X-12)^4/24 - 1892.1*X$ 1- $\Delta B = V(X=7)\ -9449.5/EI$ 2- $\Delta C = V(X=12) = -7290.55/EI$	-Deflection for point load applied at B: $v = -0.56*X^3/6 + (X-7)^3/6 + 16.29*X$ a- $fbb = V(7) = 82/EI$ b- $fbc = V(12) = 55/EI$ -Deflection for point load applied at c: $v = -0.25*X^3/6 + (X-12)^3/6 + 10*X$ a-$fbc = V(7) = 55.7/EI$ b- $fcc = V(12) = 48/EI$	1- $\Delta B + fbb*By + fbc*Cy = 0 \quad -9449.5/EI + 82/EI*By + 55.7/EI*Cy = 0$ 2- $\Delta C + fbc*By + fcc*Cy = 0 \quad -7290.55/EI + 55/EI*By + 48/EI*Cy = 0$ 3-Solving equation, no: 1 & 2: By=54.67 KN, Cy=89.24 KN 4-Ay=46.10 KN, from equilibrium 5-Dy=50.0 KN, from equilibrium
3	B, C	-Beam deflection (For X=0 at D) $EI*v = 86.64x^3/3 - 5x^4/4 + 5(x-4)^4/4 - 20(x-3)^3/3 - 25(x-7)^3/3 - (10/3)(x-12.5)^4/4 - 2590.36x$ 1-$\Delta B = V(X=4) = -8839.79/EI$ 2-$\Delta C = V(X=9) = -11192.39/EI$	-Deflection for point load applied at B: $v = -0.073*X^3 + (X-9)^3/6 + 15.11*X$ a- $fbc = V(4) = 55.76/EI$ b- $fbb = V(9)82.77$ -Deflection for point load applied at c: $v = -0.125*X^3 + (X-4)^3/6 + 14*X$ a-$fcc = V(4) = 48/EI$ b- $fbc = V(9) = 55.7/EI$	1- $\Delta B = fbc*Cy + fbb*by$ $11192.39 = 55.71*Cy + 82.77*by$ 2-$\Delta c = fcc*Cy + fcb + By$ $8839.79 = 48*Cy + 55.76*by$ 3-solving equation no:1 & 2: By=51.66 KN, Cy=124.15 KN 4-Ay=46.60 KN, from equilibrium 5-Dy=57.60 KN, from equilibrium
4	B, C, D	-Beam deflection (For X=0 at A) $v = 88.2*X^3/6 - 10*X^4/24 + 10*(X-6)^4/24 - 25*(X-8)^3/6 - 30*(X-15)^3/6 - 40*(X-18)^4/24 + 40*(X-20)^4/24 - 3303.5*X$ 1-$\Delta B = V(X=6) = -17185.873/EI$ 2-$\Delta C = V(X=12) = -22607.212/EI$ 3-$\Delta D = V(X=18) = -13134.484/$	-Deflection for point load applied at B: $v = -0.73*X^3/6 + (X-6)^3/6 + 27.86*X$ a- fbb=V(X=6)=140.858/EI b- fbc=V(X=12)=160.036/IE c- fbd=V(X=18)=79.854/EI -Deflection for point load	1- $\Delta B = fbb*By + fcb*Cy + fdb*Dy$ $-17185.873/EI + 140.858*By/EI + 156.145*Cy/EI + 77.731*Dy/EI = 0$ 2- $\Delta C = fbc*By + fcc*Cy + fdc*Dy$ $-22607.212/EI + 160.036*By/EI + 215.091*Cy/EI + 116.582*Dy/EI = 0$

		EI	applied at C: $V = -0.45 * X^3/6 + (X-12)^3/6 + 28.72 * X$ a- fcb=V(X=6)=156.14/EI b- fcc= V(X=12)=215.09/EI c- fcd= V(X=18)=115.63/EI -Deflection for point load applied at D: $V = -0.18 * X^3/6 + 1 * (X-18)^3/6 + 14.03 * X$ a- fdb= V(X=6)=77.731/EI b- fdc= V(X=12)=116.582/EI c- fdd= V(X=18)=77.673/EI	3- $\Delta D = fbd * By + fcd * Cy + fdd * Dy$ $-13134.484/EI + 79.854 * By/EI + 115.636 * Cy/EI + 77.673 * Dy/EI = 0$ 4-solving equation no:1, 2 &3: $By = 56.12Kn$ $Cy = 15.37KN$ $Dy = 88.52KN$ 5-Ay=24.30 KN, from equilibrium 6-Ey=50.70 KN, from equilibrium

5.2 Structure analysis for indeterminate beams by slope-deflection method

The slope-deflection method is a classical displacement-based method of structural analysis. The primary concept of this method is to express the end moments of structural members as functions of joint rotations and displacements. The resulting equations are then used to determine the member end moments, which in turn are utilized to calculate the unknown support reactions [14]. The method relies on three key principles: member stiffness, compatibility of rotations and displacements between connected members, and joint equilibrium.

