Comparative Study of Lateral Torsional Buckling of Steel Beams using SAP 2000 and STAAD Pro

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***Abstract*— When a steel beam is designed for lateral-torsional buckling, the elastic critical moment Mcr is an important design parameter. The factor that is considered for Lateral-torsional buckling is point of action of load. In this study, Double symmetric I-section, monosymmetric I-section and built-up I-section beams are considered for rotation around the minor axis and warping considering various load heights and varying degrees of end restraint. Various beam lengths and different forms of load with centric loading, beams with a channel cross-section are examined. Mcr (elastic critical moment) is determined using software and compared to values obtained using an empirical expression called the 3-factor formula in EC3 and the IS 800:2007.

The disparity between the software tools under investigation is due to the different methods and assumptions used to calculate Mcr. SAP2000 and STAAD.Pro are the software tools used in this report.

***Keywords*— Buckling, Beams, Lateral Torsional, Steel beams.

I. INTRODUCTION

One of the tasks engineers face, when designing beams with an open cross section is lateral-torsional buckling, often referred to as LT-buckling. LT-buckling can occur in major axis bending of a beam, where the stiffness about the minor axis is relatively small in comparison to the stiffness about the major axis. Before the steel yields, the compression flange buckles in the transversal direction to the load, pulling the beam sideways, while the flange in tension tends to hold the beam in place. This is called lateral-torsional buckling and the steel beam is no longer suitable for its original purpose.

When designing with respect to LT-buckling according to the design code EN 1993-1-1:2005, hereinafter referred to as Eurocode 3 and IS 800:2007, one parameter to be noticed is the relative slenderness of the beam. It is determined from two basic parameters; the plastic moment capacity of the cross section Mpl, and the elastic critical moment, Mcr. The lower Mcr is, the higher the relative slenderness will be. A higher relative slenderness implies a lower reduction factor, and the design moment capacity of the beam reduces. However, there is nothing stated about how to determine Mcr in Eurocode 3.

The factors influencing Mcr according to analytical expressions are: stiffness about the minor axis, torsional stiffness, warping stiffness, length of the beam, boundary conditions, type of the load, vertical position of the loading, Material parameters and Degree of symmetry about the major axis

Nowadays a considerable number of commercial structural engineering software take LT-buckling mechanism. Some software offer the possibility to design beams with a channel lateral-torsional buckling into account, when evaluating the capacity of steel beams. This means that it is possible for a designer to select a beam without putting an effort into understanding the section with regard to lateral-torsional buckling, but the design rules are only valid if the channel beams are centrically loaded (Snijder et al. 2008). It is noticed different results for Mcr depending on which software is used, even for the simplest cases. When the difference is significant, it makes the engineer raise doubts about the reliability of the results. For that reason, a good understanding of the problem, as well as of the methods and assumptions that the available software use to obtain their results is vital.

II. METHOD ADOPTED FOR STUDY

To understand the mechanism behind lateral-torsional buckling and the evaluation of Mcr. Analytical expressions for beams and their inputs are studied. Those expressions are investigated for I-beams with doubly symmetric cross section before moving on to monosymmetric I-beams, channel beams and finally built up I-section.

Software Used for Study

The two commercial structural engineering software, SAP2000 and STAAD.Pro will be used for modelling in order to find Mcr. First a doubly symmetric I-beam will be modelled in the different software in order to confirm the modelling method is appropriate. Then a monosymmetric I-beam, Channel beam and builtup I-section will be modelled using different lateral restraints with a point load applied at various heights and the result is compared with the results obtained by using Eurocode 3 and IS 800:2007.

III. LITERATURE REVIEW

Several researchers have studied the lateral-torsion buckling of steel beam with different parameters that influence the elastic critical moment, Mcr. A Brief review of the relevant to the present context is presented below.

