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BUCKLING BEHAVIOUR OF STEEL COLUMN HAVING AN INTERMEDIATE SUPPORT

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ABSTRACT

The present work focuses on the study of buckling behaviour of square steel column by varying the position of single intermediate support along the height of column. The analysis of long steel column of size 200 mm x 200 mm and height 10 m is carried out using finite element software (ANSYS) to obtain the position of intermediate support which provides maximum buckling load and lateral deflection of the column for different boundary conditions. The position of single intermediate support is varied by 1 m along the height of column measured from the bottom end of the column and buckling load and lateral deflection is evaluated for each position to determine the maximum value of buckling load and lateral deflection for different boundary conditions. The results of analysis are compared with Euler's theory for general end support conditions.

Keywords: buckling load, finite element analysis, ANSYS, Euler's theory, intermediate support, lateral deflection.

INTRODUCTION

A long column buckles along least lateral dimension under smaller axial compressive load than a short column. The buckling of long columns can be restrained by providing intermediate support(s) at proper location(s) along the height of a column. Therefore, in the present work, analysis of a long column is carried out with single intermediate support positioned at different locations along height of the column to achieve better rigidity or stiffness of the column. The analysis is carried out by ANSYS software for different end conditions and results are validated by Euler's theory for long columns.

There are different ways to provide the stiffness to a column, some of them are:

a) A column supported by guided support
b) A column supported by bracings
c) A column strengthen by retrofitting

LITERATURE REVIEW

In the past, prominent works have been carried out by the past researchers to investigate the bucking behaviour of long columns.

Rekha, B. *et al* [1] carried-out analysis of I - section column subjected to axial load using ANSYS software and compared the results of critical buckling load with conventional method (Euler Buckling theory), the results of ANSYS critical buckling load differs from Euler's critical load but the results of the ANSYS are more accurate as it considers the geometric imperfection and residual stresses.

Oludele, A. *et al* [2] studied flexural-torsional buckling of beam-column supports of field fabricated spherical pressure vessels using finite element analysis. The flexural-torsional buckling loads of the structure were evaluated using eigen values. The resulting eigen value equation obtained was coded using FORTRAN 90to aid analysis process. The results obtained by FEA and ANSYS software were compared to classical solutions available in the literature and no significant difference was found.

Tajmir. H. *et al* [3] made investigations on tapered section column using slope deflection method to find critical load and effective length coefficient for practical use. The results obtained from this method are quite accurate than analytical or finite element method.

Sudhir, S. *et al* [4] analysed an open section channel (thin walled structures) subjected to buckling load using ANSYS software. These thin walled structures constitute thin plates fixed on open section beams whose centroid does not coincide with shear centre. The results were compared with classical solutions to find the best type of open section for thin walled structures. It was concluded that the maximum critical moment of the channel is found for b/a ratio ranging between 0.5 to 1.0. Also, the effect of change in radii was studied and it was found that, higher the value of radius, higher is the maximum critical moment.

Bruce. J. *et al*. [5] proposed use of relatively slender column of the symmetrical I or WF shape loaded eccentrically in the plane of the web by longitudinal end loads which may fail by elastic instability involving a combination of lateral bending and twisting. It is observed that relatively small eccentricities of the longitudinal end load applied in the plane of the web which causes significant decrease in the Euler critical load.

Anthony. B [6] evaluated critical load that causes elastic instability for a fixed-free circular formed structural sections for better understanding of the buckling failure behaviour. Column of height 10 meters and radius 0.5 m using ANSYS. The critical load was determined with Euler's buckling load theory and results were compared with ABAQUS, and ANSYS and close agreement was found.

Martin. M *et al* [7] presented numerical investigation on the buckling behaviour of cold–formed

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thin-walled steel structural members with perforations. A FE model was generated using ANSYS to predict the ultimate strength of cold-formed thin-walled steel structural

Bhushan. P. *et al* [8] carried out made parametric study to study the behaviour of concrete-filled steel tube (CFST) columns under axial load using ANSYS. The buckling load was compared with Euro code 4 (1994) and it was found that the results by ANSYS show good agreement with the Euro code 4 (1994). It was concluded that when thickness of steel tube is increased by 1 mm, the capacity of CFST column increases nearly by 15%.

Rhodes. J [9] studied post-buckling elastic and plastic behaviour of plates and plate structures.

