Comparison Between Linear and Nonlinear Analysis of Steel Frame and Nonlinear Impact on Behavior of Structures

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ABSTRACT

As technology is improving day by day, it provides the opportunity to solve the most complicated and complex functions of different majors especially engineering. One of those is a nonlinear analysis of steel structures due to the gradual increase of various types of loads. This paper 'discusses the linear and nonlinear behavior of steel structure plus its impact on stress and deformation in different stages of loading. Furthermore, how the software such as **ADINA version 9.6** and **ANSYS version 16.0** (Mechanical APDL) analyze and simulate the material nonlinearity (bilinear, multilinear) and geometric nonlinearity of steel structure. Material nonlinearity 'depends on the young's modulus graph (strain, stress curve), which denotes how stress and strain related to each other during the loading period. The thin cantilever steel solid beam with warehouse frame thick solid cross-section has been selected for analysis purposes in two conditions of linear elastic and bilinear Plastic zone. Entire the conditions vary by replacing the values of E (Modulus of elasticity). The first condition determines the Elastic behavior of the element by considering tangent modulus as E. Bilinear analysis has been taken in two conditions. 1- strain hardening with a tangent modulus of E/100. 2- fully plastic with a tangent modulus of E=0. As the software will not accept the E=0 for fully plastic behavior of the elements so, it has taken E=100. The result, of the displacement and amount of stress generated in structures, have been computed and compared in both states. In conclusion, the linear analysis gives a linear equation of deflection and stress with respect to load. Whereas, for bilinear (strain hardening and fully plastic) the deflections increased with less stress. In the meantime, in linear analysis, the full strength and stiffness of the member are not utilized. In contrast, in nonlinear analysis, the realistic behavior of the structure has been expressed.

KEYWORDS: *Bilinear Stress-strain Curve, Finite Element Method, Linear Analysis, Load-Deflection Behavior, Nonlinear Analysis,* ***ADINA*** *and* ***ANSYS*** *software's.*

1. INTRODUCTION

A linear finite element analysis is used when the stress is directly proportional to the strain, which means it follows Hook's law of elasticity. Linear analysis is carried out by using equation $\{F\} = [K]\{\Delta\}$, where F is the force matrix and Δ is the deflection and K is the stiffness matrix. It means that the correlation of force and displacement is linear. But for materials like steel, the stress-strain behavior

is linear up to some point (yield point), thereafter it behaves non-linear nature. In order to obtain the accurate and realistic nature of material behavior, nonlinear analysis is preferred over linear analysis. [1] The non-linear analysis is not easy for manual computation, so finite element-based computer software's like **ANSYS version 16.0** and **ADINA version 9.6** are used for nonlinear analysis. Linear finite element formulation is based on two assumptions

1. Stress-strain relation is linear throughout the analysis.

2. Strain displacement relation is linear here are mainly two important types of nonlinearity related to structures. they are material nonlinearity and geometrical nonlinearity. the above two assumptions are for neglecting these two nonlinearities and for making analysis simple. the first assumption, stress-strain relation Modern performance-based design methods require ways to determine the realistic behavior of structures under inelastic conditions. is linear throughout the analysis is neglecting the effect of material nonlinearity, and the second assumption that strain displacement relation is linear is neglecting the geometrical nonlinearity.

In the material nonlinear analysis, the structure will not recover its real shape after the removal of load. Material nonlinearity is related to the inelastic characteristics of materials like steel. Inelastic behavior is characterized by a force-deformation relationship. the general force deformation relationship shows that once a structure accomplishes its yield strength, supplementary loading will cause the response to deviate from the preliminary tangent stiffness. Nonlinear behavior may then increase (hardening) to an ultimate point before decreasing (softening) to a remaining strength value. Material nonlinearity is due to the nonlinear constitutive matrix. For most of the materials, nonlinear stress-strain curves are obtained experimentally by conducting uniaxial tension/ compression tests. these results are enough to carry out nonlinear analysis of homogeneous materials like steel. Material nonlinearity is incorporated using bilinear stress-strain curves with tangent modulus E/65. E is the elastic young's modulus of the material. the values of strain-hardening rate were attained through a huge number of elastic-plastic large deflection investigation [1] Geometric and material non-linear analysis technique for frames by means of a solution procedure of diminishing the remaining displacements was presented by [2] this nonlinear solution procedure was assumed to be optimum in Newton Raphson method because it tracks the easiest way for achieving the convergence. He introduced the idea of the operative tangent stiffness matrix and it was found to be well-organized, logical, and simple in handling the nonlinear analysis of structures [3] performed an analytical simplified technique for creation of the average stress–average strain connection of lawed steel plates by considering the effect of both material and geometric nonlinearities. Idealized bilinear stress–strain model was used for the analysis [4] gives the results of an examination of the post-buckling characteristic and ultimate strength behavior of lawed pitted steel plates used in ship and other marine structures. Ideal bilinear stress–strain curve model was used for the analysis of their structures.

