

Response of Steel Knee-Braced Moment Frames Designed Using Ductility-Based Seismic Design Approach with Different Ductility Conditions



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Abstract This paper presents ductility-based seismic design approach for design of steel knee-braced moment frames (KBMF) and influence of ductility in the design process. Knee-braced moment frame is a hybrid energy dissipating frame which has combined characteristics of moment-resisting frames (MRF) and concentrically braced frames (CBF). In the proposed ductility-based seismic design approach, target displacement ductility ratio and target yield mechanism are the design criteria and the inelastic behaviour of the structure has been incorporated into the design process. A KBMF is designed using Indian Standard (IS) codes and three KBMFs are designed using the ductility-based seismic design approach for different target drifts and ductility conditions. Nonlinear static pushover analysis (NSPA) and nonlinear time history analysis (NTHA) are conducted to assess the effectiveness and study the responses of the frames under strong ground motions. The analytical test results show that the ductility-based seismic design approach produces frames with desirable and predictable structural responses.

Keywords Knee-braced moment frame (KBMF) · Ductility-based seismic design · Displacement ductility ratio · Target yield mechanism · Nonlinear static pushover analysis (NSPA) · Nonlinear time history analysis (NTHA)

1 Introduction

Knee-brace is a stiffener between a column and a beam; it provides greater rigidity in a building frame under lateral loads. Knee-braced moment frame (KBMF) is a hybrid steel structure which combines key characteristics of moment-resisting frame (MRF) and concentrically braced frame (CBF). In MRFs, the beams are rigidly connected to columns and the resistance to lateral forces is mainly due to the rigid frame action by the development of bending moment and shear force, but this causes large lateral

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421

deformability and the performance of the MRFs is dependent on the quality of materials and workmanship, particularly at the beam-to-column connections. MRFs create no architectural obstruction, and they also provide a stable hysteric behaviour. CBFs deliver excellent stiffness but they are dependent on the post-buckling behaviour of the braces, as post-buckling behaviour is complex and not well understood it is assumed that there will be considerable strength degradation post-buckling in the braces and the CBFs also create architectural obstructions which hampers the aesthetic value of the frame. In order to overcome the deficiencies of the MRFs and CBFs, the KBMFs were developed which is an innovative energy dissipating frame that creates much less architectural obstruction than any other braced frames and also provides lateral stiffness to the frame. KBMF is easy to construct and post an earthquake the damaged knee-brace can be easily replaced.

During major earthquakes, the structures designed to current codes are expected to undergo large inelastic deformations. The seismic design approach employed in the current codes is generally based on elastic structural behaviour and accounts for inelastic behaviour in an indirect manner. In the existing force/strength-based approach for the design of KBMF ductility is implicitly achieved through response reduction factor, R and the strength demand is increased through an occupancy importance factor, I .

In this study, a ductility-based seismic design approach using performance-based plastic design (PBSD) method which is based on energy balance concept is presented, where the inelastic activities are accounted for in the design process. Initially, an elastic KBMF is designed by Indian Standard (IS) code provisions; later three KBMFs are designed by ductility-based seismic design approach using performance-based plastic design (PBSD) method for different target drifts and ductility conditions.

2 Geometry and Loadings of the Test Steel KBMF

Four-storey hypothetical steel KBMF is considered for the present study. The occupancy of the building is for "Office" purpose. The span of the frame is 20 m along both X- and Y-directions. The total height of the frame is 12 m, the height of each storey is 3 m, and the height of all the columns is 3 m placed at 5 m c/c. The slabs are of M25 grade. Figure 1 represents typical plan and elevation of the test KBMF, and Table 1 illustrates the section sizes and loadings considered for the test KBMF. In the frame, the beams and columns are designed to resist the gravity loads and the knee-braces are designed to resist the lateral loads, i.e. earthquake loads. The location of the hypothetical test building is in Dharwad town, India, with earthquake zone of category III. The imposed loads are calculated using IS 875 (Part 2): 1987, design of structural members is carried out using IS 800: 2007 and the earthquake loads are calculated using IS 1893-Part 1: 2016 by "Equivalent static method".

