Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. X No. Y (20--)

Automated ILD Generation for Deflection of Simply Supported, Fixed and Propped Cantilever Beam Using Excel

Sagar E. Kore[1]*, Satish B. More[2]
[1,2] *Dept of Civil Engineering, Nagesh Karajagi ORCHID College of Engineering and Technology, Solapur, MS, India*

Abstract: Present work compares results of influence line diagram (ILD) obtained using excel. The ILD shows the behaviour of beam for unit load moving across the span. The ILD can be drawn for deflection at point, slope at a point or support, bending moment, reaction, shear force and end moments. For analysis of beams on road or railway bridges which have moving loads the Influence line diagrams (ILDs) performs the crucial role. This paper presents an automatic analysis method for developing Influence line diagram (ILD) for deflection of single span 1) simply supported, 2) Fixed, and 3) propped cantilever beam on Microsoft Excel. The Macaulay's method is taken in account for input for calculating the Values of ILD. This graphical representation helps to visualize the behaviour of beam for effect of moving load. It is seen the ILD constructed for single span simply supported beam, fixed beam, and propped cantilever beam by slope deflection method on Microsoft Excel are accurate, economical and reduces the time for manual calculation.

Keywords: *Excel, Influence Line Diagrams, Moving Loads, Structural Analysis*

1. Introduction

One of the most popular subjects in solid-state mechanical engineering in recent years has been the deflection analysis of beams. The term "large deflection of beams" describes the deflection brought on by both minor strains and big displacements. One of the topics of interest in the advancement of beam deformation analysis techniques has been deflection. A comparison of various approaches Euler-Bernoulli beam theory and the Timoshenko beam theory is crucial given the range of beam deformation techniques, [1] providing the general analytical solution by Ruler Bernoulli beam theory to Microsoft Excel will increase efficiency and be readily applicable to other beam geometrics [2]. By Mohor's theory of direct area method for uniformly varying load, the fixed end of the propped cantilever beam and fixed end beam carry zero load, and maximum load is carried at the propped end in the propped cantilever beam and at the center in the fixed end beam [3], the moment distribution method gives more accurate results as compared to other conventional methods [4], the analysis of continuous beam by finite element method gives the accurate result as per the behavior of structure because the structure is divided into small parts [5], greater variations from analytical values are caused by stress concentrations in rectangular and parallelogram holes. An intriguing addition to enhancing the analytical predictions is the addition of a multiplier to the deflection formula to account for opening geometry [6]. For suspended beams the deflection can be reduced by placing the distance between each lift point and the near end of the beam is not around one-fifth of its length [7], the maximum amount of deflection that can be accepted before compromising joints, finishes, or other building elements, the conventional restriction of L/360—where L is the member's span has been a widely accepted guideline, it might not be suitable in every circumstance, depending on the sensitivity of the related building, in some circumstances, stricter restrictions of L/480 or L/720 might be justified [8]. The Gaussian function outperforms conventional deterministic models and has a low processing cost. Uncertainty quantification is made possible by the work's Bayesian inference-based methodology, which is crucial for applications involving structural health monitoring and performance assessment [9].

The development of a model that is more general than the usual scenario of a force acting vertically downward and can manage a steady, concentrated force applied at the free end of the cantilever beam at a constant angle.

The force applied to the cantilever beam of 3.92N from the vertically downward direction from the end of the beam, the difference in manual calculation and FORTRAN programming is 2.18% in maximum y direction [10]. The use of Microsoft Excel tool and Visual Basics improves the efficiency of stress analysis by generating automatic diagrams for shear, moment, and deflection [11], utilizing the SAP2000 program to analyze continuous beams with varying span ratios and number of spans, S.N. Khuda and A.M.M.T. Anwar went beyond the constraints of ACI. When the beam moment is available, design charts are created to help choose the reinforcement and beam section [12], the successful use of the CMA-ES method for structural optimization to regulate the deflection behavior of beams, as well as the capability to generate functionally graded material property responses by computationally changing the geometrical shapes of voxelated cellular structures. The design of soft robots, compliant mechanisms, and other applications where exact control of beam deflections is essential may be significantly impacted by these discoveries [13].