Nonlinear analysis of torsion effect in RC structural members after getting the preliminary crack was performed by [5,6] developed an innovative finite element layered model used for beam-column elements in RC frame structures by means of an automatic incremental procedure. Both material and geometric nonlinearities in frame structures were considered by the suggested model [7] studied about the performance of deep beam for numerous span/depth ratio by using finite element based **ANSYS version 16.0** and **ADINA version 9.6** under 2-point loading of 50 KN and also studied about the stress distribution of the deep beam. Finite element formulation for material and geometric nonlinear model for outwardly prestressed beams was demonstrated by [8].

the numerically replicated behavior was confirmed by evaluation with experimental tests existing for steel-concrete composite beams and concrete beams.

Analytical model for the steel frame for conducting the nonlinear dynamic analysis was explained by [9] Kinematic strain hardening characteristic was modeled by using the bounding surface idea. the analysis was executed by means of the super minicomputer and computer graphics.

Material nonlinear analysis of reinforced concrete beams by taking effect of the tension softening branch and the effect of bond-slip was studied by [10]. Moment–curvature characteristics of reinforced concrete sections formerly created by the means of section analysis was used for the analysis [11] developed a computer program for the analysis of the structural problems by taking the account for the effect of nonlinear situations of material behaviors under increasing loads. he second order effects were also considered for the analysis. he matrix replacement method was used for the development of the computer program. the method used for analysis takes the effects of axial forces on the stiffness of the structural member by means of the stability functions and the effects of plastic hinges by methodically varying the stiffness matrix in each existence of the plastic hinges. A non-linear analysis of 3-Dimensional steel frames was established by [12]. He analysis was considered for both geometric and material nonlinearities. Material nonlinearity takes the steady yielding related with member forces and geometric nonlinearity comprises the second order effects. he material nonlinearity at a section of the structure was measured by means of the thought of P–M hinges [13] presents a nonlinear finite element computer program, **ANSYS version 16.0** and **ADINA version 9.6** developed for the analysis of steel-concrete composite beam and frame. A 3-Dimensional finite element model was established and the analytical outcomes of load-deflection response was compared with available experimental tests.

Parametric studies were carried out to investigate the effect of some important material and geometrical parameters. In the present research paper material nonlinearity effect on the total deflection and stress of building structures and deflection and stresses are noted at each load step. For nonlinear analysis we are considering constant young's modulus up to yield stress and after that tangent modulus is considered, while for linear analysis same young's modulus is used throughout the analysis.

2. METHODOLOGY

The material nonlinearity is considered for the analysis of beams and frame structures. For checking the effect of material nonlinearity on deflection and stress of structures, load is given gradually and at every load addition, deflection and stresses are noted. Initially linear analysis of beams and frames are carried out using FEM based **ADINA version 9.6** and **ANSYS version 16.0** Cantilever beam with tip point load is formulated by considering two nodes at each end of the beam and one storey frames is formulated by taking five nodes as shown in Figures 1 and 2 respectively. Material properties used for nonlinear analysis of beams and frames are shown in Table 1. Nonlinear analysis of beams and frames are carried out using finite element-based software **ADINA Version 9.6** and **ANSYS version 16.0** mechanical **APDL**. For nonlinear analysis, bilinear stress-strain curve with young's modulus E up to yield point and after that straight line with tangent modulus E/100 and E/65 is considered as shown in Figures 3 and 4 respectively. Material model adopted for the present study is defined as nonlinear » inelastic » rate independent » von-mises » isotropic hardening plasticity » bilinear stress strain (Given in **ADINA** and **ANSYS** software's). The load is applied step by step.

The sections used in frame for the columns section (0.3×0.6) m and for the beam (0.5×0.5) m for warehouse frame.

