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"Research Note"

THE EFFECT OF ROTATIONAL IMPERFECTION ON THE BUCKLING AND POST-BUCKLING BEHAVIOUR OF STEEL FRAMES*

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Abstract– In this paper the behaviour of steel frames is investigated under an applicable range of initial rotational geometric imperfection in joints, which are mostly created during the manufacturing process. A nonlinear analysis is applied in both geometry and material behaviour of steel frames. The results show considerable reduction in buckling and ultimate load carrying capacity of portal frames, when they are affected by a rotational imperfection.

Keywords– Rotational imperfection, steel frames, buckling behaviour, nonlinear analysis

1. INTRODUCTION

In advanced analysis of steel structures, both the geometric and material nonlinearities should be taken into consideration. [1-3]. Also, the effect of member imperfection is required in most cases with allowance for local and global instability [4-7]. In spite of many years being spent researching this topic, its application to the design of steel structures is still uncommon and more research is needed before the method can be widely used by engineers.

In this paper a rotational mode of geometric imperfection in the joints of frames, mostly created during the process of manufacturing is considered. It has a certain influence on the the serviceability as well as the ultimate strength of steel frame. The effect of shear deformations is included in the analyses. Joints between all of members are assumed to be rigidly connected. The members have compact sections and are considered to be laterally braced. All the members consisted of doubly symmetric sections.

2. MODELING SPECIFICATION

Steel frames always possess initial geometrical imperfections such as lack of frame verticality and member straightness and load eccentricities, which must be included in any design procedure as much as possible. Two types of sway and bow imperfections are required to be considered in an analysis. But in this paper, only rotational imperfection is considered at the joints of steel frames. There are three approaches to consider the frame imperfections; eigen-buckling mode (EBM) approach, notional force (NF) approach and initial geometric imperfection (IGI) approach. The NF approach could not be used in this study due to extra internal force imposition to the system members. The EBM method does not cover rotational imperfections and therefore was not applied to the subject of this study. So, IGI method was used to model rotational imperfection in the frames of this paper. Spline command was used to define two vectors in both ends of an imperfect member (Fig. 1). The sections of HEB(180, 200 and 220) and IPE220

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are considered for column and beam members respectively, with a range of 1 to 4 degrees of joint imperfection at only one column of all models.

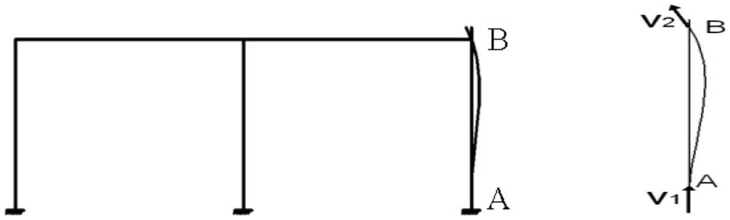

Fig. 1. Modeling of imperfection by IGI method

For the purpose of this paper, a nonlinear analysis was performed on a portal frame buckling behaviour. The numerical model for the specimens was developed using the general-purpose non-linear program of ABAQUS. Both material and geometric nonlinearities were included in the models. A non-linear explicit dynamic method was adapted to investigate imperfect frames. The finite element of S4R, which is a four node element with six degrees of freedom in each node, is used in the modelling of frames. Two models of rigid steel frames are investigated: one span and one story, two spans and one story. The spans and stories are 4.0 and 3.0 meters respectively. Inelastic material was defined with yield stress of 2400 kg/cm^2 and Poisson ratio of 0.3. The criterion of Von Mises was adapted to specify the yielding.

3. NONLINEAR ANALYSIS AND DISCUSSIONS

The load-displacement curves and buckled modes are shown in Figs. 2 and 3 for two sample frames. The values of maximum buckling load for different imperfections are calculated and displayed comparatively in Tables 1 to 4.