Goutam. S *et al* [10] studied the buckling load of beam-column by using multi-segment integration technique and compared the results with Euler's buckling load and Finite Difference Method in order to determine the efficiency of this method compared to other methods. It was found that multi-segment integration technique is quite capable of solving this kind of problem and is an effective and efficient technique

Ziółkowski. A. *et al* [11] investigated the buckling and post-buckling behaviour of prismatic aluminium columns from stocky to very slender in shape. The experimental study revealed that the value of Euler's buckling load drops down to nearly by 20% in the columns of intermediate slenderness ratio. This observation is in contradiction to predicted results from the elasto-plastic buckling models proposed by Engesser or Shanley. Further tests on columns of intermediate slenderness, with strain gauges glued at node and anti-node locations of the buckled profiles, revealed that even minute buckling results in highly non-symmetric residual micro plastic strain.

Changgen. D *et al* [12] made experimental investigations on six steel specimens of welded H-section subjected to axial compressive load, the in-plane shear force and the resulting bending moment around the cross-section major axis to investigate the elasto-plastic interactive buckling performances of beam-columns. They observed that the normalized ultimate moment capacity decreases remarkably as the axial compression ratio or the flange width-thickness ratio increases, however, insignificant effect is found as the web height-thickness ratio increases.

Bouras. F *et al* [13] investigated the behaviour and life span of columns made up of wood based material such as Glulam (GL) or laminated veneer lumber (LVL) under repeated loading leading to buckling failure. The experimental studies show that solid wood column mainly damaged in compression first followed by a prompt failure in tension. The fracture took placed not in the middle of the specimen but near the knots. The breaking of Glulam column is similar to that of solid wood column. The LVL column also damaged in compression and the rupture is due to detachment of layers of veneers in the tension zone. Aytekin, E.J *et al* [14] studied the buckling of column by Homotropy Analysis Method (HAM) to find the critical buckling load of columns with continuous elastic restraints. The results are compared with the analytic solutions. It was concluded that HAM method is quite accurate than analytic solutions.

Yasin, Y. *et al* [15] studied of the buckling behaviour of axially loaded and functionally graded non-uniform columns with elastic restraintsusing Localized Differential Quadrature Method (LDQM). A comparison of buckling behaviour of homogeneous uniform columns and functionally graded non-uniform columns with elastic restraints was presented to show the effectiveness of the method.

Hamid, H. *et al* [16] proposed the buckling behaviour of column due to retrofitting of beam-column joint using CFRP (Carbon Fibre Reinforced Polymer) and steel plate. By retrofitting the exterior beam-column joint with CFRP, the lateral strength is increased by 5% for the beam-column joint.

Bairavi, G. *et al* [17] investigated the behaviour of retrofitted RCC column. The RCC column was retrofitted by wrapping the specimens by singly or doubly basalt fibre sheet. It was found that due to retrofitting, the ultimate load carrying capacity increased by nearly 43%.

Yiyan. L *et al* [18] conducted experimental study to study the behaviour of concrete-filled steel tube columns confined by fibre-reinforced polymer (FRP).The predicted results are generally in good agreement with the experimental ones obtained in this study and in the literature.

PROBLEM UNDER INVESTIGATION

The analysis of long steel column of size 200 mm x 200 mm and height 10 m is carried out using finite element software (ANSYS) to obtain the position of intermediate support which provides maximum buckling load and lateral deflection of the column for different end conditions. For this analysis, an axial load of 1N (compressive) is applied over the top node of the column. The position of single intermediate support is varied along the height of column from the bottom end by 1m and buckling load and lateral deflection is evaluated for each position to determine the maximum value of buckling load and lateral deflection for different boundary conditions. The modelling of the column is shown in Figure-1.