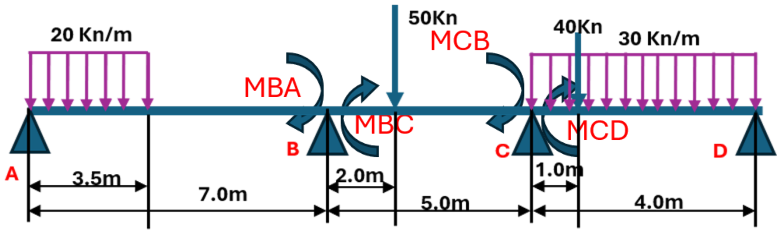

Figure 8 (Continuous beam for slope-deflection analysis)

In the slope-deflection method, the moment at the end of a span is expressed as a function of joint rotation, joint translation, and fixed-end moments (FEMs) [9]. Generally, the procedure involves determining the end moments of an indeterminate structure by relating the moments to the joint rotations, θN and θF. For example, considering span B–C in the structure shown in Figure No.8, the end moments are related to the rotations at joints B and C. Furthermore, joint displacement, Δ, should also be considered if support settlement occurs. In addition to joint rotations and translations, the fixed-end moments at both ends of the span must be included to obtain the final end moments [4].

Equation (1) can be used to determine the end moments of an internal span or an end span with the far end fixed, such as MBC and MCB in the beam shown in Figure No.8. Equation (2) is applicable to an end span with the far end pinned or roller-supported, such as MBA and MCD.

$$MN = 2 * E * k(2 * \theta N + \theta F - 3 * \psi) + (FEM)N \quad -(1)$$

$$MN = 2 * E * k(2 * \theta N - \psi) + (FEM)N \quad -(2)$$

Where θ represent the angular deflection, K is I/L, $\psi = \Delta/L$ and FEM is the fixed end moments. The fixed-end moments for each span can be determined using the conjugate beam method, while many structural analysis textbooks provide ready-to-use formulas for common loading cases, as illustrated in Figure No.9.

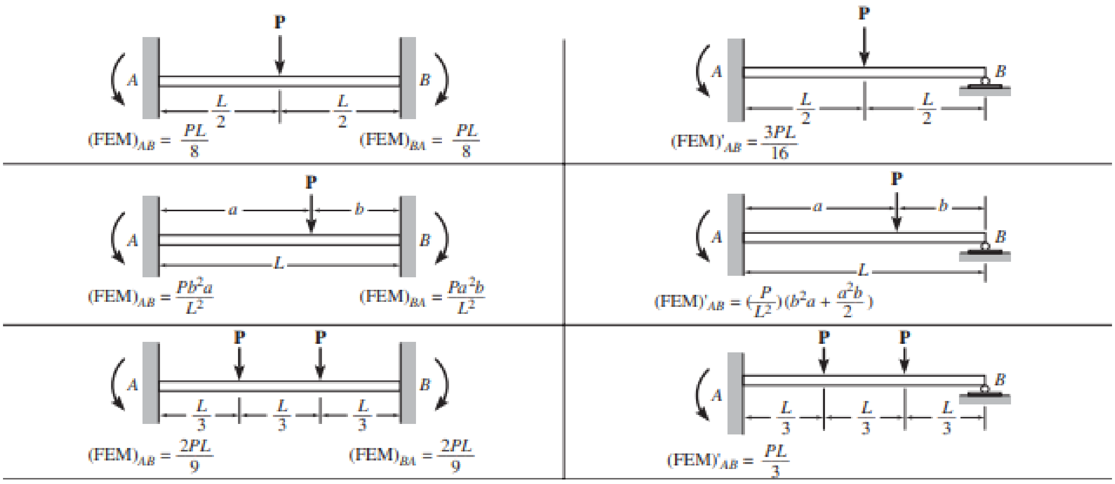

Figure 9 (Fixed-end moment formulas)