Today, most science courses conduct their experimental portions outside of labs using computer-based software simulation packages. Although publicly accessible simulation packages are incredibly capable, they are also very expensive and difficult to afford. Most scientific, engineering and mathematical experiments are easily simulated through the development of inexpensive spreadsheet-based simulators, such as Excel, as detailed in this study [14]; Jacek Boroń also used Microsoft Slover in solving structural and management problems [15], the teaching-learning process can be enhanced using Microsoft Excel to create automated routines in Moodle using Fast Test Plug-In [16]. The finite element method is challenging to teach, for Solving the 2D stress problem on Microsoft Excel VBA is an ideal platform for providing visualization for data processing and implementation of boundary conditions [17].

The influence line for an indeterminate structure can be determined by the kinematic method, by applying the virtual displacement [18] and the design and state identification of structures and infrastructure engineering benefit from the acquisition of the force influence line of an indeterminate structure. The matrix approach gives the more accurate result for any structural analysis, we can do analysis either by force method or displacement method, in terms of matrix formulation the displacement method has a great advantage over the force method [19]. An electronic digital computer can perform the mathematical operations required once the initial matrices have been constructed since they are so routine. Dr. Moujalli Hourani developed the mathematical model for the construction of an influence line diagram for continuous beam. [20].

2. Analytical Derivation of Beam Deflection Using Macaulay's Method

The deflection of beams under transverse loading is a fundamental problem in structural engineering. Macaulay's method provides an efficient approach to handle discontinuities in bending moment functions, particularly for beams subjected to point loads. This method simplifies the derivation of slope and deflection equations by incorporating step functions to represent load discontinuities.

The detailed derivation of beam deflection equations using Macaulay's method, this equation is derived for classical beam types: simply supported beam, fixed beam, and propped cantilever beam.

The deflection y(x) of a beam under a bending moment M(x), with Young's modulus E and the second moment of area I, is governed by the following fourth-order differential equation [21]:

$$\frac{d^2y}{dx^2} = \frac{M}{EI} \quad (1)$$

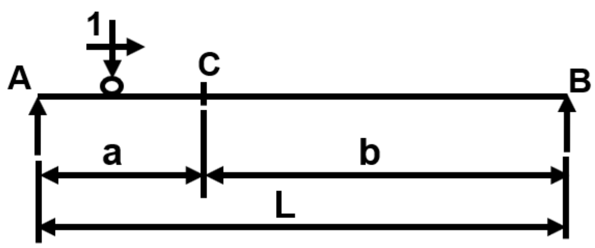

Figure 1 Single Span Simply Supported Beam

For a simply supported beam in figure No. 1 of length L, subjected to a point load P at a distance a from the left support, the bending moment function using Macaulay's method is:

$$M = R_A x - P(x-a)^1 \quad (2)$$

$(x-a)^1$ Follows the Macaulay's notation it says that if the load is at distance x form left support and a is the point on beam where the value of slope or deflection is calculating; if value distance of load is greater than or equal to a then it will be taken as $(x-a)^1$ if not then it will be taken as 0.

$$R_A = \frac{P(L-a)}{L}, R_B = \frac{Pa}{L} \quad (3)$$

Substituting Equation (3) into Equation (2) and inserting into the governing differential equation (1):

$$\frac{d^2y}{dx^2} = \frac{1}{EI}\left[\frac{P(L-a)}{L}x - P(x-a)^1\right] \quad (4)$$

First integrating $\frac{dy}{dx}$ (slope):

$$\frac{dy}{dx} = \frac{1}{EI}\left[\frac{P(L-a)}{2L}x^2 - \frac{P}{2}(x-a)^2\right] + C_1 \quad (5)$$

Second Integration y (deflection):

$$y = \frac{1}{EI}\left[\frac{P(L-a)}{6L}x^3 - \frac{P}{6}(x-a)^3\right] + C_1 x + C_2 \quad (6)$$