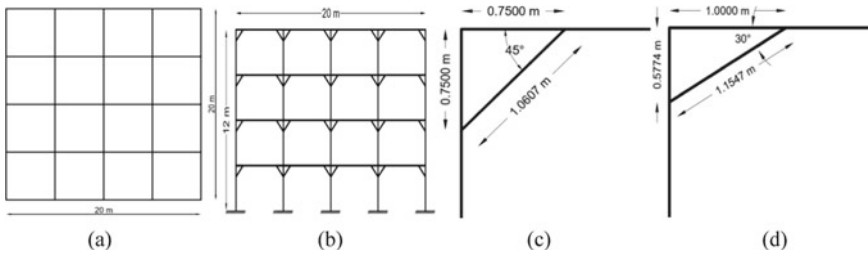


Fig. 1 **a** Plan of the test steel KBMF; **b** elevation of the test steel KBMF; **c** geometry of knee-braced section designed by elastic method; **d** geometry of knee-braced section designed using ductility-based seismic design approach

Table 1 Section sizes and loadings considered in the test steel KBMF

Slab thickness	0.1250 m	Live load (floor)	4.0000 kN/m ²
Area of slab	25.0000 m ²	Live load (roof)	1.5000 kN/m ²
Unit weight of slab	25.0000 kN/m ³	Dead load (structural wall)	13.8000 kN/m
Unit weight of wall	20.0000 kN/m ³	Dead load (parapet wall)	3.0000 kN/m
Height of wall	3.0000 m	Dead load (floor finish)	1.0000 kN/m ²
Height of parapet wall	1.0000 m	Dead load (wpc)	1.5000 kN/m ²
Thickness of wall	0.2300 m	Importance factor, I	1.0000
Thickness of parapet	0.1500 m	Response reduction factor, R	4.0000
Earthquake zone factor, Z	0.1600		

3 Design of KBMF by Elastic Method

The test steel KBMF is designed by elastic method using IS codes, the beams and columns are designed to resist gravity loads ((Dead load) + (Live load)) and the knee-braces are designed to resist the lateral loads, i.e. earthquake loads. The knee-brace is placed at a distance of 3H/4 from the base of the column, and the geometry of the knee-brace is represented in Fig. 1. The knee-brace makes 45° with the beam and column. The beams are designed using Eq. (1); the columns are designed using Eqs. (2–5) based on the end conditions. Knee-brace as a tension member is designed using Eq. (6) and as a compression member using Eqs. (2–5) based on the end conditions. The largest section among the tension and compression member is selected as the knee-braced member. The beam, column and knee-braced member sections of the designed frame are represented in Fig. 2.

$$Z_{reqd} = \frac{(M \times \gamma_m)}{f_y} \tag{1}$$

For compression member with both ends fixed:

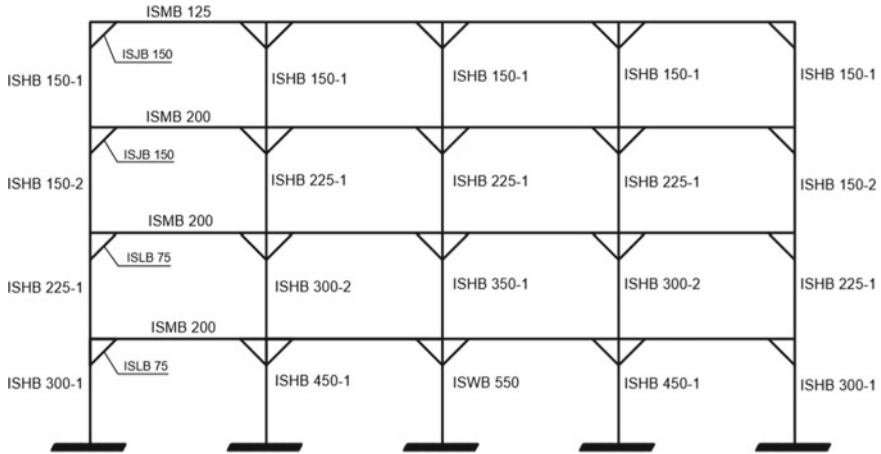


Fig. 2 Member sections of KBMF designed by elastic method

$$P_{cr} = \frac{(2\pi^2 EI)}{l^2} \tag{2}$$

$$L = .7 \times l \tag{3}$$

For compression member with one end fixed and the other end hinged:

$$P_{cr} = \frac{(1.4\pi^2 EI)}{l^2} \tag{4}$$

$$L = .85 \times l \tag{5}$$

$$T_d = \frac{f_y A}{\gamma_{M_o}}, \tag{6}$$

where Z_{reqd} is required section modulus; M is the maximum moment acting on the beam; γ_m is the factor of safety, i.e. 1.15; f_y is the yield strength of the steel i.e. 250,000 kN/m² for mild steel; P_{cr} is the critical load of the compression member; E is Young's modulus; I is the moment of Inertia; L is the effective length of the column member; l is the actual length of the column member; T_d is the design strength of the tension member; A is the gross area of the section; γ_{M_o} is the partial safety factor for failure, i.e. 1.15.