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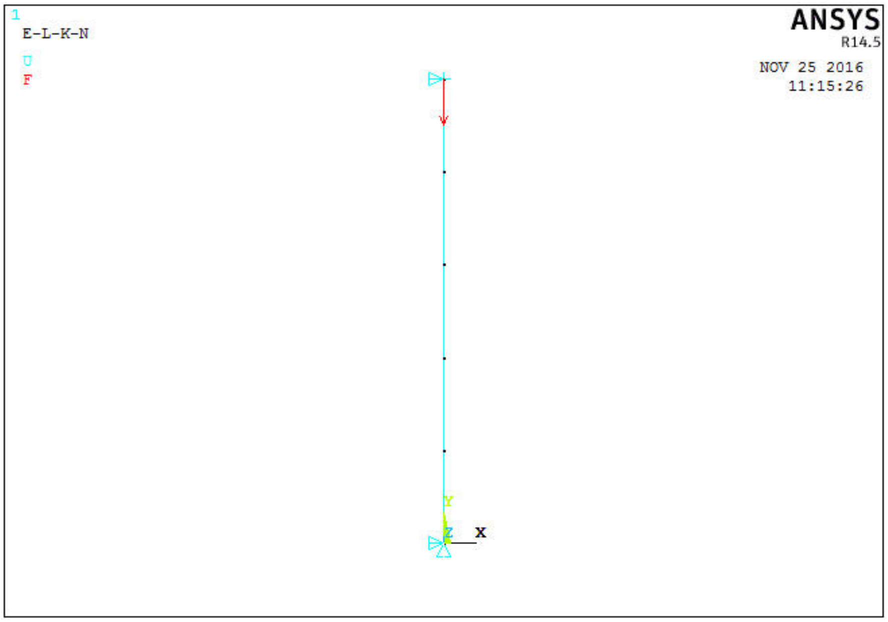

Figure-1. Modeling of column with compressive load at its top node

FINITE ELEMENT MODELLING

The FE modelling of the column is achieved in ANSYS with 2node beam element (BEAM 188). The details of BEAM188are provided in Figure-2. The long steel column is discretized with 5 beam elements as shown in Figure-3. The material properties of the column are provided in Table-1. The column is loaded with 1 Newton (compressive). The finite element analysis is performed using ANSYS and critical buckling load and lateral deflection value are found for these 32 cases. Theoutput data for 44 cases are provided in Table-2 to Table-5.

The BEAM188 element is suitable for analyzing slender to moderately stubby/thick beam structures. This element is based on Timoshenko beam theory. Shear deformation effects are included. It is a linear (2-node) beam element in 3-D with six degrees of freedom at each node. The degrees of freedom at each node include translations in x, and z directions, and rotations about the x, y and z directions. The warping of cross sections is assumed to be unrestrained. The stress stiffness terms provided enable the elements to analyse flexural, lateral and torsional stability problems (using eigen value buckling or collapse studies with arc length methods). BEAM188 can be used with any cross section having elastic and isotropic hardening plasticity models are supported (irrespective of cross section subtype).

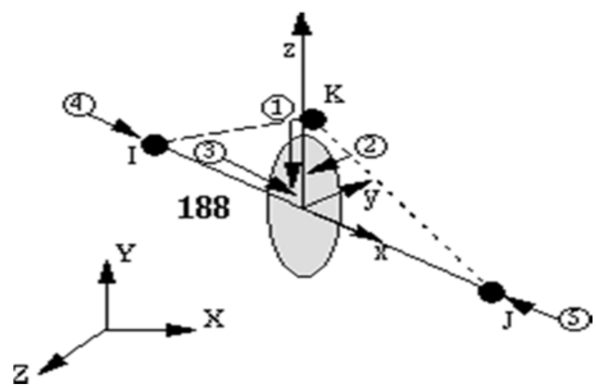

Figure-2. BEAM 188.