Putting the boundary condition in equation of deflection (6) and slope (5) gives the value of constants C1 (7) and C2 (8); boundary conditions: At x =0 and x= L, y = 0. The equation (1) is governing fourth order differential equation, equation (2) and (3) are the moment at C and reaction at A when load is placed at x from left support of simply supported beam. Integrating (4) with respect to x gives the equation for slope. The (6) is deflection equation get by integrating (5) with respect to x or double integrating (4) with x.

$$C_1 = -\frac{P}{6L}(L-a)(2aL - a^2) \quad (7)$$

$$C_2 = 0 \quad (8)$$

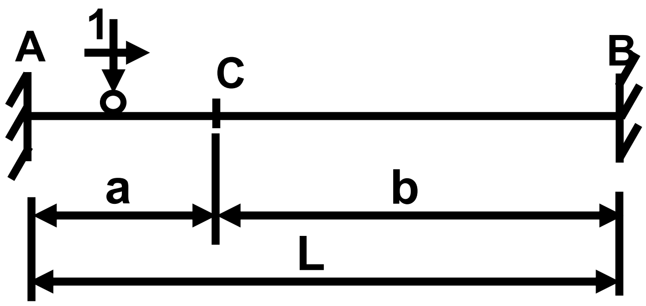

Figure 2 Single Span Fixed Beam

The fixed beam is shown in figure no. 2 carrying unit moving load along the beam. The (9) and (10) are Moment and Reaction of Fixed beam.

$$M = R_A x - M_A - [P(x-a)]H(x-a) \quad (9)$$

$$R_A = R_B = \frac{P}{2} \quad (10)$$

$$M_A = M_B = \frac{PL}{8} \quad (11)$$

Putting value of M(x) and RA from equation (9) and (10) in equation (1)

$$\frac{d^2y}{dx^2} = \frac{1}{EI}\left[\frac{P}{2}x - \frac{PL}{8} - P(x - L/2)\right] \quad (12)$$

This equation (11) is the differential equation for bending moment for fixed beam, integrating equation (12) gives equation (13) and double integrating equation (12) gives the equation (14).

$$\frac{dy}{dx} = \frac{1}{EI}\left[\frac{P}{4}x^2 - \frac{PL}{8}x - \frac{P}{2}(x - L/2)^2\right] + C_1 \quad (13)$$

$$y = \frac{1}{EI}\left[\frac{P}{12}x^3 - \frac{PL}{16}x^2 - \frac{P}{6}(x - L/2)^3\right] + C_1x + C_2 \quad (14)$$

$C_1$and C_2in equation (15) and (16) are the constants for fixed beam obtained by substituting boundary condition in equation of slope (13) and deflection (14) of fixed beam. For fixed beam when load is put either on left support or on right support the slope and deflection are zero.

$$C_1 = 0 \quad (15)$$

$$C_2 = 0 \quad (16)$$

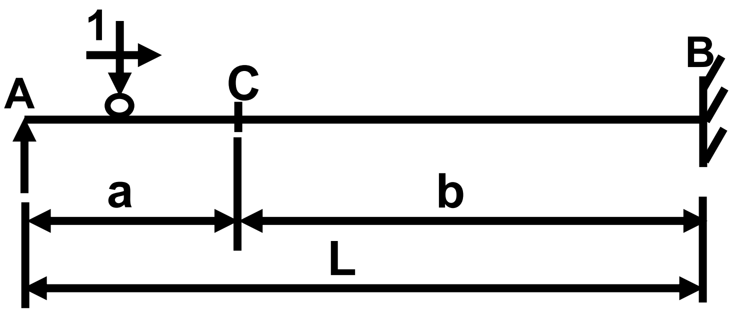

Figure 3 Single Span Propped Cantilever Beam

M in equation (17) is moment for Propped cantilever beam in figure No. 3, equation (18) is general equation for bending moment of propped cantilever beam; equation (19) and (20) are equation of slope and deflection for propped cantilever beam obtained by integrating equation (18) and equation (19) with respect to x.