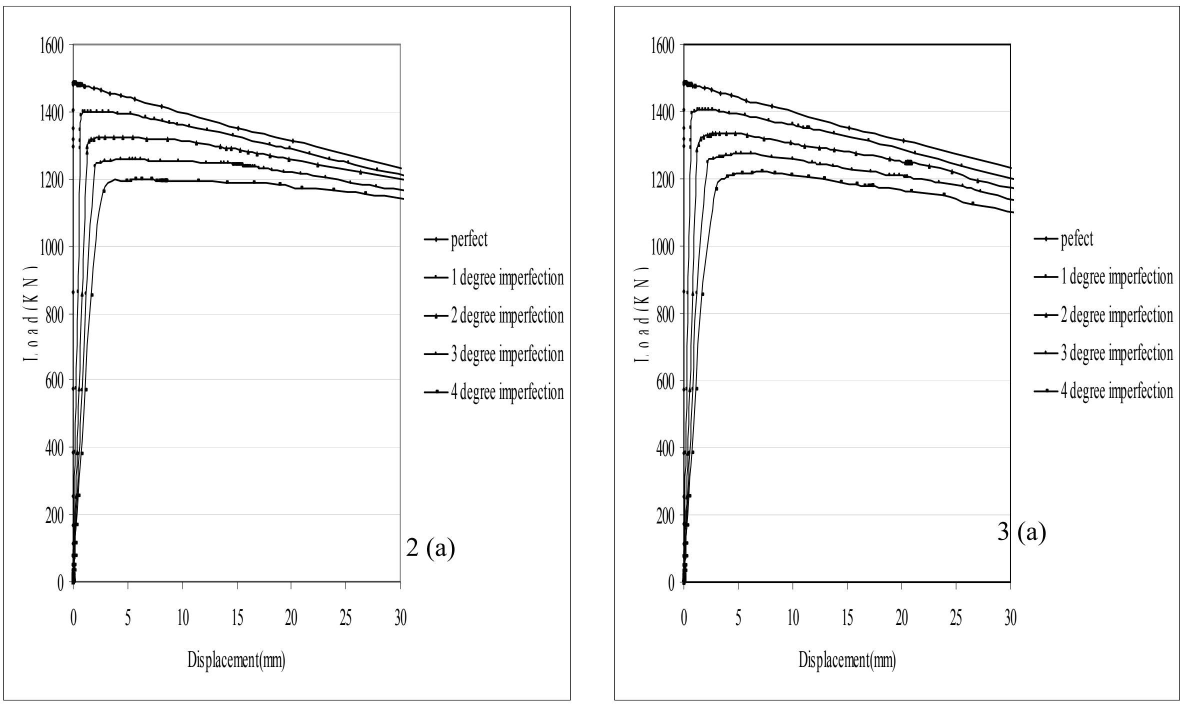

Fig. 2. a) Load-displacement curves of the frame with different values of imperfection
b) Buckled mode of imperfect portal frame under concentrated load

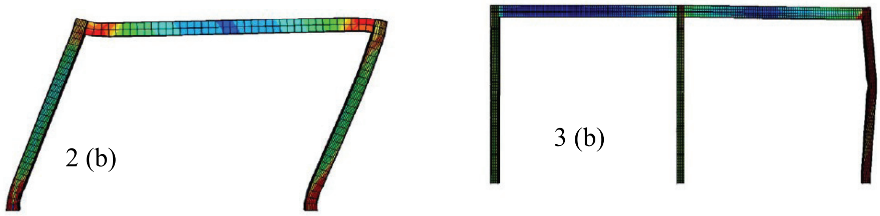

Fig. 3. a) Load-displacement curves of the frame with different values of imperfection
b) Buckled mode of two span frame with imperfect side column

It is evident the effect of imperfection reduces by increasing the number of frame spans when only one column of the frame is surrounded by rotational imperfection.

As is obvious from Tables 2 and 3, the buckling loads are almost identical in both imperfection cases of two span frames under concentrated load. This means the buckling load is independent from the effective column length of kL in this range. Also, the effect of geometric imperfection is reduced by increasing the column size. In other words, the thinner members are more sensitive to geometric imperfections than thicker ones. The results of this paper show that the buckling capacity of the frames has an almost linear relation with the values of rotational imperfection.

In Table 4 the obtained results for a group of frame specimens under distributed load when a rotational imperfection is present at the end of only one column are shown. It is concluded that the difference between perfect and imperfect frame behavior under distributed load is not meaningful in the range of this investigation.

Table 1. Buckling loads of specimens with HEB180 column under concentrated load (kN)

Frame specimens	Imperfection at	Perfect case	1 Degree imperfection	2 Degrees imperfection	3 Degrees imperfection	4 Degrees imperfection	Max. load difference
portal	side column	1485.83	1400.83	1324.18	1257.09	1196.41	19.5%
two span	side column	1485.43	1407.97	1337.57	1275.28	1220.40	17.8%
two span	middle column	1485.63	1408.53	1338.21	1275.71	1220.15	17.8%

Table 2. Buckling load of specimens with HEB200 column under concentrated load (kN)

Frame specimens	Imperfection at	Perfect case	1 Degree imperfection	2 Degrees imperfection	3 Degrees imperfection	4 Degrees imperfection	Max. load difference
portal	side column	1767.18	1675.33	1591.31	1516.61	1447.94	18.1%
two span	side column	1767.03	1681.44	1602.85	1533.76	1471.60	16.7%
two span	middle column	1767.24	1683.00	1605.07	1536.94	1474.79	16.5%

Table 3. Buckling load of specimens with HEB220 column under concentrated load (kN)

Frame specimens	Imperfection at	Perfect case	1 Degree imperfection	2 Degrees imperfection	3 Degrees imperfection	4 Degrees imperfection	Max. load difference
portal	side column	2070.65	1972.57	1880.80	1798.63	1721.99	16.8%
two span	side column	2070.43	1975.35	1887.49	1810.99	1749.70	15.5%
two span	middle column	2070.55	1981.50	1897.69	1822.19	1753.67	15.3%

Table 4. Buckling load of specimens with HEB180 column under distributed load (kN/m)

Frame specimens	Imperfection at	Perfect case	1 Degree imperfection	2 Degrees imperfection	3 Degrees imperfection	4 Degrees imperfection	Max. load difference
portal	side column	54.88	54.96	55.04	54.90	54.87	0.02%
two span	side column	60.31	60.29	60.29	60.27	59.93	0.6%
two span	middle column	60.29	60.04	60.08	60.15	60.19	0.16%

4. CONCLUSION

As a general conclusion, it is found in this study that the influence of rotational imperfection of frames under a distributed vertical load can be ignored. But in the case of point load at the top of columns, there is a reduction between 15.3% and 19.5% in the frame buckling load in the range of this paper. The effect of only one imperfection is reduced by increasing the number of frame spans, as well as by increasing the column size. But this effect is independent from the effective column length of kL.

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