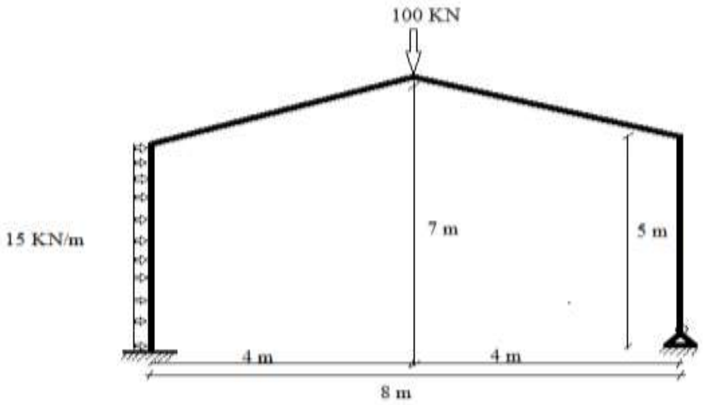

Figure 1. One Storey Warehouse Frame

Figure 2. Cantilever Beam with Tip Point Load

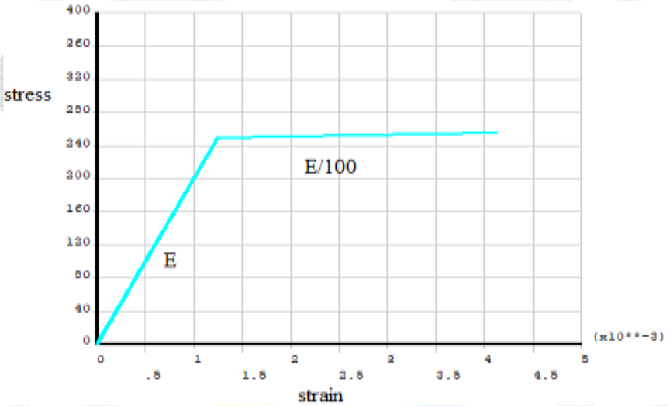

Figure 3. Bilinear Model of Stress–Strain Curve with Tangent Modulus E/100

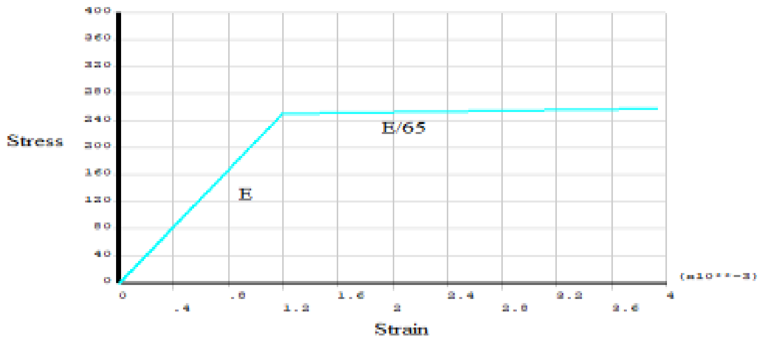

Figure 4. Bilinear Model of Stress–Strain Curve with Tangent Modulus E/65

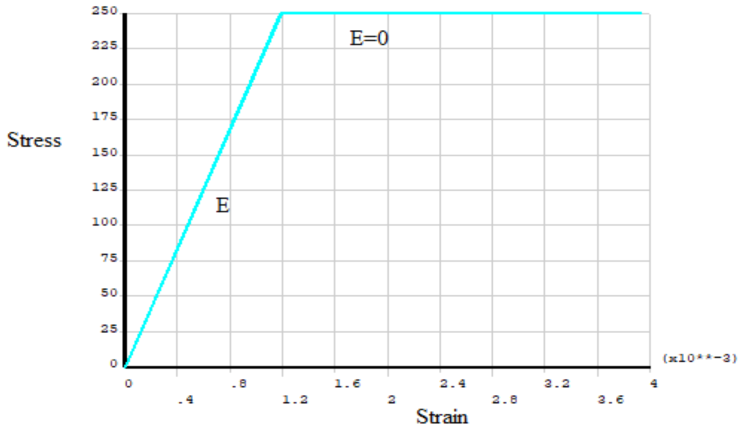

Figure 5. Linear Model of Stress–Strain Curve with Tangent Modulus E

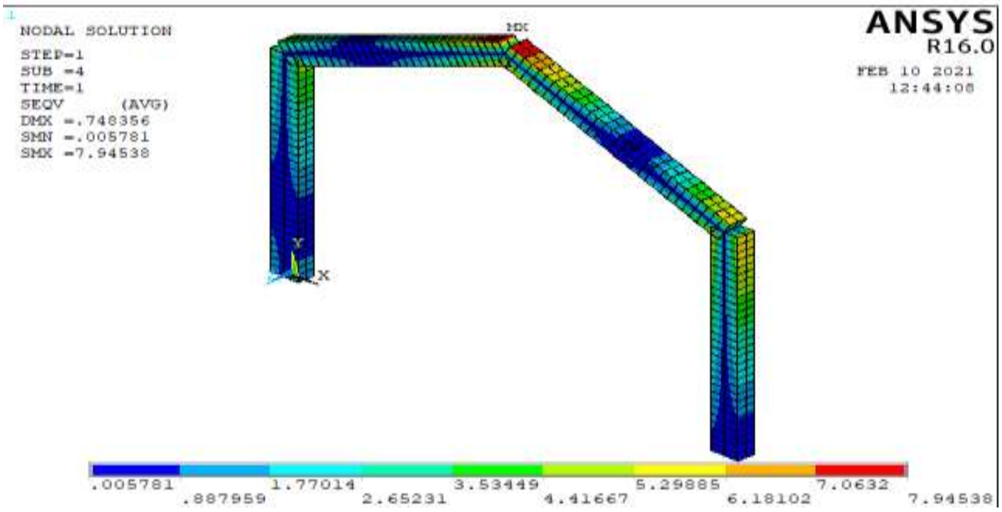

Figure 6. Warehouse Frame in ANSYS software

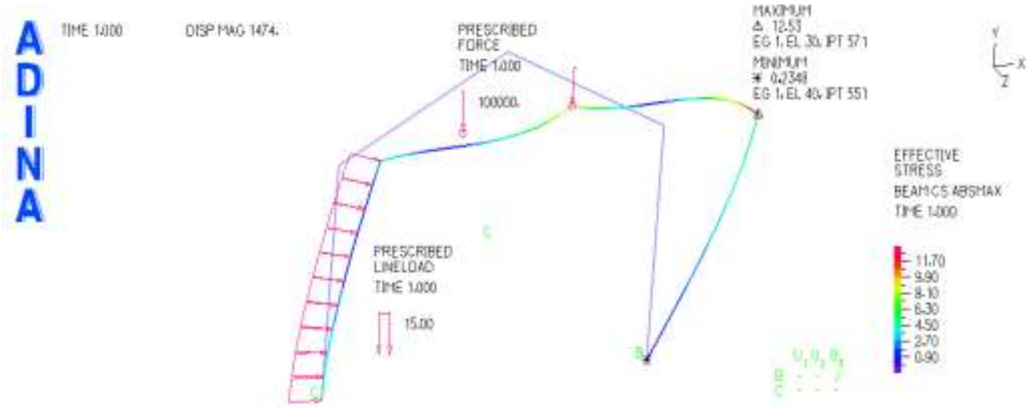

Figure 7. Warehouse Frame in ADINA Software

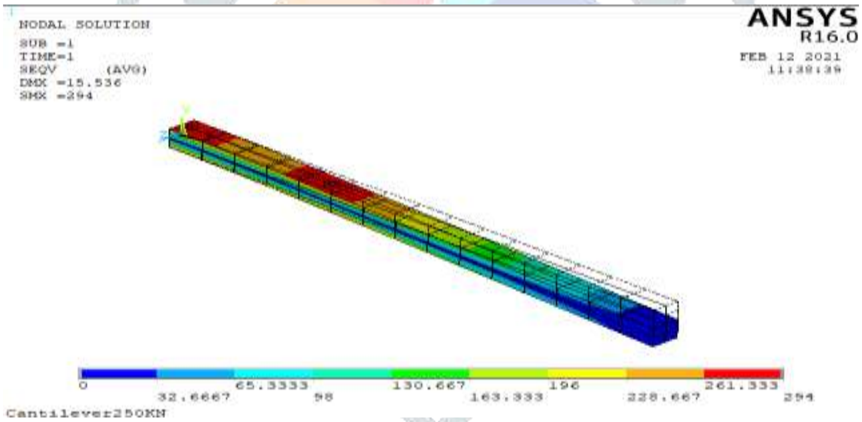

Figure 8. Cantilever Beam in ANSYS

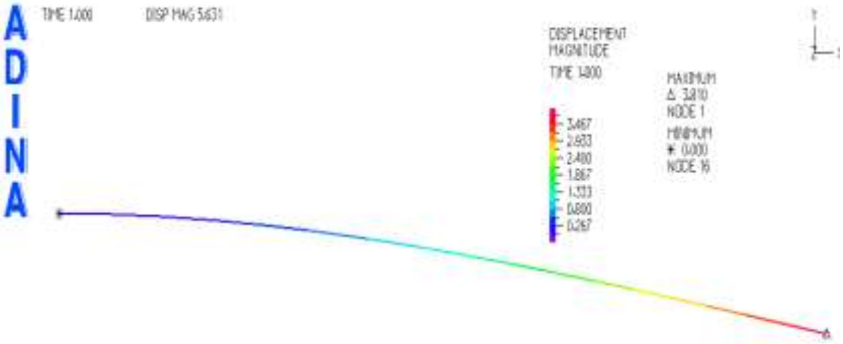

Figure 9. cantilever beam in ADINA

Table 1. Material Properties Used for Nonlinear Analysis of Beams and Frames

Material properties	Values
Elastic modulus (E)	2.1×10^5 N/mm^2
Yield stress	250 N/mm^2
Poisson's ratio	0.3
Tangent modulus (Et) for E/100	21000 N/mm^2
Tangent modulus (Et) for E/65	3231 N/mm^2

Table 2. Deflection and Stress of Ware House Steel Frame with Horizontal Load by ADINA Software

Software	Displacement under load in mm				Maximum Stress in N/mm^2		
ADINA	Loads, KN	E	E/100	E/65	E	E/100	E/65
	100	1.592	1.592	1.592	12.53	12.53	12.53