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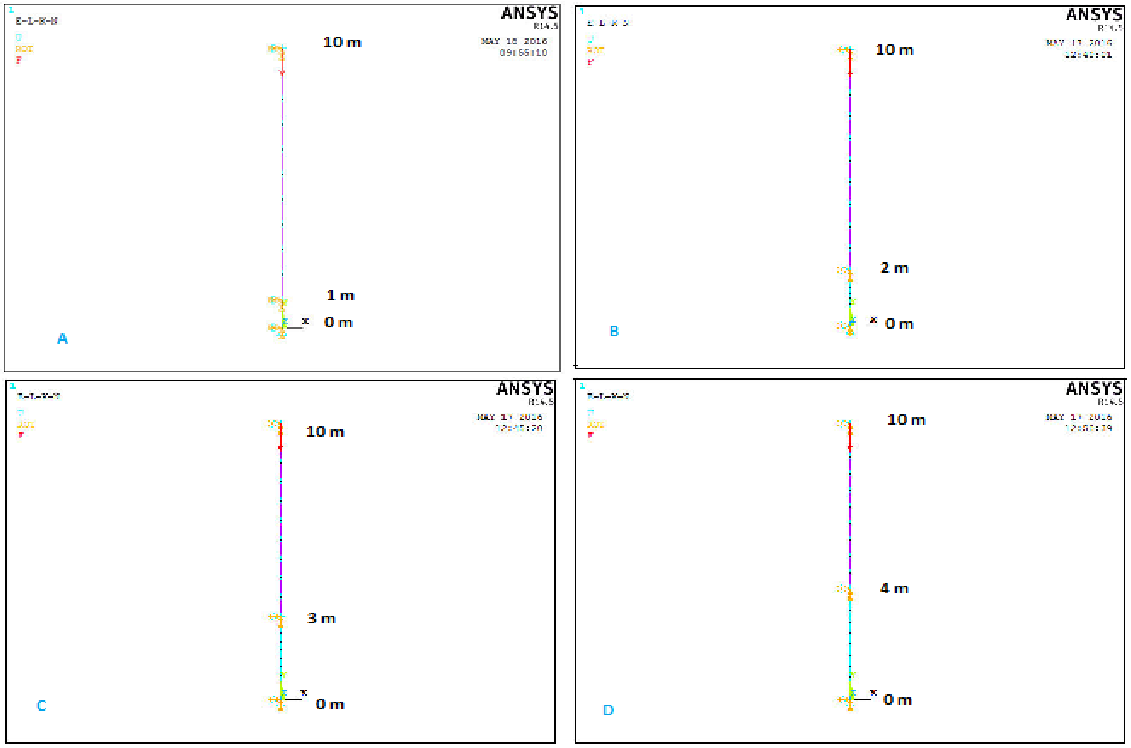

Figure-3. Finite element discretization of long column

Table-1. Material properties

S. No.	Name of property	Value
1	Modulus of Elasticity	2 x 10^5 N/mm^2
2	Shear modulus	10^4 N/mm^2
3	Poisson's ratio	0.29
4	Bulk modulus	1.58 x 10^5 N/mm^2

ANALYSIS OF RESULTS

The buckling load and lateral deflection of long column under consideration are evaluated under different end conditions. Table-2 shows the values of buckling load and lateral deflection of long column for both ends hinged. It is found that there is increase in buckling load as the position of intermediate support is moved towards centre of the column. The maximum value of buckling load is found at the mid height. The insignificant variation is found in the lateral deflection of the column. Figure-4 shows the variation of the lateral deflection for both end hinged condition. There is insignificant variation found in lateral deflection.

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Table-2. Buckling load for various positions of intermediate support for both ends hinged.

S. No.	Boundary condition	Position of intermediate support from bottom end of column (m)	Buckling load (kN)	Lateral deflection (mm)
1	Both ends hinged	0	2630	0.95
2	Both ends hinged	1	6170	1.00
3	Both ends hinged	2	7190	1.00
4	Both ends hinged	3	8440	0.99
5	Both ends hinged	4	9770	0.97
6	Both ends hinged	5	10500	0.95
7	Both ends hinged	6	9770	0.95
8	Both ends hinged	7	8440	0.96
9	Both ends hinged	8	7190	1.00
10	Both ends hinged	9	6170	1.00
11	Both ends hinged	10	2630	0.95