The end moments of each span are therefore expressed in terms of joint rotations, displacement and FEM. To determine the unknown variables (rotation and displacement) in the slope-deflection equations, equilibrium conditions are applied at each joint. For the beam shown in Figure No.8, the joint equilibrium equations are:

MBA+MBC=0
MCB+MCD=0

The calculated joint rotations and translations are subsequently substituted into the slope-deflection equations to obtain the member end moments. Finally, the equations of static equilibrium are used to determine the unknown support reactions. Table No.3 presents the slope-deflection equations required to solve Beams 1 to 4. It is evident that, as the degree of beam indeterminacy increases, the number of required equations and the complexity of the solution also increases. It can be observed that the number of equations required for Beam No. 04 is significantly greater than that required for Beam No. 01 due to the higher degree of indeterminacy of Beam No. 04. The results obtained using this method are almost identical to those obtained from the force method.

Table 3 (Slope-deflection method results)

Beam no	**Span End moments equations**	**Angular rotation**	**Beam Reactions**
1	$1 - MBA = 3*E*K*(\theta N - \psi) + (FEM)N$ -MBA=(3/7)*EI*θB+153.125 2- $MBC = 3*E*K*(\theta N - \psi) + (FEM)N$ -MBC=(3/5)*EI*θB-28.8	1- MBA+MBC=0 -$\theta B = -120.7/EI$	1-$MBA = 101.40 Kn.m$ 2-$MBC = -101.40 Kn.m$ From Equilibrium: -Ay=73KN, -By=140.30KN -Cy=-8.30 KN
2	1-MBA=$3*E*K*(\theta N - \psi) + (FEM)N$ - MBA=3*E*(I/7)*(θB)+53.6 2-MBC= $2*E*K*(2*\theta N + \theta F - 3*\psi) + (FEM)BC$ -MBC=$2*E*(I/5)*(2*\theta B + \theta C) - 36$ 3-MCB= $2*E*K*(2*\theta N + \theta F - 3*\psi) + (FEM)CB$ - $MCB = 2*E*(I/5)*(2*\theta C + \theta B) + 24$ 4-MCD=$3*E*K(\theta N - \psi) + (FEM)CD$ -MCD=$3*E*(I/4)(\theta C) - 60$	1-$MBA + MBC = 0$ 2-$MCB + MCD = 0$ $\theta B = -23.89/EI$ $\theta C = 29.39/EI$	1-MBA=43.36 KN.m 2-MBC=-43.36 KN.m 3-MCB=37.96 KN.m 4-MCD=-37.96 KN.m From Equilibrium: Ay=46.30 KN By=54.78 KN Cy=88.41 KN Dy=50.51KN

3	1 − $MBA = 3*E*(I/7)*(\theta B) + 53.6$ 2- $MBC = 2*E*(I/5)*(2*\theta B + \theta C) - 36$ 3- $MCB = 2*E*(I/5)*(2*\theta C + \theta B) + 24$ 4- $MCD = 3*E*(I/4)(\theta C) - 86.25$	1-MBA + MBC = 0 2-MCB + MCD = 0 $\theta B = -29.91/EI$ $\theta C = 47.88/EI$	1- MBA=40.8 Kn-m 2-MBC=-40.8 Kn-m 3-MCB=50.34 Kn-m 4-MCD=-50.34 Kn-m From Equilibrium: Ay=46.67 Kn, By=51.42 KN Cy=124.5 KN, Dy=57.41 Kn
4	1-MBA=$3*E*(I/6)(\theta B) + 45$ 2-MBC= $2*E*(I/6)*(2*\theta B + \theta C) - 22.22$ 3-MCB= $2*E*(I/6)*(2*\theta C + \theta B) + 11.11$ 4-MCD=$2*E*(I/6)*(2*\theta C + \theta D) - 22.5$ 5-MDC= $2*E*(I/6)*(2*\theta D + \theta C) + 22.5$ 6-MDE=$3*E*(I/4)(\theta D) - 45$	MBA+MBC=0 MCB+MCD=0 MDC+MDE=0 $\theta B = -22.63/EI$ $\theta C = 10.87/EI$ $\theta D = 13.33/EI$	1- MBA=33.68 Kn-m, 2-MBC=--33.68 Kn-m 3-MCB=15.64 Kn-m 4-MCD=-15.64 Kn-m 5-MDC=35.00 Kn-m 6-MDE=-35.00 Kn-m Ay=24.40 Kn, By=55.2 KN Cy=16.00 KN, Dy=87.00 Kn , Ey=51.25 KN