	1000	10.65	10.67	10.67	107.7	107.7	107.7
	1500	14.9	15.85	15.85	160.6	160.6	160.6
	2000	20.5	21.02	21.02	213.5	213.5	213.5
	3000	29.6	31.69	31.69	250.9	250.9	250.9
	3500	36.56	38.48	38.41	253.3	254.4	250
	4500	195.4	197.6	146	12.53	12.73	11.96

Table 3. Deflection and Stress of Ware House Steel Frame with Horizontal Load by ANSYS Software

Software	Displacement under load in mm				Maximum Stress in N/mm^2		
ANSYS	Loads, KN	E	E/100	E/65	E	E/100	E/65
	100	0.769	0.7	0.7	7.94	7.678	7.678
	1000	9.3	7.51	7.51	79.6	70.3	70.1
	1500	13.2	12.5	12.5	140.8	130.6	130.2
	2000	15.38	18.6	18.67	205.3	153.57	153.21
	3000	20.6	19.2	18.9	240.3	220.6	219.2
	3500	26.9	26.665	25.89	280.142	268.747	265.45
	4500	30.60	30.12	29.54	310.150	302.15	301.4

Table 4. Deflection and Stress of Cantilever Beam

Displacement under load in mm				Maximum Stress in N/mm^2		
Loads, KN	E	E/100	E/65	E	E/100	E/65
150	2.289	2.291	2.291	174	179.98	179.98
250	3.81	3.871	3.871	290	250.7	250.7
350	5.34	28.5	28.5	406	324.5	324.5
450	6.87	92.87	92.87	522	366.4	366.4
750	11.44	155	155	870	728.2	728.2

3. RESULTS AND DISCUSSIONS

❖ The tables showing the behaviour of warehouse frame (stress and strain) due to a dramatic rise in the number of loads on the apex of the frames as well as constant lateral uniformly distributed loads on the column of fixed supported side of the frame.