$$M = R_Ax - P(x - a)^1 \quad (17)$$

$$\frac{d^2y}{dx^2} = \frac{1}{EI}[R_Ax - P(x - a)^1] \quad (18)$$

$$\frac{dy}{dx} = \frac{1}{EI}\left[\frac{R_A}{2}x^2 - \frac{P}{2}(x - a)^2\right] + C_1 \quad (19)$$

$$y = \frac{1}{EI}\left[\frac{R_A}{6}x^3 - \frac{P}{6}(x - a)^3\right] + C_1x + C_2 \quad (20)$$

$$C_1 = \frac{P}{6L}(L - a)^3 + \frac{R_A}{6}L^2 \quad (21)$$

$$C_2 = 0 \quad (22)$$

For propped cantilever beam the deflection will be zero at simple support and at fixed support both slope and deflection will be zero. These boundary condition gives the value of C_1 and C_2 for propped cantilever beam which are calculated and shown in equation (21) and (22).

3. Result and Discussion

A Microsoft Excel sheet is prepared for single span simply supported, fixed and propped cantilever beam using Macaulay's deflection equation. A 5-meter span beam with constant EI is assumed for all three beams. The deflection curve is plotted for unit load at different point along the beam i.e. load is at 0m, 1m. 2m, 2.5m, 3m, 4m, and 5m. figure no. 4, 5, and 6 shows the ILD for deflection curve for load at various sections. Figure no. 7 compares the behaviour of all three beams SS indicates Simply Supported beam, likewise PB and FB represents propped cantilever and Fixed Beam when span is 5m with constant EI.

The deflection profiles will guide the optimal design choices and shows the behavioural differences between simply supported, fixed, and propped cantilever beams. Beam deflection leads structural performance, ensuring safety, serviceability, and user comfort.

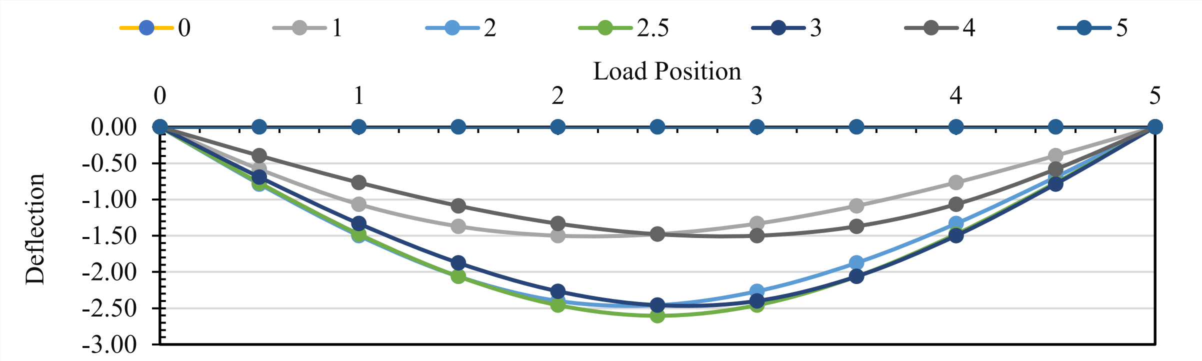

Figure 4. IL for Deflection of Simply Supported Beam for various section at x = 0 to x = 5

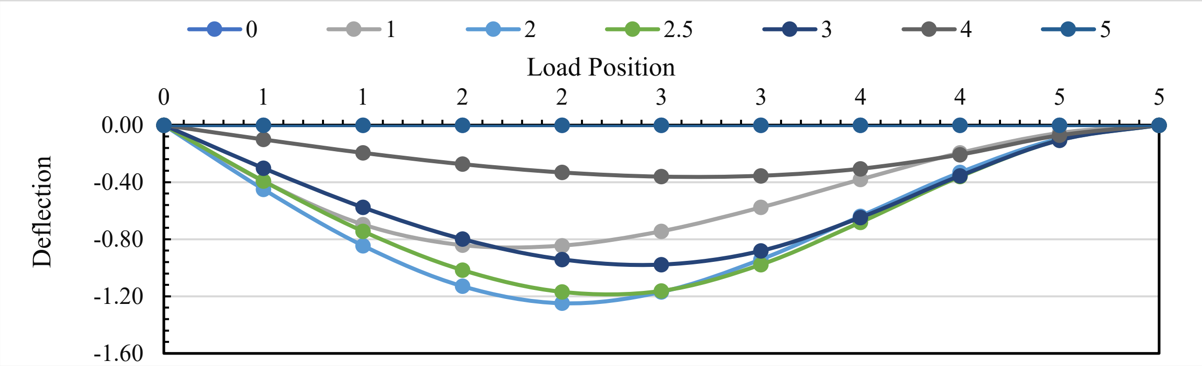

Figure 5. IL for Deflection of Propped Cantilever Beam for various sections at x = 0 to x = 5