4 Design of KBMF by Ductility-Based Seismic Design Approach

The test steel KBMF is designed using ductility-based seismic design approach by performance-based plastic design (PBPD) method. PBPD method which is based on energy balance concept is used in the present study. In this method, target displacement ductility ratio (μ_s) and target yield mechanism are the design criteria. All the inelastic activities are confined to the knee-braces which are the designated yield members (DYMs) and the beams–columns are the non-designated yielding members (non-DYMs) which are designed to remain elastic.

The design procedure of PBPD method [5] is given below:

- Select a desired yield mechanism and target drift for the structure consistent with the intended performance objectives for the design earthquake hazard. Estimate the yield drift ratio, Θ_y , for the structure.
- Estimate the natural period, T , of the structure given by Eq. (7) and assume an appropriate vertical distribution of design lateral forces.
- With the information from the above steps along with the design spectral acceleration value, S_a , calculate the design base shear, V , by equating the work needed to monotonically push the structure to the target drift (no pushover analysis needed) to the energy needed by an equivalent EP-SDOF to be displaced up to the same drift.
- Use the plastic method to design the structural members that are expected to dissipate the earthquake energy in-elastically, i.e. designated yielding members (DYMs). Members that are required to remain elastic, i.e. non-designated yielding members (non-DYMs) are designed by a capacity design approach.

4.1 Target Displacement Ductility Ratio (μ_s)

Target displacement ductility ratio (μ_s) is given by Eq. (8), and it is dependent on the target drift (Θ_u) for which the KBMF is designed; target drift is selected based on the earthquake zone in which the frame is located such as low drift values for regions with high earthquake activities and high drift values for regions with moderate earthquake activities. The yield drift (Θ_y) which is given by Eq. (9) [1] is varied throughout the frame in order to prevent uneconomic design.

4.2 Target Yield Mechanism

As part of pre-selected yield mechanism, inelastic activities are confined within the DYMs and the global yield mechanism also includes plastic hinge formations at column bases since plastic hinges are formed at these locations during a major

earthquake. In the present KBMF, all the inelastic activities are confined to the knee-braced sections, whereas the beams and columns are designed to remain elastic.

4.3 Design Base Shear (*V*)

In the current code practice, the design base shear is calculated using earthquake zone factor (*Z*), response reduction factor (*R*) which accounts for ductility and an occupancy importance factor (*I*) which accounts for increase in strength demand thus unable to utilize the significant inelastic deformation capacity of the structures. But in the PBPD method, design base shear is based on the inelastic state of the structure. Using the energy balance concept, after the formation of the pre-selected yield mechanism the structure is monotonically pushed up to a target drift and it is equated with the energy needed by an equivalent EP-SDOF to be displaced up to the same drift to calculate the design base shear of the structure. Equations (10–12) are used in calculation of the design base shear of the frame.

4.4 Design Lateral Forces

It is necessary to incorporate inelastic behaviour of the structures in the design process to obtain desirable and predictable structural response. The design lateral force distribution in PBPD method is based on maximum storey shears and frames designed with this lateral force distribution exhibit uniform inter-storey drifts throughout the height of the structure. Whereas the structures designed according to current code procedures undergo large deformations in inelastic range under major earthquakes leading to different lateral force distributions from those given by code formulas. Equations (13–15) are used for calculation of the lateral force distribution in the frame.

4.5 Design of Designated Yielding Member (*DYM*)

DYMs are the members in a structure where all the inelastic activities are confined and are designed by plastic method. The DYMs can be replaced post an earthquake while the other members of the structure remain elastic and unaffected. In the present KBMF, the knee-braces are the DYMs, and the required brace strength is very large when the values of L_k/L (length of knee portion/length of the beam portion) are small. The minimum required strength occurs when L_k/L is in the range of 0.13 to 0.25 for all values of the brace angle [6]. Considering large bay openings for utility, the angle of the brace with the beam is taken as 30° and the L_k/L ratio of 0.23 is considered.

Figure 1 gives the geometry of the knee-brace and their design is carried out using Eqs. (16–19).