Ahnlen, M., Westland, J. (2013) carried out a parametric study on single-spanned IPE500 steel beams. The differences in sectional constants and material properties were small. Thus, comparisons could be made directly by studying the C-factors. In finite element programs equivalent C-factors could be refracted from the expression of the critical moment. It was observed that the point of load application has a great influence on Mcr, and that this influence is of greater magnitude when the beam is fixed about the major axis.

Mohri, F., Brouki, A., Roth J.C. (2003) investigated the stability analysis of thin-walled elements with open section. The developed model permits the study of bar buckling and lateral buckling of unrestrained beams. The lateral buckling of mono-symmetric I-beam is developed and analytical solutions are formulated. The lateral buckling resistance of a beam is a function of stress bending distribution, of load height parameter and of the degree of monosymmetry of the section related to Wagner's coefficient. Coefficients C1, C2 and C3 are computed for some selected load cases and compared to the usual coefficients adopted in Eurocode 3. It is found that some coefficients are the same as those adopted in Eurocode 3, but the C3 are very different for some load cases.

Serna, M.A., Lopez, A., Puente, I., Yong, D. (2005) studied about the equivalent uniform moment factor (EUMF) which is used to compute the elastic critical moment. They show that codes may lead to very consevative values for simply supported beams, non-conservative values are obtained in the case of support types designed to restrict lateral bending and warping. They present a significant set of EUMF values obtained using both finit diffrence and finite element techniques.

IV. COMPARISON OF SECTIONAL PARAMETERS IN DIFFERENT SOFTWARE

This section contains a numerical comparison of the values for sectional parameters for the sections studied, using the different software introduced before.

Table I: Numerical comparison of sectional parameters for the doubly symmetric I-section using the different calculation methods.

Table I: Numerical comparison of sectional parameters for the doubly symmetric I-section using the different calculation methods.

Parameter	SAP 2000	STAAD Pro	3 factor formula	IS 800:2007
It [.105 mm4]	8.91	8.93	8.93	8.93
Iw [.1012 mm4]	NA	1.249	1.249	8.93
Iy [.108 mm4]	4.82	4.82	4.82	4.82
Iz [.105 mm4]	2.142	2.142	2.142	2.142
Zj [mm]	NA	NA	0	0

Table II: Numerical comparison of sectional parameters for the doubly symmetric I-section with various depth

Parameter	IPE 400	IPE 450	IPE 500	IPE 550
Iz [.107 mm4]	1.318	1.676	2.142	2.668
It [.106 mm4]	0.513	0.667	0.891	1.23
Iw [.1012 mm6]	0.492	0.794	1.25	1.884
Iy[.108 mm4]	2.313	3.374	4.82	6.71

Table III: Numerical comparison of sectional parameters for the monosymmetric I-section using the different calculation methods.

Parameter	SAP 2000	STAAD.Pro	3-factor formula	IS 800:2007
It [.105 mm4]	1.191	1.251	1.251	1.251
Iw [.1010 mm6]	N.A.	2.805	2.805	2.805
Iy [.107 mm4]	6.012	6.012	6.012	6.012
Iz [.105 mm4]	3.394	3.394	3.394	3.394
Zj [mm]	N.A.	N.A.	103.77	152.27

Table IV: Numerical comparison of sectional parameters for the channel section using the different calculation methods.

Parameter	SAP 2000	3-factor formula	IS 800:2007
It [.104 mm4]	5.491	5.823	5.823
Iw [.109 mm6]	4.451	4.426	4.426
Iy [.106 mm4]	9.373	9.373	9.373
Iz [.106 mm4]	1.131	1.131	1.131
Zj [mm]	N.A.	0	0

Table V: Numerical comparison of sectional parameters for Built-up I-section beam using the different calculation methods.