To look from an overall perspective, strain hardening graph contain the maximum stress. while, fully plastic with less stress deformed more than linear and strain hardening lines.

With gradual increasing of the amount of the loads, stress and strain surge linearly with sharp contrast. Starting from 100 KN load, stress and strain are 12.53 KN/mm^2 and 1.59 mm respectively. The relation remained linear till the loads above from 3500 KN, which stress and strain took average value of 250 MPA and strain of 37 mm for this amount of load. Whereas, yield zone started from 4000 KN point load on the apex of the frame. 250 MPA is the yield stress for the all condition and behaviour of the frame. For 4000 KN loads the stress significantly sore for strain hardening graph from 250 MPA to 269 MPA and simultaneously the strain surged from 38.48 mm to 63.89 mm. While, interestingly the stress for fully plastic behavior marginally remained constant to 252 MPA but strain values leapt from 38.61 mm to 88.24 mm. As result reflect the reality of fully plastic zone. Eventually, the linear zone behaviour remained elastically and surged smoothly from 36.56 mm to 38.9 mm strain and 253.3 MPA to 260 MPA for stress. This shows the direct proportioning of stress and load with displacements which draw the relations linearly. Hence, as the amount goes up the graph would behave systematically. Like the amount of load surged to 4500 KN accordingly fully plastic zone took is maximum value of strain 300 mm while the stress remained constant with sharp difference of 2 MPA in 252.1 MPA. On the other hand, strain hardening zone value rose spectacularly, starting the exertion of loads from 100 KN to 3500 KN the frame behavior is elastic. There are not so significant changes while applying the loads in strain and stress curve for linear, Bilinear of fully plastic and strain hardening and the behaviour of frame is linear.

❖ Cantilever thin cantilever beam the table for denotes the impact of material nonlinearity on the stress and strain behaviour of appropriate beam.

To look from an overall perspective, same as result for frame the maximum strain devote for fully plastic whereas, it contains the lesser stress.

To embark upon, same as frame the values are quite similar with very small changes for linear strain hardening, and fully plastic material. The loading starts from 150 N and strain values initiates from 2.29 mm and stress for all the conditions nearly average of 175 MPA. It remains direct proportion till the 250 N loads. While, with the value of 400 N load the strain soared from 4.45 mm to the 26.5 mm. Linear, and strain hardening values sharply increased from 3.9 mm to 4.1 mm and 4.25 mm to 5.83 mm. As result, the stress in contrast to strain values went up with tiny difference of 8 mm to 258.5 mm for fully plastic which denotes the real behavoiur of the fully plastic. As by gradual increasing of the loads the stress sharply rose up for fully plastic and strain hardening to nearly 287.6 while the strain value soared to 145.9 mm for fully plastic and strain hardening experienced less increased compare to fully plastic to 11.83 mm. Whereas, the values of strain and stress rose up consistently due application of loading for linear values.

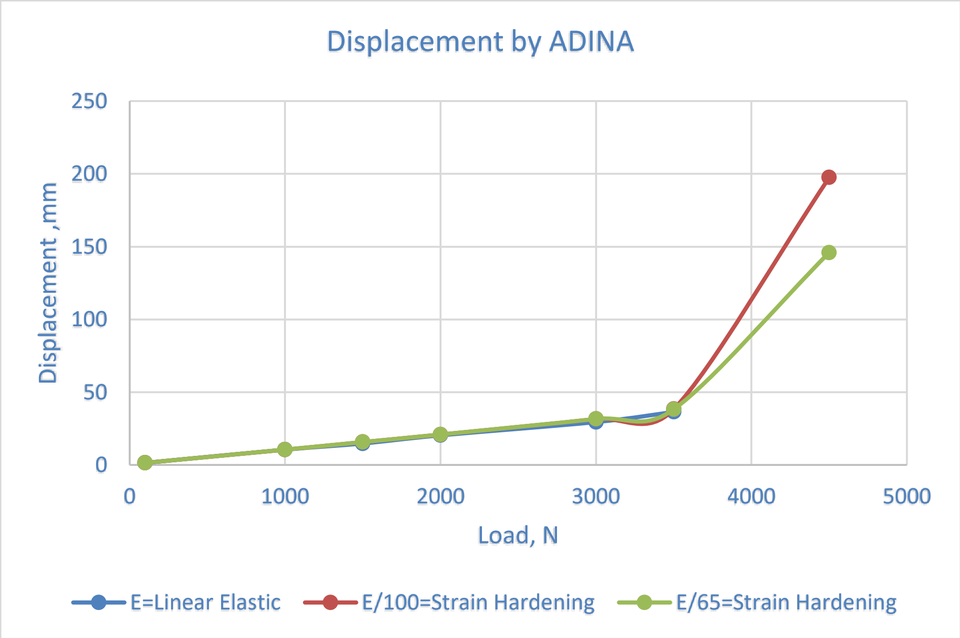

Figure 10. Displacement Under Load by ADINA Software for the Warehouse Frame.