The Process of plotting ILDs is simplified by Excel's computational and graphical capabilities. Results for different span or loading conditions can obtained by spreadsheet formulae, enhances flexibility and accuracy in structural analysis. In real-world engineering decisions ILDs is a crucial part. for bridges where vehicles passes and load is moving will affect the internal forces for different points, it points out the world loading conditions; ensuring the safety. Via Excel ILDs are plotted without specialized software and makes structural analysis cordial for students and professional alike. This contributes to more resilient and reliable infrastructure by providing understanding of load behaviour.

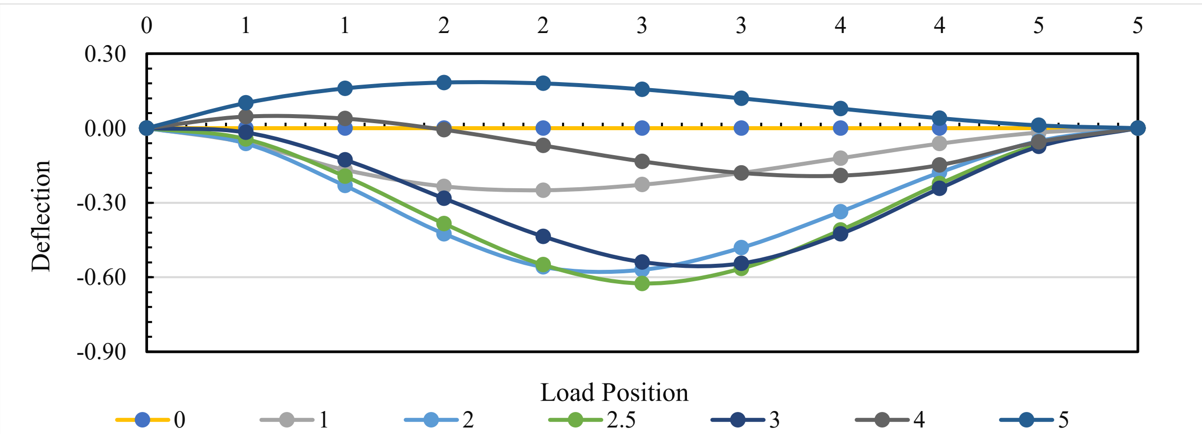