4.6 Design of Non-Designated Yielding Member (Non-DYM)

Non-DYMs are the members in a structure that are designed to remain elastic. The non-DYMs are designed to resist combined gravity loads and maximum expected strength of the DYM accounting for reasonable strain-hardening and material over-strength. In the present KBMF, beams and columns are the non-DYMs and they are designed by capacity design approach [4]. In the design of columns column tree approach is employed, Fig. 3 shows the forces considered in design of beams, exterior columns and interior columns. Figure 4 [2] represents PBPD flowchart for KBMF.

$$T = \left(\frac{0.09H}{\sqrt{d}} \right) \quad (7)$$

$$\mu_s = \frac{\theta_u}{\theta_y} \quad (8)$$

$$\theta_y = .25 + \left(0.012 \times H \times \left(\frac{h_i}{lb} \right) \right) \quad (9)$$

$$\frac{V}{W} = \frac{-\alpha + \sqrt{\alpha^2 + 4\gamma \left(\frac{s_a}{g} \right)^2}}{2} \quad (10)$$

$$\alpha = \left(\sum_{j=1}^n (\beta_i - \beta_{i+1}) h_i \right) \left(\frac{w_n h_n}{\sum_{j=1}^n w_j h_j} \right)^{0.75T^{-0.2}} \left(\frac{\theta_p 8\pi^2}{T^2 g} \right) \quad (11)$$

$$\gamma = \frac{(2 \times \mu_s) - 1}{R_\mu^2} \quad (12)$$

$$F_i = C'_{vi} V \quad (13)$$

$$C'_{vi} = (\beta_i - \beta_{i+1}) \left(\frac{w_n h_n}{\sum_{j=1}^n w_j h_j} \right)^{0.75T^{-0.2}}, \quad \text{when } i = n, \beta_{n+1} = 0 \quad (14)$$

$$\beta_i = \frac{v_i}{v_n} = \left(\frac{\sum_{j=1}^n w_j h_j}{w_n h_n} \right)^{0.75T^{-0.2}} \quad (15)$$

$$V_i = \sum F_i \quad (16)$$

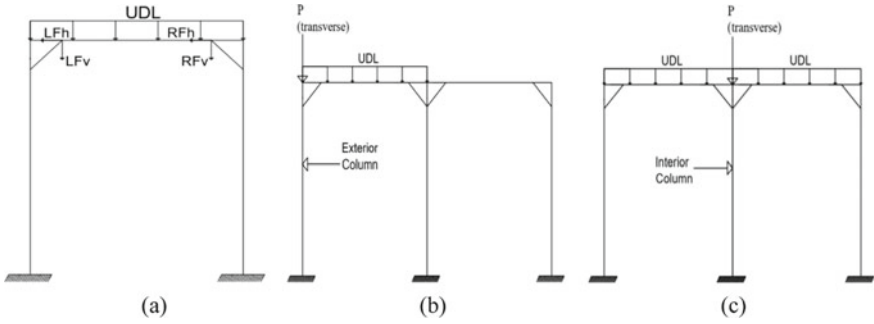


Fig. 3 **a** Forces considered in the design of beams; **b** forces considered in the design of exterior columns; **c** forces considered in the design of interior columns

$$\frac{(V_{\text{storey shear}})_i}{0.9 \cos \alpha_i} \leq (P_y + 0.5 P_{cr})_i \tag{17}$$

$$P_y = F_y \times A_g \tag{18}$$

$$P_{cr} = F_{cr} \times A_g, \tag{19}$$

where T is the fundamental period; H is the total height of the structure; d is the base dimension; h_i is the height at i th level from base; lb is the bay length of the brace; V is the total design base shear; W is the total seismic weight of the structure; g is the acceleration due to gravity (9.81 m/s^2); β_i is the shear distribution factor at i th level; w_j is the seismic weight at j th level; h_j is the height at j th level from base; w_n is the seismic weight at n th level, i.e. top level; h_n is the height at n th level, i.e. top level from base; θ_p is the inelastic drift ($\Theta_u - \Theta_y$); γ is the energy modification factor; R_μ is the ductility reduction factor, it is time period (T) and ductility ratio/factor (μ_s)-dependent; F_i is the lateral force at level i ; V_i, V_n are the storey shear forces at i th and n th level; $V_{\text{storey shear}}$ is the storey shear; α is the angle of brace with beam; P_y is the nominal yield strength; P_{cr} is the nominal compressive strength; F_y is the yield strength, i.e. $250,000 \text{ kN/m}^2$; F_{cr} is the compressive strength; A_g is the gross area.