Parameter	SAP 2000	3-factor formula	IS 800:2007
It [.106 mm4]	4.121	4.556	4.556
Iw [.1012 mm6]	N.A.	1.82	1.82
Iy [.107 mm4]	6.012	6.012	6.012
Iz [.105 mm4]	3.394	3.394	3.394
Zj [mm]	N.A.	N.A.	103.77

V. ANALYSIS OF RESULT

A. *Doubly Symmetric I Beams*

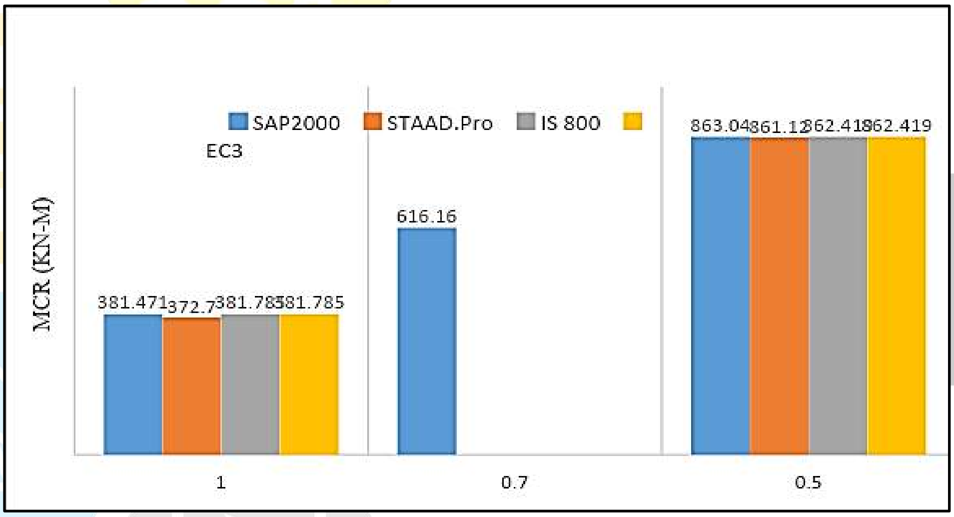

Figure 1: Comparison of the resulting Mcr of doubly symmetric I-beam using C-factors.

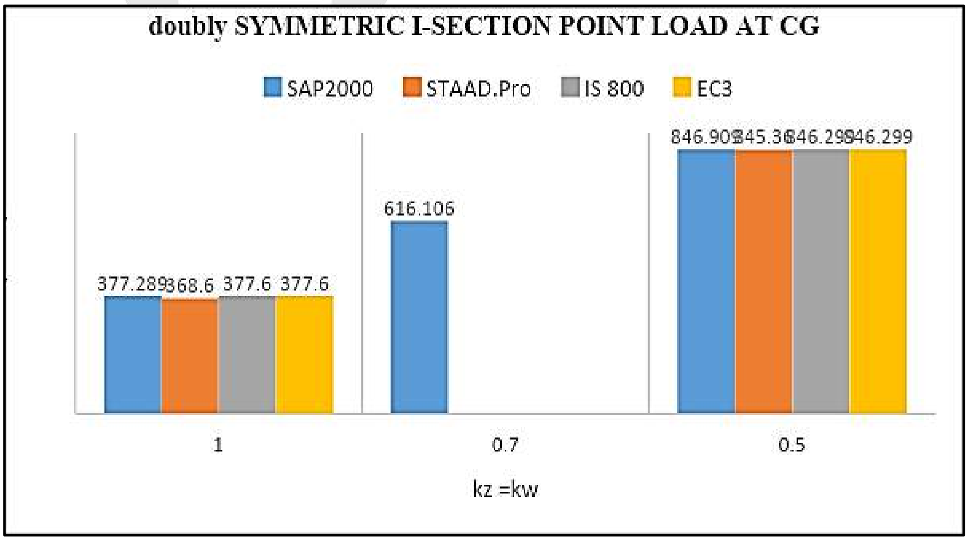

Figure 2: Comparison of the resulting Mcr using C-factors given in ECCS (2006)

