Journal of Ferdowsi Civil Engineering, Vol.31, No.1, 2018.

Seismic Behavior of Knee-Braced Steel Moment Frames

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1-Introduction

Moment-resisting steel frames (MRSFs) have high ductility. However, they suffer from low lateral stiffness which may lead to large lateral drifts. Recently, a new lateral force resisting system called knee-braced moment frame (KBMF) has been introduced in the literature in which the seismic behavior of an ordinary moment frame is improved using some knee elements as structural ductile fuses in the vicinity of beam-to-column moment connections. This system has the key characteristics of both moment frames (ductility) and concentrically braced frames (stiffness) simultaneously.

The main advantage of this type of structural system pertains to the type of its beam-to-column moment connections in which there is no need to use the costly specific moment resisting connections in SMRFs. Instead, relatively simple ordinary moment connections can be used for such systems.

Considering the necessity of identifying the characteristics of the proposed system, the seismic behavior of KBMFs are investigated in this study using the macro-modeling approach and nonlinear static and dynamic analyses and their seismic parameters are evaluated.

2-Design and Modeling of Frames

In this study, six moment frames of 3-, 6- and 10-story with different span lengths are considered. All story heights and span lengths were 3 and 4 m, respectively. For convenience, the frame models were assigned a specific symbol as Km-n where m and n stand for the number of frame stories and spans, respectively.

The column members are modeled with elastic beam-column elements with the relevant section properties and an elastic material constitutive model. However, the beam and brace members are modeled nonlinearly with a Menegotto–Pinto uniaxial steel material model. To describe the nonlinear behavior and plastification of beams, the distributed plasticity approach using fiber-section beam-column elements was adopted.

In order to simulate geometric imperfections and accurate modeling of knee-brace buckling, a physical-theory model (PTM) is utilized in which an out-of-plane camber (geometric imperfection) is applied to the longitudinal profile of the knee-brace members.

3-Frames Analysis

To perform nonlinear dynamic analyses on the models, seven earthquake records that have occurred in California were selected. Based on the dynamic analyses results, the frames overall overstrength factor as well as the overstrength factor of the side columns were estimated. The frame overall overstrength factor is calculated by dividing the average dynamic base shear demand (V_u) by the elastic base shear demand (V_e) as per the equivalent static lateral force procedure.

4-Conclusions

The overall overstrength factors were determined to be between 2.74 and 2.21 for the 3-story to 10-story KBMFs, respectively. These factors are less than the code-prescibed overstrength factor of 3.0 for conventional moment frames. This reduction in the overall overstrength factor as the frames height increases is attributed to: (1) different governing forces to design the studied low- and high-rise frames; and (2) the effect of frames higher vibrational modes.

As it was pointed out earlier, the ratio of column dynamic axial force demand to the elastic axial force based on the equivalent static analysis procedure was determined as the columns overstrength factor. The normalized column demand (overstrength factors) variations for the studied frames are shown in Fig. 1. As it can be seen, the columns overstrength factor increases with the height of the corresponding story level. After performing nonlinear static analysis on the studied frames and drawing their capacity curves, some important seismic parameters were computed.

The determined factors include: ductility reduction (R_μ) and static overstrength factors (Ω_o) as shown in Table 1 for the initial base

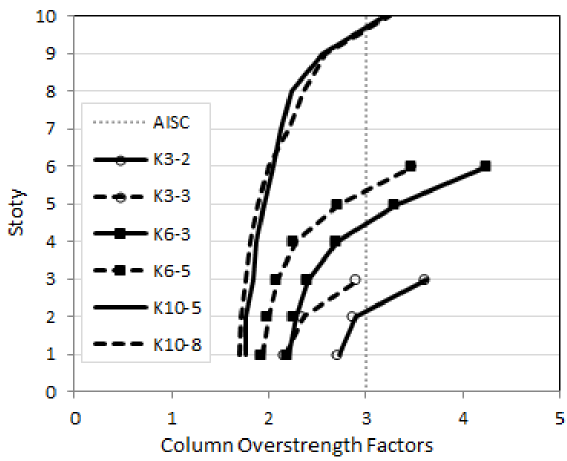

Fig. 1. Height-wise variation of the columns overstrength factor

moment frames and the corresponding KBMFs to estimate their behavior factors. According to Table 1,

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it is seen that the base moment frames designed with the ultimate behavior factor of R_u=3.5, have an average behavior factor of 3.1. However, in spite of reducing the ductility reduction factor (R_μ) in the KBMFs, their behavior factor increases due to the use of knee braces (R_{ave} =4.7).

By comparing the average behavior factor of the KBMFs with the corresponding value of intermediate moment frames (IMFs), it can be seen that by adding knee braces to the base bending frame and increasing its degree of indeterminacy, the dual frame behavior has improved and it is comparable with the IMFs in terms of energy dissipation.

Furthermore, inelastic story drifts were computed from the dynamic analyses as the average of the maximum story drifts for each story from seven analyses. It was observed that the KBMFs drifts are lower than the Life Safety allowable drift ratio.

Table1. Behavior factor of the frames

Model	R_μ	Ω_o	R_u
M3-2	2.4	1.42	3.4
K3-2	2.15	1.96	4.23
M3-3	2.32	1.29	3.0
K3-3	2.2	1.82	4.02
M6-3	2.8	1.61	4.46
K6-3	2.13	2.34	5.0
M6-5	1.66	1.49	2.48
K6-5	2.07	2.15	4.47
M10-5	2.11	1.21	2.56
K10-5	2.55	2.13	5.45
M10-8	2.11	1.30	2.74
K10-8	2.55	2.04	5.22