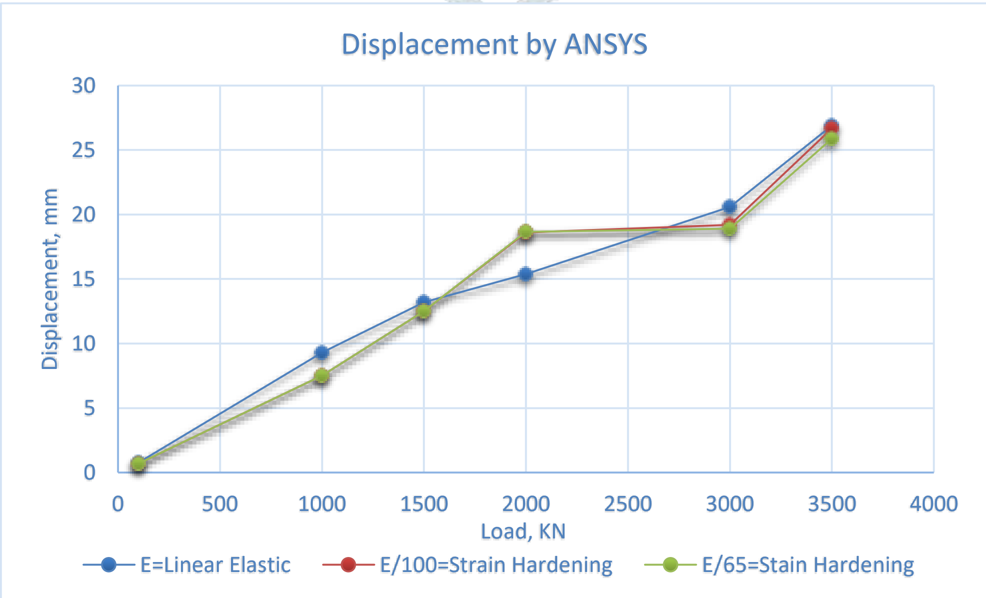

Figure 11. Displacement Under Load by ANSYS Software for the Warehouse Frame.

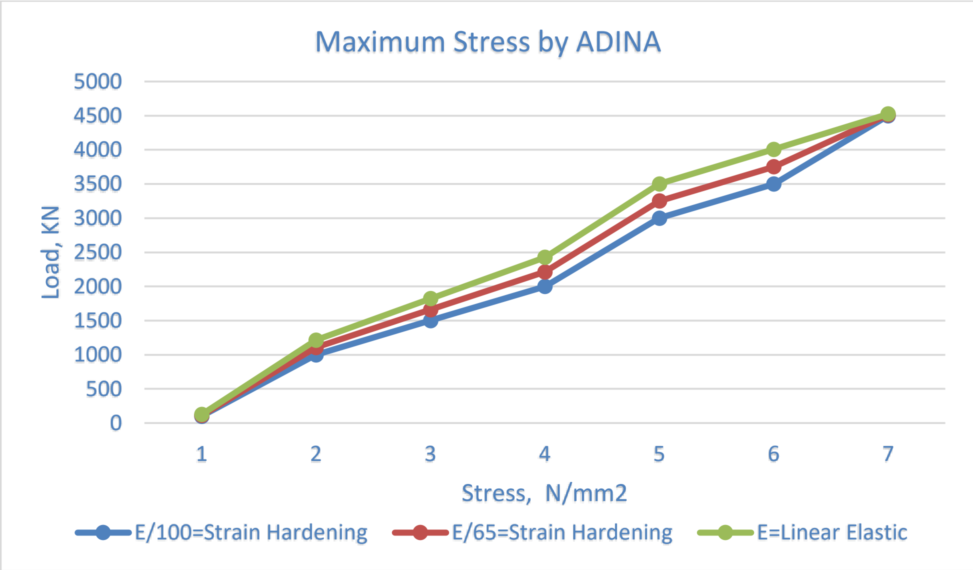

Figure 12. Maximum Stress by ADINA Software for the Warehouse Frame.