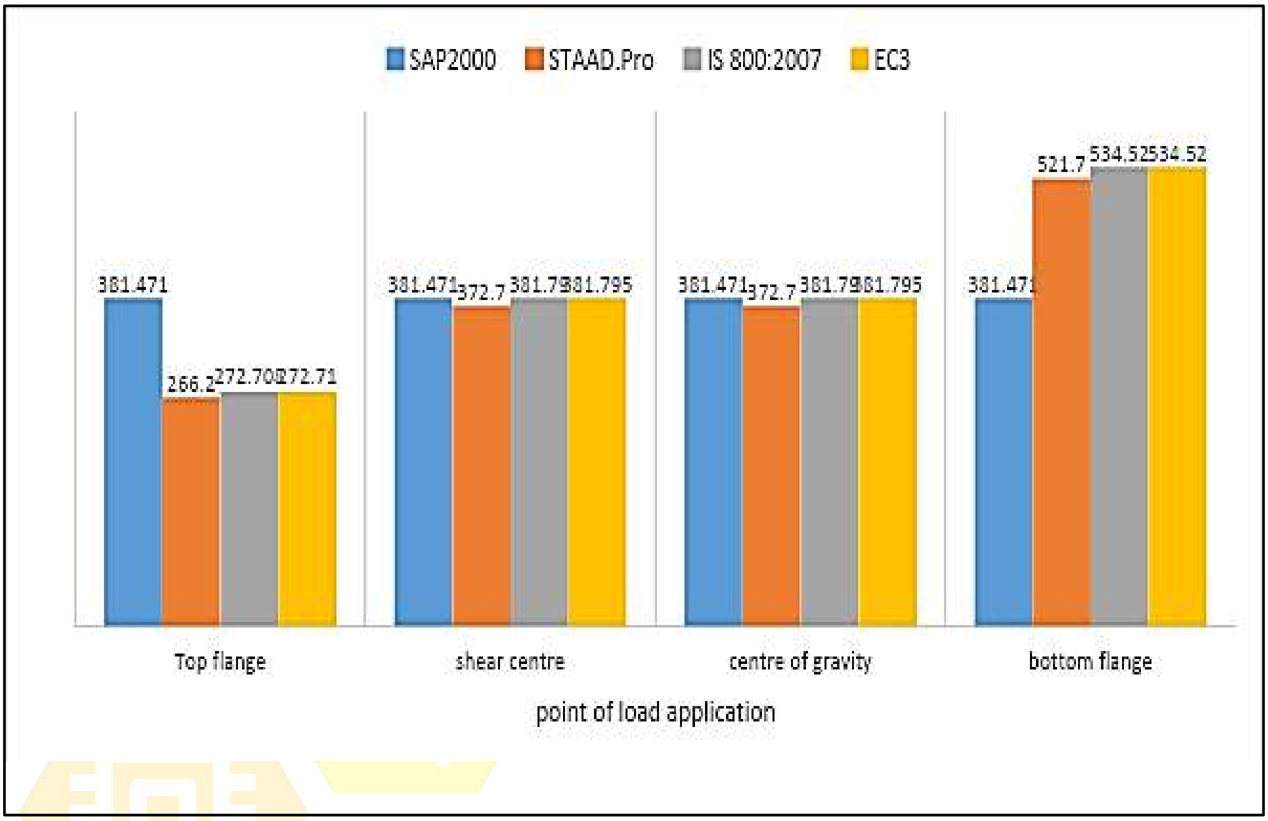

Figure 3: Comparison of the resulting Mcr for the doubly symmetric I-beam, with kz = kw = 1.