5.3 Structure analysis for indeterminate beams by structural analysis software

To verify the results obtained from the force and slope-deflection methods, the beams were analyzed using the structural analysis software Sap2000. Sap2000 uses the global matrix equation [K]{u} = {Fext} to determine the unknown free displacements {u}, and subsequently calculates the internal forces and support reactions, {R} = ∑({finternal} − {Fext,joint}) [13]. A model was created in Sap2000 for the four beams shown in Figure No.7. The self-weight was set to zero in the model, as it was not considered in the previous analyses. The results obtained from Sap2000 are presented in Table No.4. It can be observed that the results are in close agreement with those obtained using the force and slope-displacement methods.

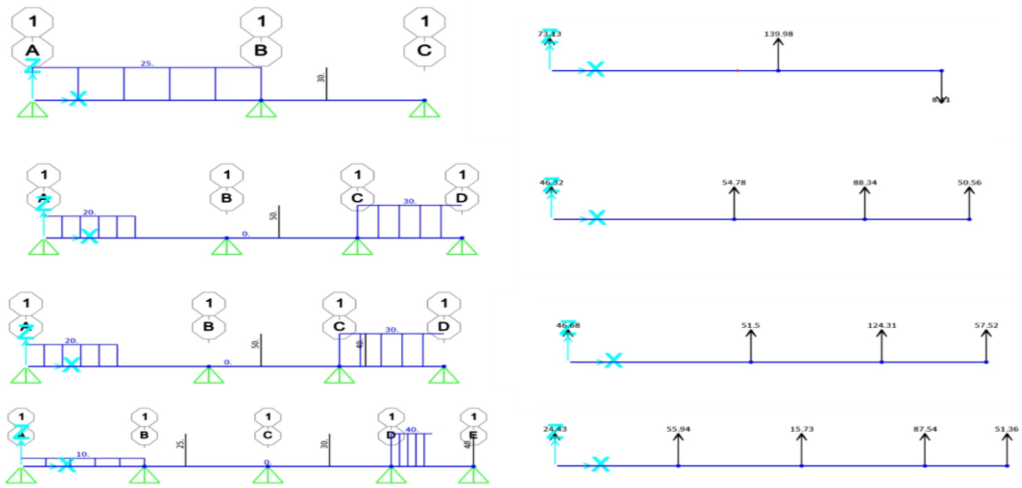

Figure 10 (SAP2000 beam models and outputs)

5.4 Using AI for structure analysis

The AI models ChatGPT, DeepSeek, Gemini, and Perplexity were provided with the four beams to evaluate their structural analysis capabilities. Initially, the models were provided with images of each beam showing the geometry and applied loads. However, none of the models was able to accurately interpret all the information from the provided images. Therefore, the beam geometry and applied loads were subsequently provided in text format to assess the structural analysis capabilities of the AI models.

The results obtained from the different AI models are presented in Table No.4. Preliminary observations indicate that the accuracy of the AI-generated results decreased with increasing degree of static indeterminacy. In addition, noticeable variations were observed among the different AI models for the same beam, indicating differences in their capability to perform structural analysis calculations. Differences were observed between the AI-generated results and those obtained from Sap2000 and the classical analysis methods, indicating limitations in the accuracy of the AI models.

Table 4 (Comparison of obtained reactions from different analysis methods)