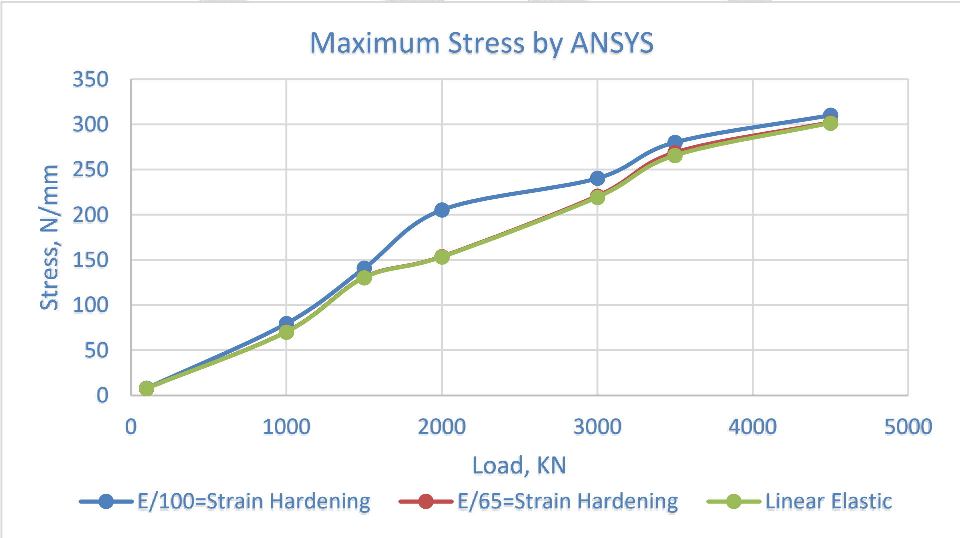

Figure 13. Maximum Stress by ANSYS for the Warehouse Frame.

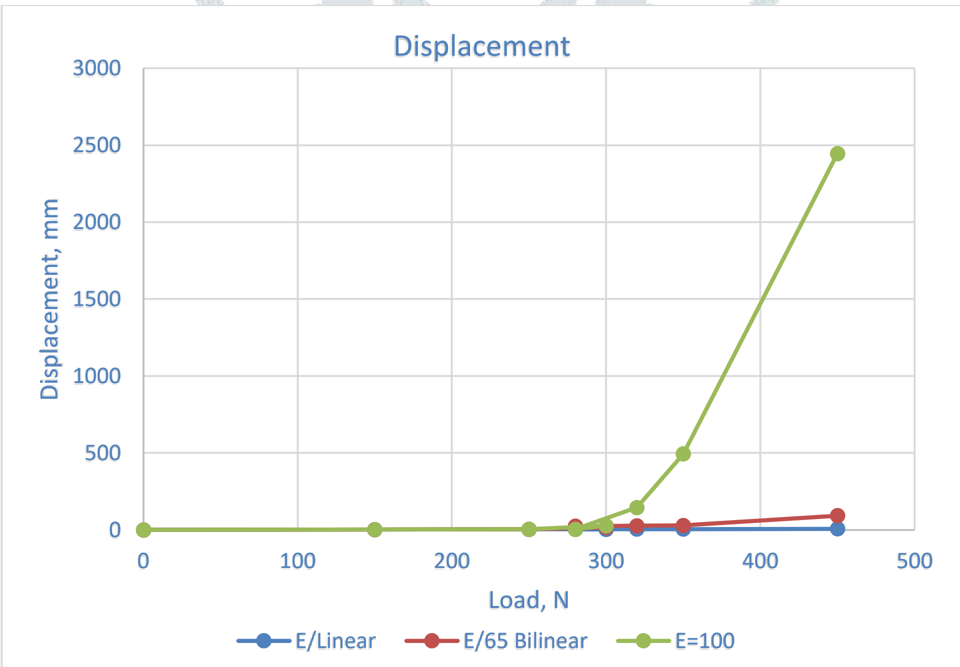

Figure 14 Displacement for the Cantilever Beam

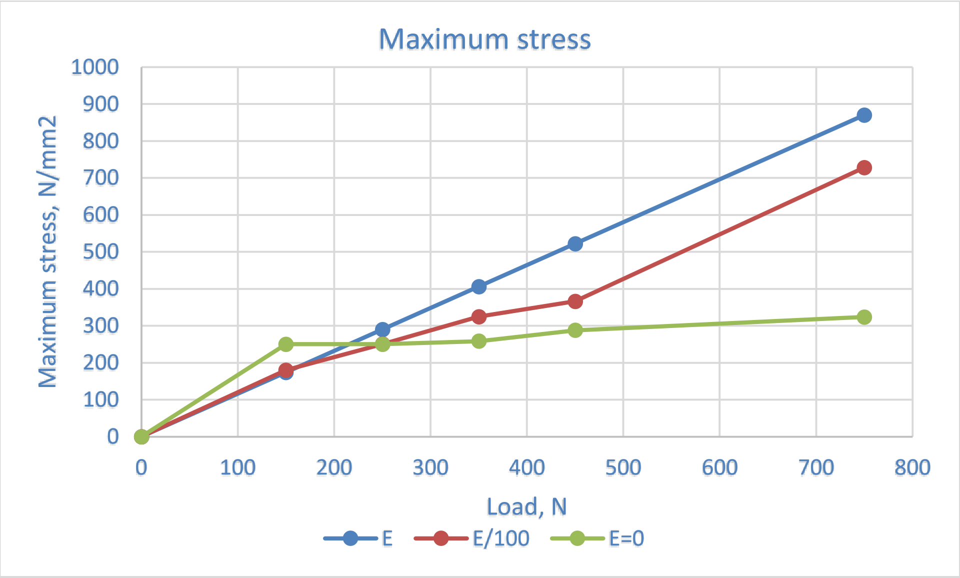

Figure 15. Maximum Stress for Cantilever Beam.