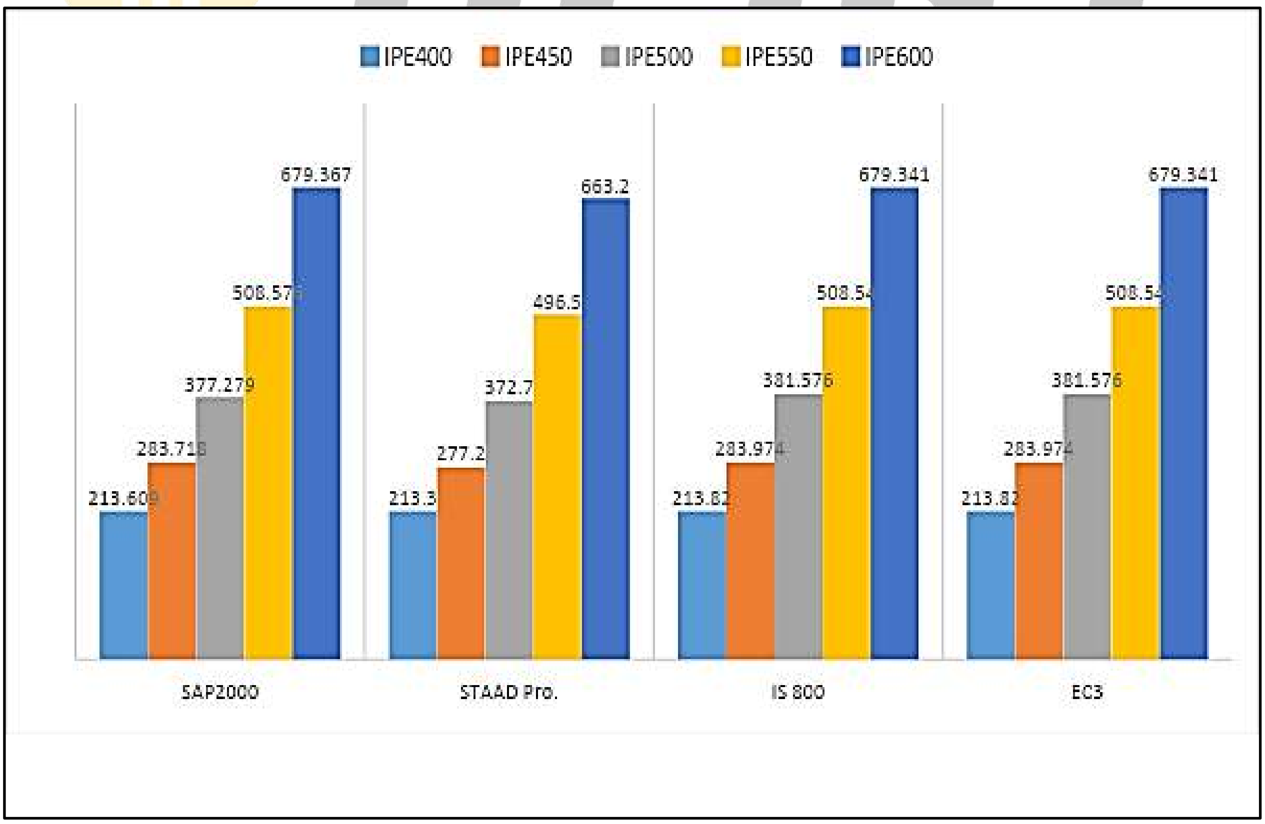

Figure 4: Comparison of the resulting Mcr of different I-sections considered, with kz = kw = 1.

We observe that as we increase the depth of the section the value of M_{cr} is also increases. It is due to increase in moment of inertia (I_z), warping constant (I_w) and torsional constant (I_t) of the section. The reason for the difference in values obtained from the different calculation methods is the same as described.