4.7 Design of KBMF for 2% Target Drift with Varying Ductility by PBD Method

The test steel KBMF is designed by PBD method with target drift of 2%, and the target displacement ductility ratio (μ_s) is varied throughout the structure. The

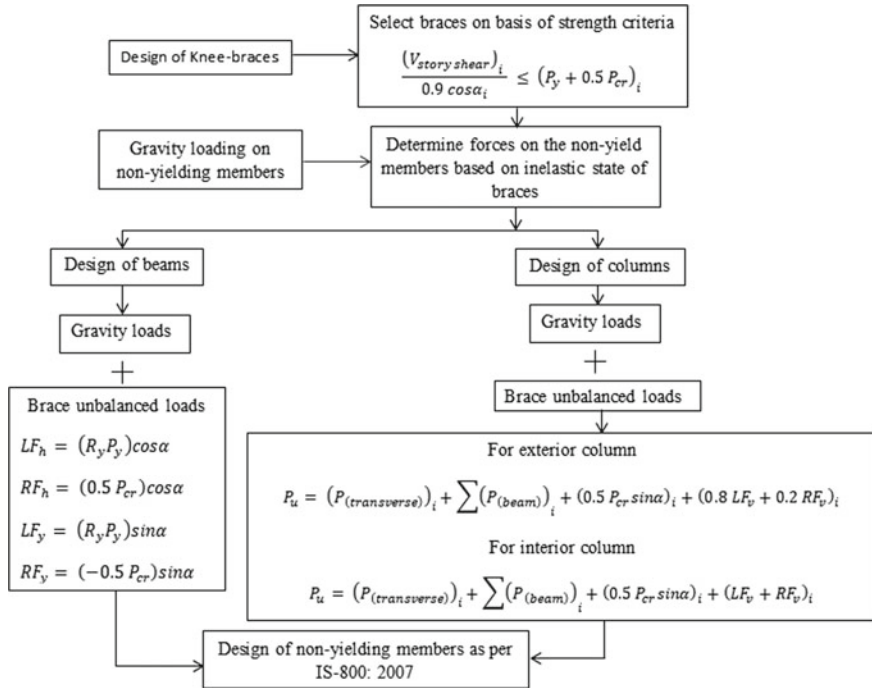


Fig. 4 Performance-based plastic design flowchart for KBMF

parameters used in the design are illustrated in Table 2. The beam, column and knee-braced member sections of the designed frame are represented in Fig. 5.

Table 2 Calculated parameters used in design of PBPD KBMF for target drift of 2% with varying ductility

Parameters	For 2% target drift			
Sa/g	2.5000			
T (s)	0.2415			
Yield drift, θ_y	0.0047	0.0041	0.0036	0.0030
Target drift, θ_u	0.0200	0.0200	0.0200	0.0200
Inelastic drift, θ_p	0.0153	0.0159	0.0164	0.0170
Ductility factor, μ_s	4.2918	4.8544	5.5866	6.5789
Ductility reduction Factor, R_μ	2.7539	2.9511	3.1895	3.4868
Energy modification factor, γ	1.0000	1.0000	1.0000	1.0000
A	17.9040	18.5342	19.1645	19.7948
V/W	0.3425	0.3313	0.3208	0.3109
Design base shear, V (kN)	4700.8800	4546.6341	4402.0302	4266.2051

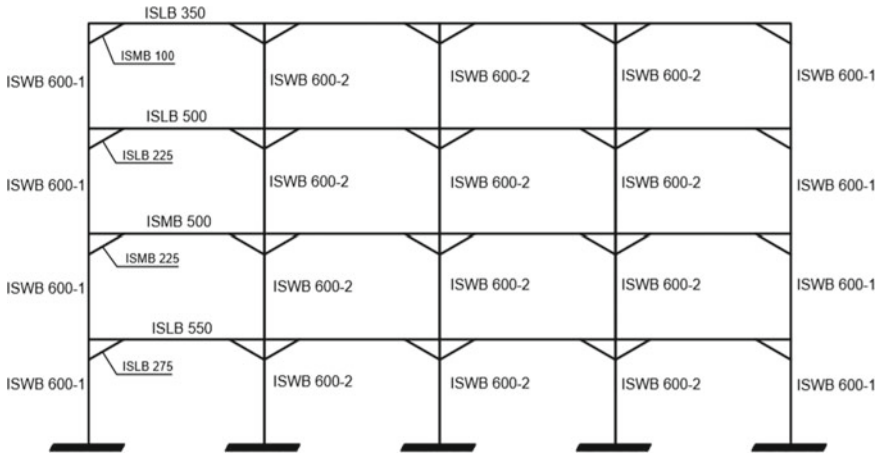


Fig. 5 Member sections of KBMF designed by PBPD method with 2% target drift and ductility varied throughout the structure

4.8 Design of KBMF for 3% Target Drift with Varying Ductility by PBPD Method

The test steel KBMF is designed by PBPD method with target drift of 3%, and the target displacement ductility ratio (μ_s) is varied throughout the structure. The parameters used in the design are illustrated in Table 3. The beam, column and knee-braced member sections of the designed frame are represented in Fig. 6.