4. CONCLUSIONS

- The nonlinear analysis of material has been done in this paper. Mostly has been focused on the material nonlinearity of the elements in two conditions. Elastoplastic (fully plastic) and Elastoplastic with the strain hardening. For full plastic, the value of modulus of elasticity is been taken near to zero and for strain, hardening has been taken E/100 and E/65 as a tangent modulus. This analysis has been done by two analytical and simulation software of **ANSYS** and **ADINA**. Which the overall conclusion of the project is as below.
- A deep understanding of the concept of nonlinearity in steel structures Plus the stages of stress and strain behavior by using the two structures, thin and thick cross-sections have been included in this research paper.

- It has been cleared due to Euro Code the behavior of the elements when loads are getting exerted on it. Which are linear, bilinear, and multilinear. The bilinear has been divided into two parts of strain hardening and fully plastic which the tangent of modulus is taken as E/100 and E near to zero respectively.
- For warehouse frame due to having a solid section of 500×500 and 300×500 for columns and beam respectively. Having great yield point and heavy loads caused to reach its strain hardening and fully zone. The nonlinear analysis has been performed for warehouse frame containing thick beams and a cantilever with thin cross section two simulating and analyzing software's **Adina** and **Ansys** and the result has been taken as follow,
  - 4.1 For thick cross-section in beams and columns of the warehouse there are sharp changes between linearity and biplanarity for a small number of loads. while by huge increasing the number of loads, steel is taken its yield point and spectacular changes in stress and strain appear.
  - 4.2 Nonlinear analysis in the thin beam has concluded that by gradually enhancing the number of loads all the behavior would approaching the same yielding point. While, after yielding point the values for linear elastic, strain hardening, and fully plastic vary spectacularly from each other.
  - 4.3 It has been noted that a fully plastic zone with the minimum and constant stress after yield point reached high strain. Moreover, for strain hardening zone stress and strain surged proportionally. Whereas, the linear elastic zone contains high stress with the least strain.
  - 4.4 Comparison of software for bilinear analysis of the structures has been done in ANSYS and ADINA Software the comparison of the results are so near.

5. ACKNOWLEDGMENTS

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6. REFERENCES

1. **Khedmati MR** (2000). Ultimate Strength of Ship Structural Members and Systems Considering Local Pressure Loads. Ph.D. Thesis, *Graduate School of Engineering, Hiroshima University*.
2. **Chan SL**. (1988). Geometric and Material Non-Linear Analysis of Beam-Columns and Frames Using the Minimum Residual Displacement Method. *International Journal for Numerical Methods in Engineering*. 26(12):2657–69.

3. **Khedmati MR, Nouri ZHME (**2015). Analytical Simulation of Nonlinear Elastic–Plastic Average Stress–Average Strain Relationships for Un-Corroded/Both-Sides Randomly Corroded Steel Plates Under Uniaxial Compression. *thin-Walled Structures*., 86:132–41.
4. **Nouri ZHME, Khedmati MR, Sadeghifard S**. (2012). An Effective Thickness Proposal for Strength Evaluation of One Side Pitted Steel Plates Under Uniaxial Compression. *Latin American Journal of Solids and Structures*. 9:475–96.
5. **Hosseini M, Ashrai HR, Beiranvand P, Ghanbari B (**2016). Nonlinear Analysis of Torsion in Reinforced Concrete Members After Developing Initial Crack. *Indian Journal of Science and Technology*. 9(7): 10.17485.
6.**Sun CH, Bradford MA, Gilbert RI** (1993). Nonlinear Analysis for Concrete Frame Structures Using the finite Element Method. Journal of *Comparers and Structures*.48(I):73–9.
7. **Sabale VD, Borgave MD, Joshi PK (**2014). Non-Linear Finite Element Analysis of Deep Beam. *International Journal of Engineering Research and Technology*.3(5).
8. **Zona A, Ragni L, Asta AD (**2008). Finite Element Formulation for Geometric and Material Nonlinear Analysis of Beams Prestressed with External Slipping Tendons. *Finite Elements in Analysis and Design*. 44:910–19.
9. **Himly SI, Abel JF (**2002). Material and Geometric Nonlinear Earthquake Analysis of Steel Frame Using Computer Graphics. Computers and Kwak HG, Kim SP. Nonlinear analysis of RC beams based on moment–curvature relation. *Computers and Structures*. 80:615–28.
10.**Kwak HG, Kim SP (**2002)**.** Nonlinear Analysis of RC Beams Based on Moment–Curvature Relation. *Computers and Structures*.80:615–28.
11.**Cosgun T, Sayin B (**2014). Geometric and Material Nonlinear Analysis of Three-Dimensional Steel Frames. *International Journal of Steel Structures*. 14(1):59–71.
12.**Kim SE, Kim Y, Choi SH (**2001). Nonlinear Analysis Of 3-D Steel Frames. Thin-Walled Structures.39:445–61.
13.**Ibrahim AM, Ahmed QW (**2013). Nonlinear Analysis of Simply Supported Composite Steel - concrete beam. *Journal of Engineering Sciences*. 6(3):107–26.