B. Mono Symmetric I Beams

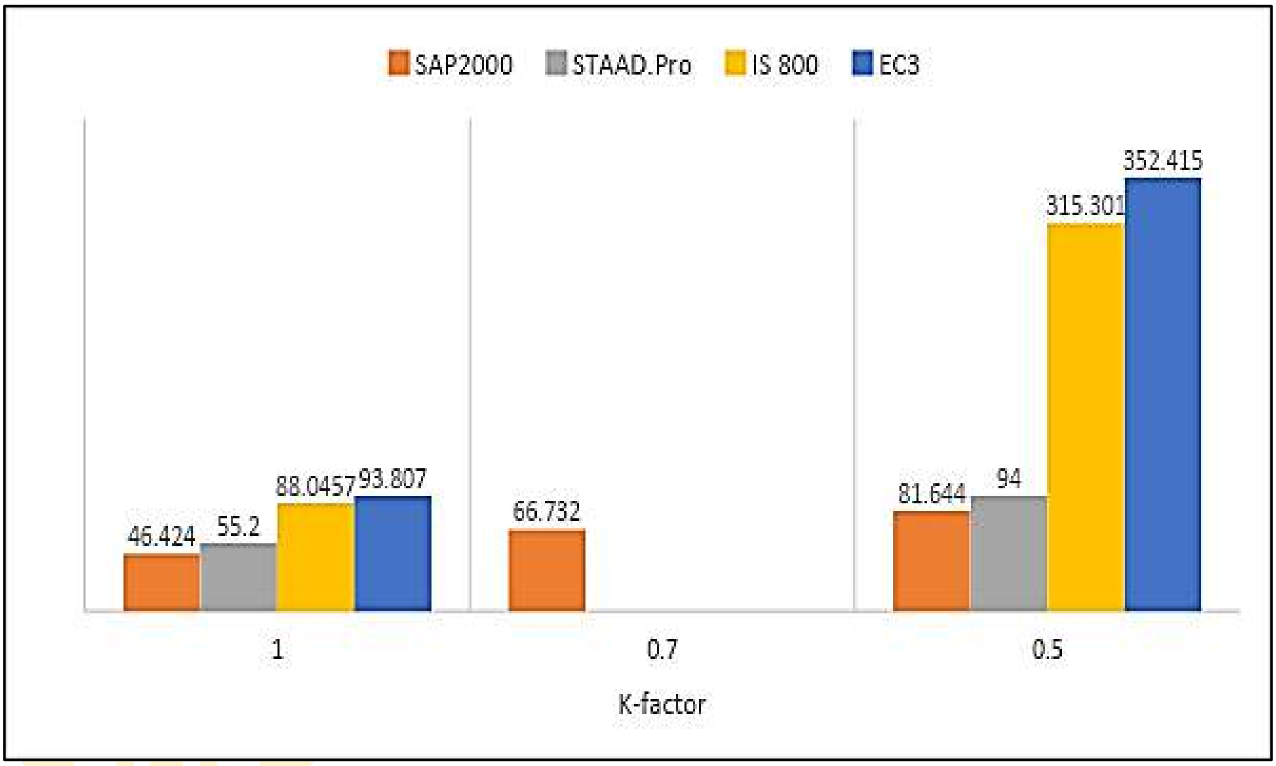

Figure5: Comparison of the resulting Mcr for the 8m long monosymmetric I-beam, subjected to a concentrated load at mid-span, applied at the centre of gravity, using C-factors given in ENV 1993-1-1:1992