Table 3 Calculated parameters used in design of PBPD KBMF for target drift of 3% with varying ductility

Parameters	For 3% target drift			
Sa/g	2.5000			
T (s)	0.2415			
Yield drift, θ_y	0.0047	0.0041	0.0036	0.0030
Target drift, θ_u	0.0300	0.0300	0.0300	0.0300
Inelastic drift, θ_p	0.0253	0.0259	0.0264	0.0270
Ductility factor, μ_s	6.4378	7.2816	8.3799	9.8684
Ductility reduction Factor, R_μ	3.4461	3.6828	3.9699	4.3286
Energy modification Factor, γ	1.0000	1.0000	1.0000	1.0000
A	29.5754	30.2057	30.8359	31.4662
V/W	0.2098	0.2055	0.2014	0.1974
Design base shear, V (kN)	2879.7697	2820.4968	2763.5993	2708.9380

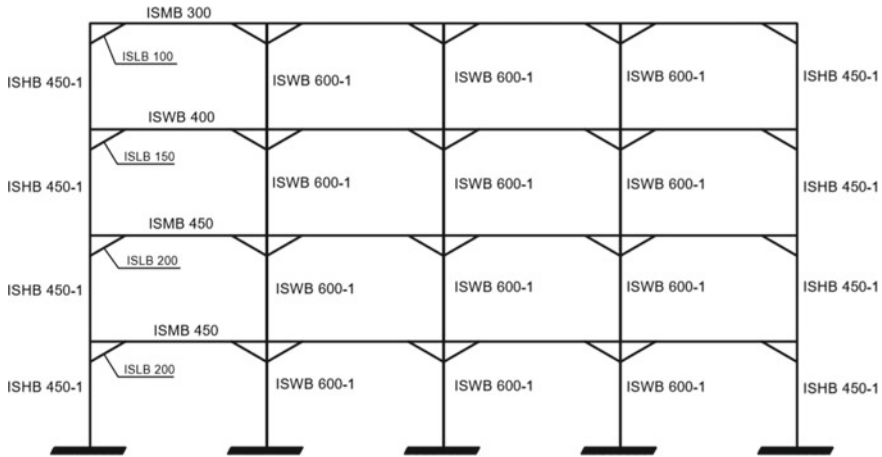


Fig. 6 Member sections of KBMF designed by PBPD method with 3% target drift and ductility varied throughout the structure

Where F_h is the horizontal component; $F_y = F_v$ is the vertical component; LF_h is the horizontal component due to left brace; RF_h is the horizontal component due to right brace; LF_v is the vertical component due to left brace; RF_v is the vertical component due to right brace; P_u is the total load used for column design; $P_{(transverse)}$ is the tributary factored gravity load (1.2 DL + LL); $P_{(beam)}$ is the tributary factored gravity load from the beam, i.e. ($= \frac{1}{2} (W_u) L$).

4.9 Design of KBMF for 3% Target Drift with Constant Ductility by PBPD Method

The test steel KBMF is designed by PBPD method with target drift of 3% and the target displacement ductility ratio (μ_s) is maintained constant throughout the structure. The parameters used in the design are illustrated in Table 4. The beam, column and knee-braced member sections of the designed frame are represented in Fig. 7.

5 Results and Discussions

The effectiveness of the designed KBMFs in terms of seismic performance is assessed through nonlinear static pushover analysis (NSPA) and nonlinear time history analysis (NTHA). NSPA is conducted for gravity loading (1.5(dead load) + 1.5(live load)) condition with the check for P- Δ effects included to determine the maximum

Table 4 Calculated parameters used in design of PBPD KBMF for target drift of 3% with constant ductility