Beam no		Ay	By	Cy	Dy	Ey
Beam no:01	Force method	72.70 KN	141.0 KN	-8.70 KN		
	Slope-deflection method	73.0 KN	140.30 KN	-8.30 KN		
	Sap2000	73.13 KN	139.98 KN	-8.41 KN		
	1- ChatGPT	73.24 KN	139.72 KN	-7.96 KN		
	2-Deepseek	73.0 KN	140.20 KN	-8.30 KN		
	3-Gemini	73.24 KN	99.80 KN	31.96 KN		
	4-Perplexity	62.14 KN	91.75 KN	51.11 KN		
Beam no:02	Force method	46.10 KN	54.67 KN	89.24 KN	50.0 KN	
	Slope-deflection method	46.30 KN	54.78 KN	88.41 KN	50.51 KN	
	Sap2000	46.32 KN	54.78 KN	88.34 KN	50.56 KN	
	1- ChatGPT	46.31 KN	37.43 KN	86.77 KN	69.49 KN	
	2-Deepseek	48.39 KN	57.59 KN	59.35 KN	74.67 KN	
	3-Gemini	48.23 KN	49.41 KN	92.79 KN	49.57 KN	
	4-Perplexity	82.50 KN	118.30 KN	129.70 KN	19.50 KN	
Beam no:03	Force method	46.60 KN	51.66 KN	124.15 KN	57.60 KN	
	Slope-deflection method	46.67 KN	51.24 KN	124.50 KN	57.41 KN	
	Sap2000	46.68 KN	51.50 KN	124.31 KN	57.52 KN	
	1- ChatGPT	39.30 KN	108.40 KN	74.70 KN	57.60 KN	
	2-Deepseek	32.50 KN	51.70 KN	87.50 KN	67.50 KN	
	3-Gemini	47.05 KN	50.36 KN	125.36 KN	57.23 KN	
	4-Perplexity	47.50 KN	72.30 KN	61.80 KN	38.40 KN	
Beam no:04	Force method	24.30 KN	56.10 KN	15.37 KN	88.52 KN	50.70 KN
	Slope-deflection method	24.40 KN	55.20 KN	16.50 KN	87.00 KN	51.25 KN
	Sap2000	24.43 KN	55.94 KN	15.73 KN	87.54 KN	51.36 KN
	1- ChatGPT	50.36 KN	95.22 KN	8.97 KN	89.69 KN	50.76 KN
	2-Deepseek	101.00 KN	82.00 KN	60.00 KN	52.00 KN	93.00 KN
	3-Gemini	69.64 KN	58.11 KN	37.70 KN	78.79 KN	50.76 KN
	4-Perplexity	79.17 KN	103.89 KN	45.31 KN	52.74 KN	13.89 KN

6.0 assessment of the capability of AI models in structural analysis

The examination of the capability of AI models in structural analysis has shown that AI models such as ChatGPT, DeepSeek, Gemini, and Perplexity lack the ability to consistently provide accurate results. Figure No.11 shows that the classical structural analysis methods, namely the Force Method and Slope-Deflection Method, exhibited only minor variations from the reference results. In contrast, the results obtained from the AI models showed significantly higher deviations from the reference solutions, as presented in Figure No.11.

Furthermore, the results presented in Table No.4 indicates that the variation between the AI-generated results and the reference solutions increased as the beam complexity and degree of indeterminacy increased. Among the AI models evaluated, ChatGPT produced the lowest deviation from the reference results, while Perplexity exhibited the highest deviation, as illustrated in Figure No.11. These findings suggest that, although AI models demonstrate some capability in structural analysis, their accuracy and reliability remain insufficient for practical engineering applications involving complex indeterminate structures.

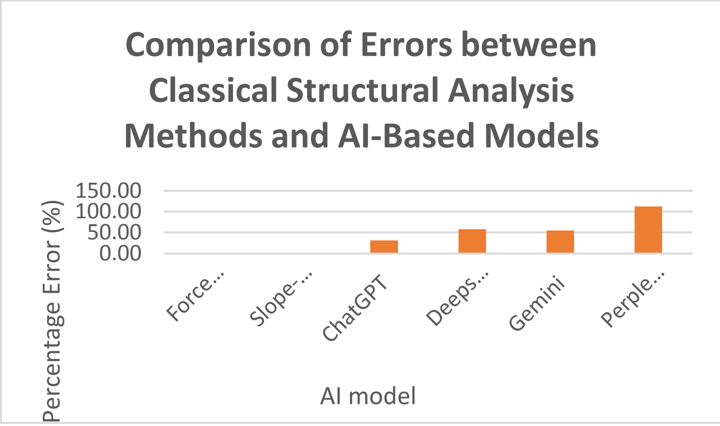

Figure 11 (Average percentage error for different analysis methods)

7.0 CONCLUSION

This paper has investigated the capability of different AI models in structural analysis. Several AI models were tested by requesting them to perform analysis on beams with different configurations, which had different levels of complexity and indeterminacy. The results obtained from the AI models were compared with classical methods and with the reference results obtained from SAP2000 software.

The study has yielded the following findings:

1- Classical structural analysis methods, like the Force Method and Slope-Deflection Method, provided results with minor variation from the SAP2000 outputs.
2-The AI models were performing reasonably well when dealing with simple, determinate structures and cases with low indeterminacy.
3-But as the structure becomes more complex and the indeterminacy degree increases, the results obtained from AI model varied significantly from the correct solutions.
It can be concluded that the tested AI models are not yet ready for the use in structural analysis, as they have shown limited efficiency and low accuracy, particularly for indeterminate and complex structures.

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