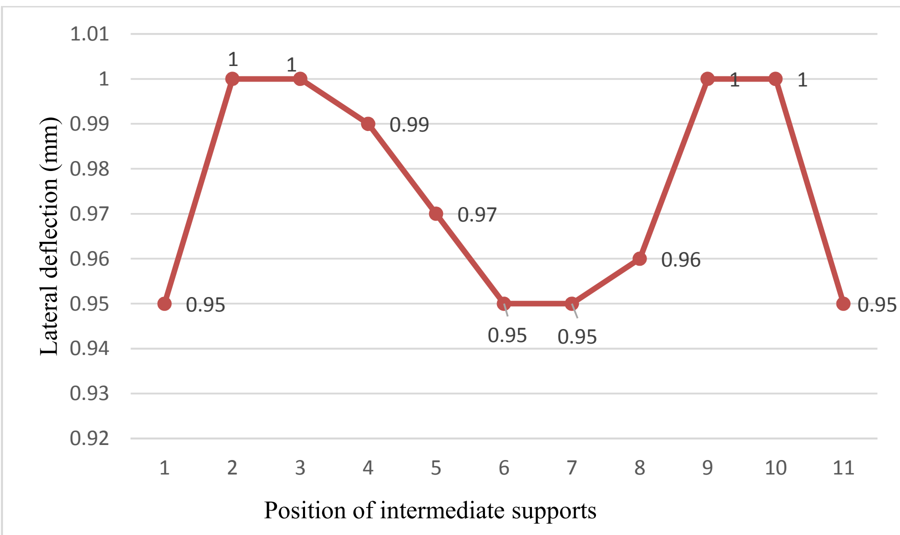

Figure-4. Lateral defection at different position of intermediate support for both end hinged.

Table-3 shows the values of buckling load and lateral deflection of long column for both ends fixed. It is found that there is increase in buckling load as the position of intermediate support is moved towards centre of the column. The maximum value of buckling load and lateral deflection is found at the mid height. The higher value of bucking load is found as compared to both ends fixed condition. There is cyclic variation found in the lateral deflection. Figure-5 shows the variation of the lateral deflection having for both end fixed condition.

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Table-3. Buckling load for various positions of intermediate support for both ends fixed.

S. No.	Boundary condition	Position of intermediate support from bottom end of column (m)	Buckling load (kN)	Lateral deflection (mm)
1	Both ends fixed	0	10500	0.93
2	Both ends fixed	1	12200	0.93
3	Both ends fixed	2	14400	0.95
4	Both ends fixed	3	1710	0.98
5	Both ends fixed	4	1990	1.00
6	Both ends fixed	5	21300	1.00
7	Both ends fixed	6	1990	1.00
8	Both ends fixed	7	17100	0.98
9	Both ends fixed	8	14400	0.95
10	Both ends fixed	9	12200	0.93
11	Both ends fixed	10	10500	0.93

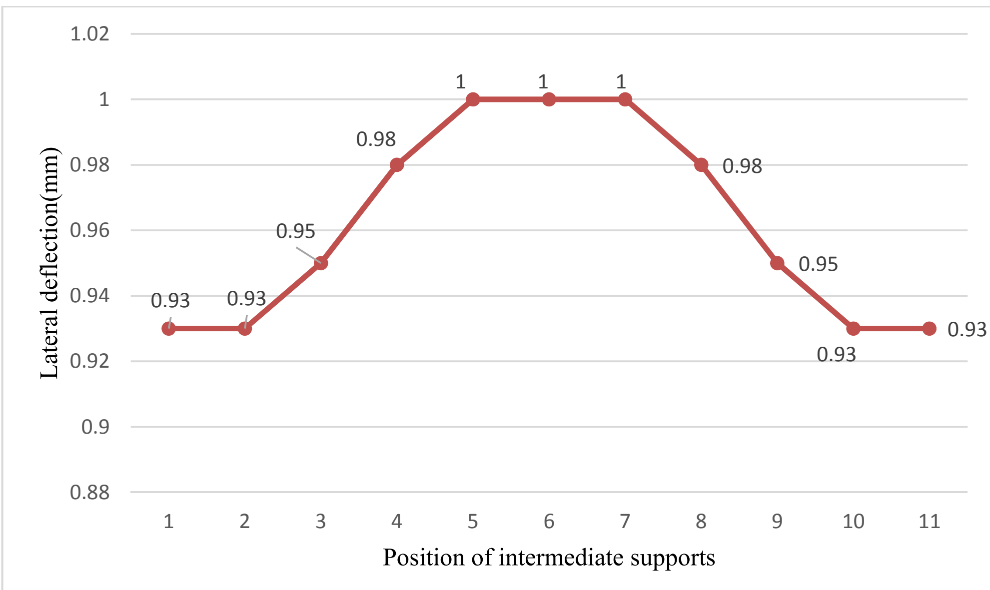

Figure-5. Lateral defection at different position of intermediate support for both end fixed.

Table-4 shows the values of buckling load and lateral deflection of long column for one ends fixed and other end is hinged. It is found that there is increase in buckling load as the position of intermediate support is moved towards centre of the column. The maximum value of buckling load is found at 6 m height from the base of the column. The insignificant variation is found in the lateral deflection of the column. Figure-6 shows the variation of lateral deflection for one end fixed and other end hinged condition. The insignificant variation found in lateral deflection.