Parameters	For 3% target drift with constant ductility			
Sa/g	2.5000			
T (s)	0.2415			
Yield drift, θ_y	0.0047	0.0047	0.0047	0.0047
Target drift, θ_u	0.0300	0.0300	0.0300	0.0300
Inelastic drift, θ_p	0.0253	0.0253	0.0253	0.0253
Ductility factor, μ_s	6.4378	6.4378	6.4378	6.4378
Ductility reduction Factor, R_μ	3.4461	3.4461	3.4461	3.4461
Energy modification Factor, γ	1.0000	1.0000	1.0000	1.0000
A	29.5754	29.5754	29.5754	29.5754
V/W	0.2098	0.2098	0.2098	0.2098
Design base shear, V (kN)	2879.7697	2879.7697	2879.7697	2879.7697

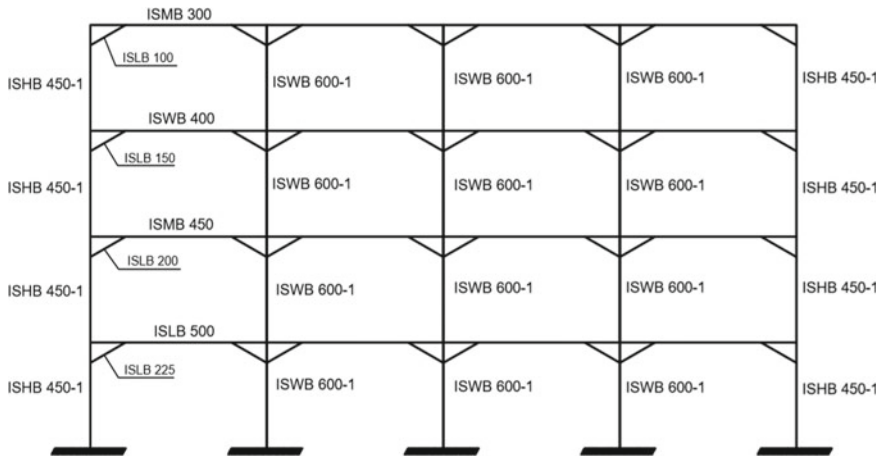


Fig. 7 Member sections of KBMF designed by PBPD method with 3% target drift and constant ductility throughout the structure

base force of the frames, in NSPA displacement is maintained constant and the base force is varied and Fig. 8 represents the pushover curves for all the KBMFs. NTHA is conducted for 1940 El Centro and 2001 Gujarat earthquake, the response of the KBMFs under both the earthquakes in terms of displacement is studied and are presented in Figs. 10 and 11. The inelastic activities in the KBMFs under both NSPA and NTHA are indicated by the formation of plastic hinges which represents the yielding of the particular frame member, and Fig. 9 represents the plastic hinge formations in the frames.

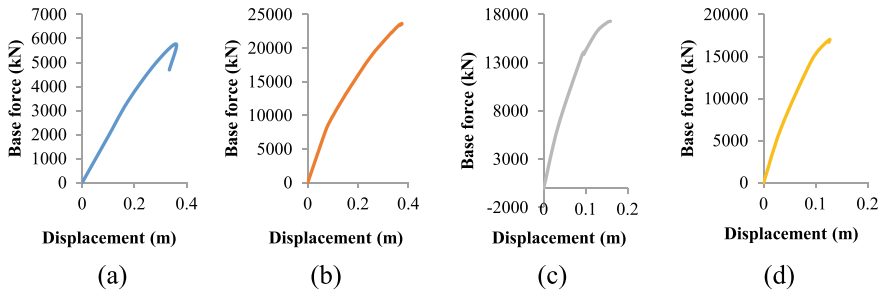


Fig. 8 Pushover curve **a** elastic method; **b** PBPD method with 2% target drift and varying ductility; **c** PBPD method with 3% target drift and varying ductility; **d** PBPD method with 3% target drift with constant ductility

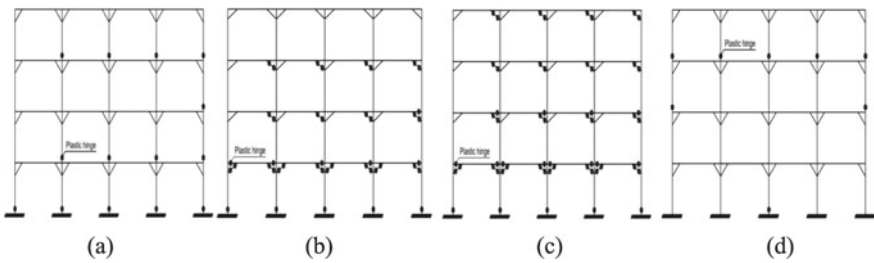


Fig. 9 Plastic hinge formation at collapse under NSPA **a** elastic method; **b** PBPD method for 2% target drift with varying ductility; **c** PBPD method for 3% target drift with varying and constant ductility; **d** plastic hinge formation for elastic method KBMF under El Centro earthquake