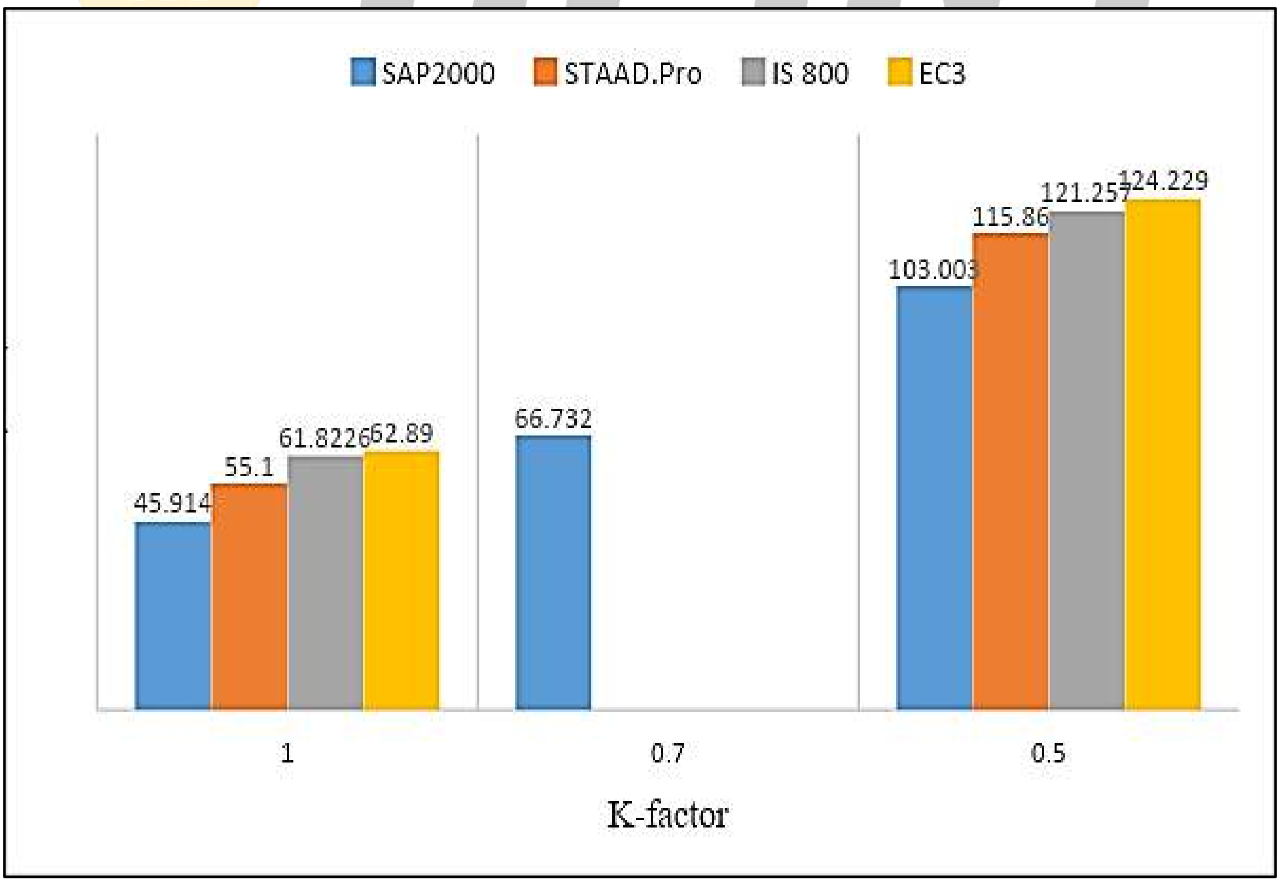

Figure 6: Comparison of the resulting Mcr of the monosymmetric I-beam, subjected to a concentrated load at mid-span, applied at the centre of gravity, using C-factors given in ECCS