Figure 6. IL for Deflection of Fixed Beam for various sections at x = 0 to x = 5

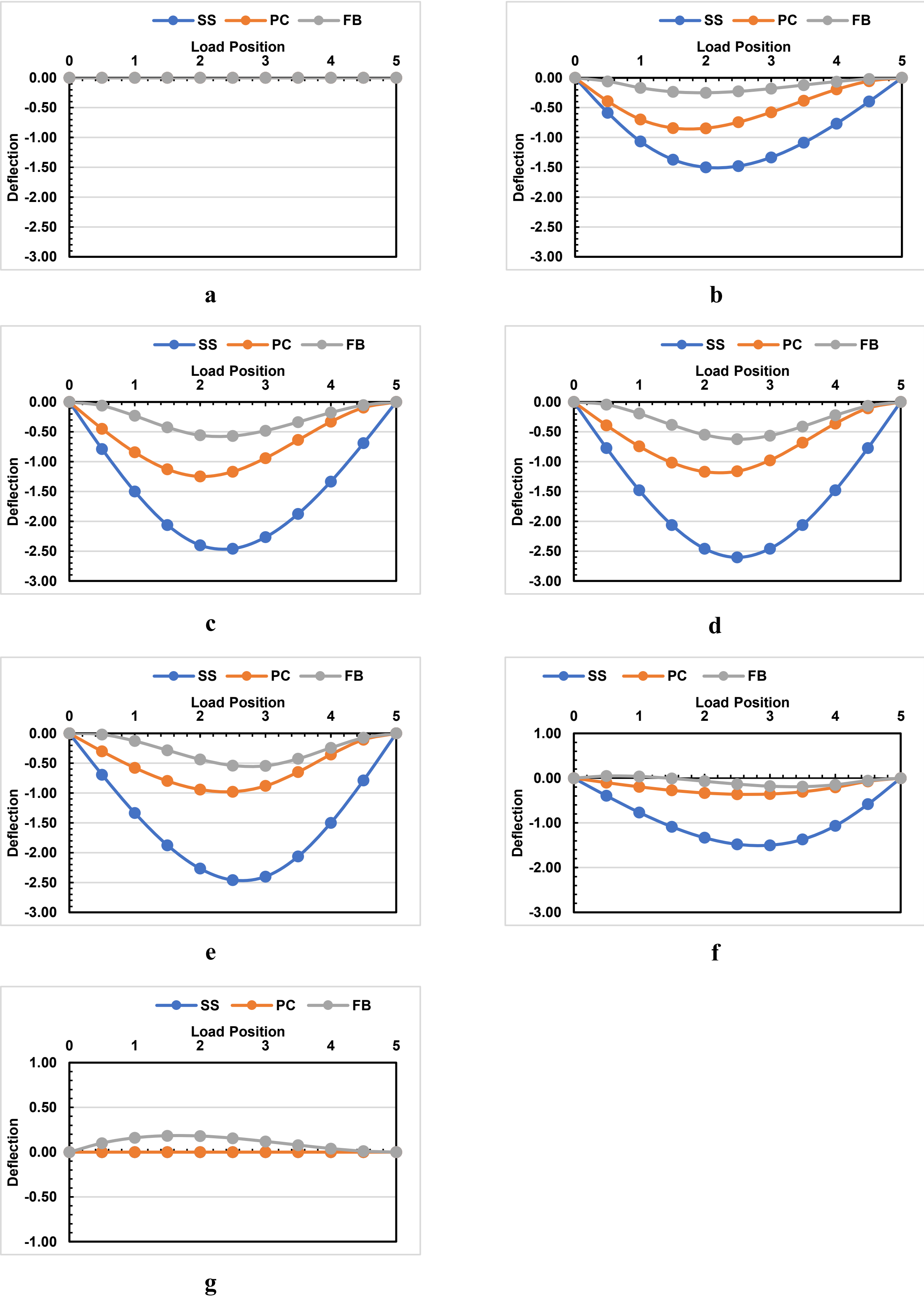

Figure 1. IL for Deflection of Simply Supported, Propped Cantilever and Fixed Beam for section at a) x = 0, b) x = 1, c) x = 2, d) x = 2.5, e) x = 3, f) x = 4, g) x = 5

4. Conclusion:

The study offers a compressive analysis of Influence line diagrams for deflection in simply supported, fixed, and propped cantilever beams. The derived formulae and graphical representations provide discernment behaviour of beams under moving loads. The use of Microsoft Excel gives the accurate results and is economical. The results can be used for designing beams ensuring safety and efficiency. The Microsoft Excel data can be implemented into AI for automatic generation of ILDs.