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Table-4. Buckling load for various positions of intermediate support (one end fixed other hinged).

S. No.	**Boundary condition**	**Position of intermediate support from bottom end of column** (m)	**Buckling load** (kN)	**Lateral deflection** (mm)
1	One end fixed other hinged	0	5370	1.00
2	One end fixed other hinged	1	6260	1.00
3	One end fixed other hinged	2	8330	1.00
4	One end fixed other hinged	3	9010	1.00
5	One end fixed other hinged	4	11100	0.98
6	One end fixed other hinged	5	14700	1.00
7	One end fixed other hinged	6	15600	1.00
8	One end fixed other hinged	7	15400	0.99
9	One end fixed other hinged	8	13800	0.97
10	One end fixed other hinged	9	12000	0.94
11	One end fixed other hinged	10	5370	1.00

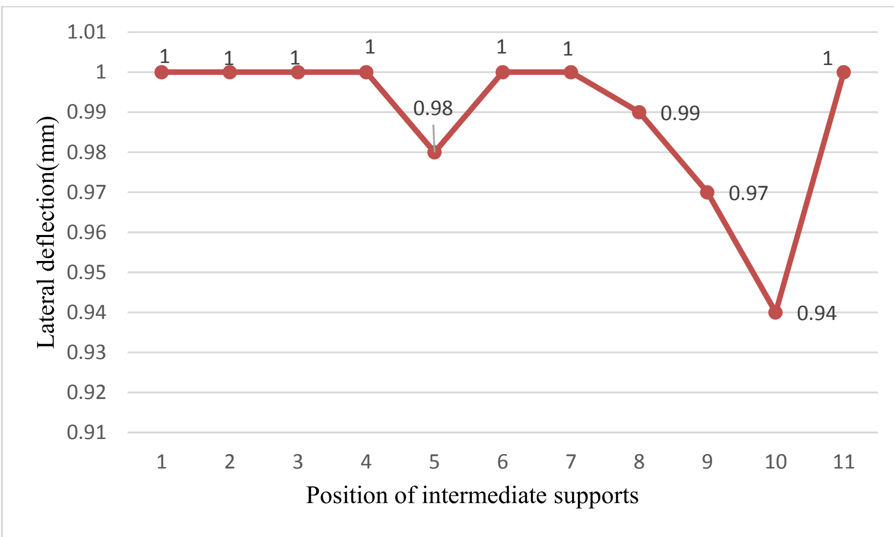

Figure-6. Lateral defection at different position of intermediate support for one end fixed other hinged.

Table-5 shows the values of buckling load and lateral deflection of long column for both ends hinged. It is found that there is increase in buckling load as the position of intermediate support is moved towards centre of the column. The maximum value of buckling load is found at 10 m height. The lateral deflection remains almost constant. Figure-7 shows the variation of lateral deflection for one end fixed and other end is free condition. The lateral deflection remains almost constant.

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Table-5. Buckling load for various positions of intermediate support (one end fixed other free).

S. No.	Boundary condition	Position of intermediate support from bottom end of column (m)	Buckling load (kN)	Lateral deflection (mm)
1	One end fixed other free	0	657	1.18
2	One end fixed other free	1	765	1.00
3	One end fixed other free	2	907	1.00
4	One end fixed other free	3	1090	1.00
5	One end fixed other free	4	1340	1.00
6	One end fixed other free	5	1670	1.00
7	One end fixed other free	6	2130	1.00
8	One end fixed other free	7	2760	1.00
9	One end fixed other free	8	3620	1.00
10	One end fixed other free	9	4590	1.00
11	One end fixed other free	10	5370	1.00