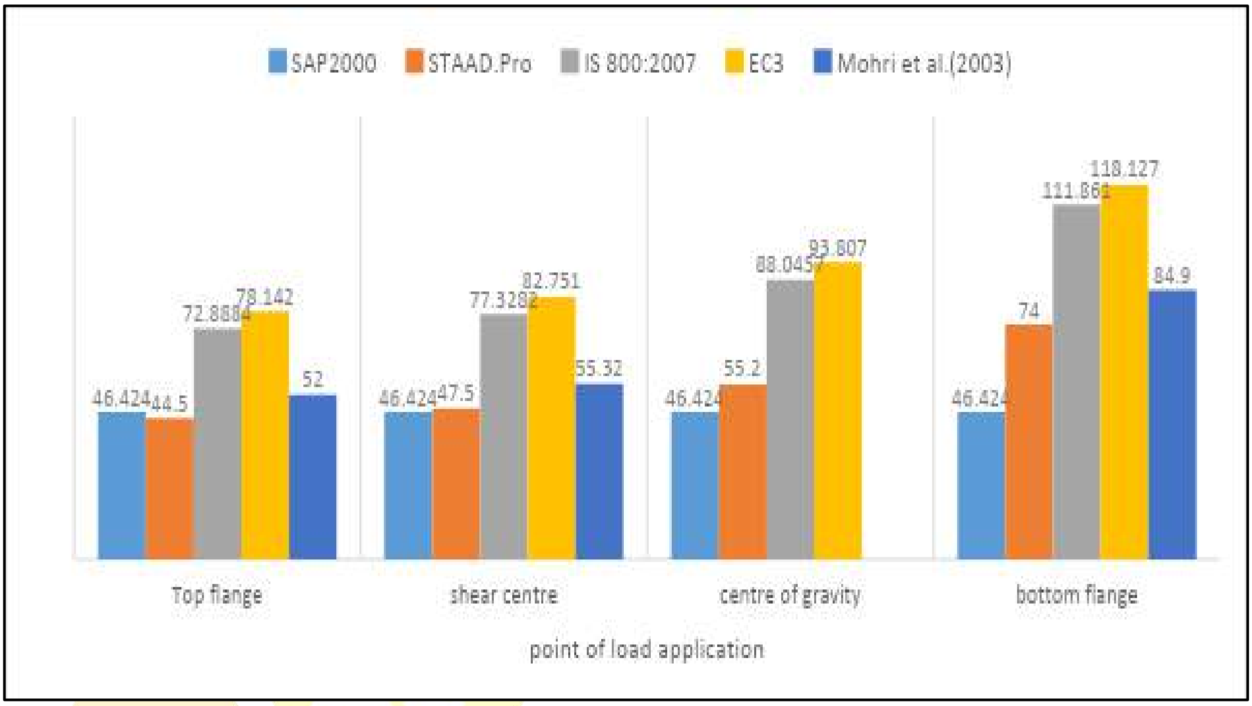

Figure 7: Comparison of the resulting Mcr of the monosymmetric I-beam, subjected to a concentrated load at mid-span, with kz = kw = 1, for varied height of the point of load application.

VI. CONCLUSION

In this Study, the elastic critical moment, Mcr, has been evaluated for centrically loaded beams with different setups and four types cross sections; a doubly symmetric I-section, monosymmetric I-section using two commercial engineering software.

(1) A doubly symmetric I-beam was modelled using two different software tools, subjected to a concentrated load at different load heights with different degrees of lateral restraint. Hand calculations using the 3-factor formula and formula given in IS 800:2007 were performed for comparison. The main conclusion drawn from those studies for doubly symmetric I-beam are:

- The obtained results were overall as anticipated, when considering the assumptions made by each software tool and the resulting limitations.
- The degree of lateral restraints affects Mcr and is taken into account by all the applied calculation methods.
- The vertical position of the point of load application has significant influence on Mcr as expected, with destabilising effects for loading above the shear centre (SC) and stabilising effects for loading below the SC.
- SAP2000 does not take the vertical position of the loading into account when calculating Mcr,it takes only the moment curve,material and sectional properties and the buckling length.
- As we increase the depth of section the elastic critical moment, Mcr, of the member is also increases.
- The Eurocode 3 and IS 800:2007 both uses similar expression for the calculation of elastic critical moment, Mcr and also the C-factor values given in both codes are same for different K-factor.
- It is also observed that there is not much difference in the values of elastic critical moment, Mcr, when we use C-factor values given in ENV 1993-1-1:1992 (Annex F) and ECCS (2006 Table 64) for the doubly symmetric I-beam.

(2) A monosymmetric I-beam was modelled using two different software tools, concentrated load at different load heights with different degree of lateral restraint. Hand calculations using the 3-factors formula and formula given in IS 800:2007 were performed for comparison. The main conclusion drawn from those studies for doubly symmetric I-beam are:

- The obtained results were overall as expected, when considering the assumptions and limitations made by each software tool.
- A good correlation is between the reference values of Mcr and the values obtained by the various calculation methods, when using C-

factor value given in ECCS (2006 Table 64), with the exception of SAP2000, and the obtained results are rather on the safe side

- The values of Mcr obtained by various calculation methods using C-factor value given in Eurocode 3 and IS 800:2007 are much higher than reference values of Mcr. It is also mentioned in some literature that the C-factor value given in Eurocode 3 is the over estimation of elastic critical moment, Mcr.

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