References

[1] Yasser TAGHIPOUR and Sara DARFARIN, A METHOD FOR COMPARISON OF LARGE DEFLECTION IN BEAMS, Int. J. of Applied Mechanics and Engineering, 27(4) (2022) 179. 10.2478/ijame-2022-0058
[2] Witold Waldman and Xiaobo Yu, Deflection and Supporting Force Analysis of a Slender Beam under Combined Transverse, Aerospace Division Defence Science and Technology Group (2016).
[3] R. M. KARTHIKEYAN, C. MUNUSAMY, AK. MD MUBARAK, Analysis of Propped Cantilever Beam Carries "U.V.L" Zero at Fixed End and Maximum at Propped End and Analysis of Fixed Beam Carries "U.V.L" Maximum at Centre by Mohr's Theorem, Journal of Emerging Technologies and Innovative Research, 8(5) (2021) 875. 10.13140/RG.2.2.29002.34240
[4] Ronit Sharma, Ankush Kumar Jain, Vaibhav Jain, Analysis of a continuous beam by using different structural analysis methods, International Research Journal of Engineering and Technology (IRJET), 4(9) (2017) 1281.
[5] Xuzhan Xiao, Deflection analysis of two-span reinforced concrete continuous beam under load, Advances in Engineering Research, (2023) 228. https://doi.org/10.2991/978-94-6463-336-8_92
[6] Ilker Kalakan, Ece Ceylan, Saruhan Kartal and Mehmet Baran, Deflections if reinforced concrete beams with transverse openings of different geometrics, 80(3) (2021) 323. https://doi.org/10.12989/sem.2021.80.3.323
[7] R.H. PLAUT, C.D. MOEN and R. COJOCARU, Beam Deflections and Stresses During Lifting, ENGINEERING JOURNAL, (2012) 187.
[8] W.G. Plewes and G.K. Garden, Deflections of Horizontal Structural Members, Canadian Building Digest, (1964), https://doi.org/10.4224/40000867
[9] Raed S. Batbooti, Bassam A. Mohammed, Tahseen Ali Jabbar, Safaa H. Faisal, Bayesian Regression Based Approach for Beam Deflection Estimation, Advances in Science and Technology Research Journal, 17(3) (2023) 206. https://doi.org/10.12913/22998624/166313
[10] John C. Visner, ANALYTICAL AND EXPERIMENTAL ANALYSIS OF THE LARGE DEFLECTION OF A CANTILEVER BEAM SUBJECTED TO A CONSTANT, CONCENTRATED FORCE, WITH A CONSTANT ANGLE, APPLIED AT THE FREE END, Degree of Master of Science, University of Akron, (2007).
[11] Cody Jacobucci, Automating Structural Stress Analysis: Beam Deflection, Shear, and Moment Diagram Generator for Single and Multi-Span Beams, Degree of Bachelor of Science in Mechanical Engineering, Department of Mechanical Engineering, (2017).
[12] S.N. Khuda, A.M.M.T. Anwar, DESIGN AID FOR CONTINUOUS BEAMS
[13] Wuxin Yang, Malaya Prasad Behera, Yifan Lv, Loulin Huang & Sarat Singamneni, Structural optimisation for controlled deflections of additively manufactured single material beams, Scientific Reports, (2023). https://doi.org/10.1038/s41598-023-33946-x
[14] Dogan Ibrahim, Using the Excel spreadsheet in teaching science subjects, Procedia Social and Behavioral Sciences, (2009) 309. 10.1016/j.sbspro.2009.01.058
[15] Jacek Boroń, Application of MS Excel® Solver in Solving Structural and Management Problems, Computational Civil Engineering 2007, (2007).
[16] M. Huerta-Gomez-Merodio and M. V. Requena-Garcia-Cruz, Application of MS Excel, and FastTest PlugIn to automatically evaluate the students' performance in structural engineering courses, (2024). https://doi.org/10.1002/cae.22799
[17] Keiji YANASE, An Introduction to FE Analysis with Excel-VBA.
[18] Dixiong Yan, Guohai Chen and Zongliang Du, Direct kinematic method for exactly constructing influence lines of forces of statically indeterminate structures, Structural Engineering and Mechanics, 54(4) (2015) 793. http://dx.doi.org/10.12989/sem.2015.54.4.793
[19] BHALCHANDRA SHANKERPRASAD MEHTA, MATRIX SOLUTION FOR INFLUENCE LINES, MASTER OF SCIENCE, Department of Civil Engineering, KANSAS STATE UNIVERSITY Manhattan, Kansas, (1963).
[20] Dr. Moujalli Hourani, Mathematical Model of Influence Lines for Indeterminate Beams, American Society for Engineering Education, (2002).
[21] B S Basavarajaiah and P Mahadevappa, STRENGTH OF MATERIALS Third Edition, Universities Press, (2010).