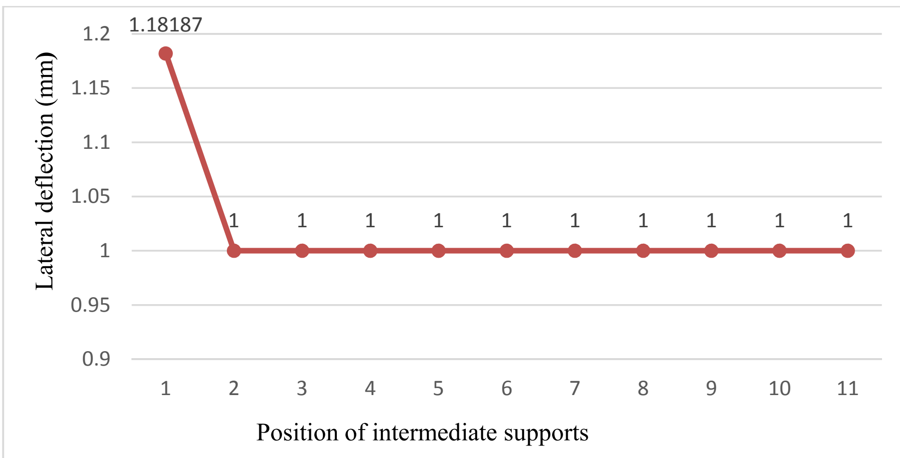

Figure-7. Lateral defection at different position of intermediate support for one end fixed other free.

The buckling load and lateral deflection of above 44 cases are found. It is found that intermediate supports provide better stiffness to the column and helps in finding effective position of intermediate support necessary for retrofitting of column, if required. Table-6 shows position of intermediate and maximum buckling load values for different boundary conditions.

Table-6. Position of an intermediate support for maximum buckling load

S. No.	Boundary condition	Position of intermediate support (m) from bottom end of column	Maximum buckling load (kN)
1	Both ends hinged	5	10500
2	Both ends fixed	5	21300
3	One end fixed other hinged	6	15600
4	One end fixed and other free	10	5370

The comparison of results of column having end boundary conditions (no intermediate support) and column having single intermediate support is presented in Table-7. The variation of bucking load for long column for different end conditions is depicted in Figure-4. The ratio of increase in buckling load value is shown in Table-7. From the above results effective position of intermediate supports can be determined. Figure-8 shows the variation

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of buckling load for the column with intermediate support and without intermediate support for different end condition.

Table-7. Comparison of the results with and without an intermediate support.

S. No.	Boundary condition	Buckling load (kN)		Ratio (3)=(2)/(1)
		without intermediate support (1)	with intermediate support (2)	
1	Both ends hinged	2630	10500	4.00
2	Both ends fixed	10500	21300	2.00
3	One end fixed other hinged	5370	15600	2.90
4	One end fixed other free	658	5370	8.16

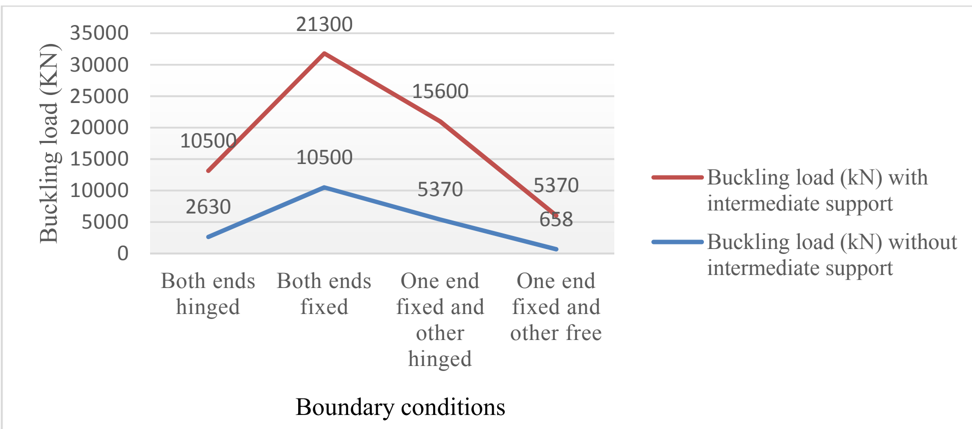

Figure-8. Comparison of buckling load with and without intermediate supports.

CONCLUSIONS

a) The buckling load for columns with intermediate supports is nearly 4 times higher than that of columns without intermediate support for both ends hinged condition.
b) There is significant increase in buckling load of column with both ends fixed when intermediate support is provided. The increase of nearly 2 times is found for column intermediate support compared to column having no intermediate support.
c) The increase of nearly 3 times is found in buckling load of column with intermediate support when one end is fixed and other is hinged compared to column with no intermediate support.
d) Highly significant increase of nearly 8 times is found in the bucking load of column with one end fixed and other free.
e) There is insignificant variation in lateral deflection of columns with intermediate support for different end conditions.

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