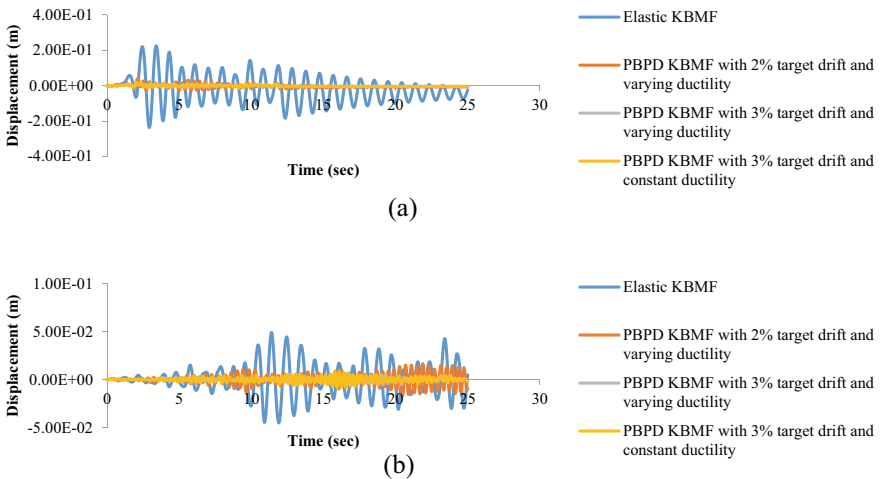


Fig. 10 Roof displacements of the KBMFs **a** El Centro earthquake; **b** Gujarat earthquake

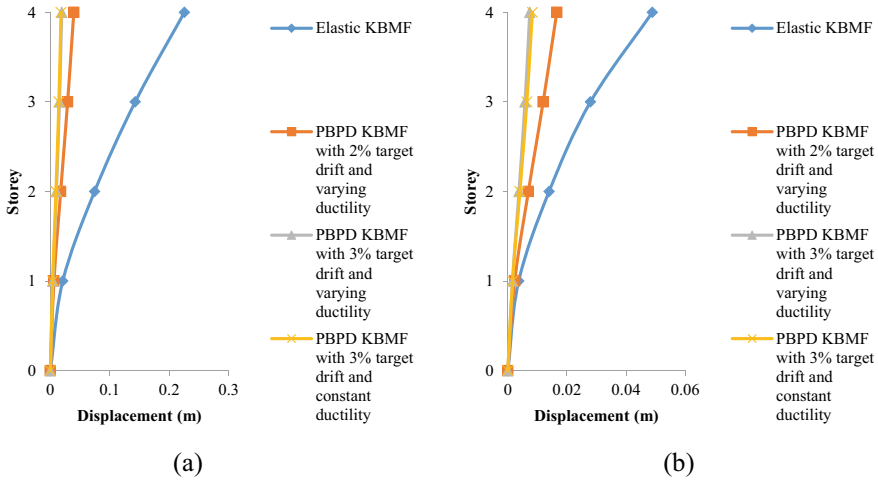


Fig. 11 Storey displacements of KBMFs **a** El Centro earthquake; **b** Gujarat earthquake

The maximum base force and corresponding displacement for the KBMF designed by elastic method are 5770.115 kN and 0.3594 m, for the KBMF designed by PBPD method with 2% target drift 23627.175 kN and 0.3745 m, for the KBMF designed by PBPD method with 3% target drift with varying ductility is 17299.842 kN and 0.1590 m and for the KBMF designed by PBPD method with 3% target drift with constant ductility is 16705.103 kN and 0.1256 m. The roof displacements of elastic KBMF, PBPD KBMF with 2% target drift, PBPD KBMF with 3% target drift-varying ductility and PBPD KBMF with 3% target drift-constant ductility under El Centro earthquake are 0.2254, 0.0395, 0.0192 and 0.0180 m and under Gujarat earthquake are 0.0489, 0.0166, 0.0074 and 0.0083 m, respectively. In terms of base force, PBPD frame with 2% target drift is superior to all other frames. Plastic hinges are formed in the columns of elastic KBMF randomly which is not desirable, for the PBPD KBMFs expected yield mechanism is achieved and the plastic hinges are evenly distributed throughout the frame. Inelastic activity is only observed under El Centro earthquake in elastic KBMF in all the other frames under both the earthquakes no inelastic activities are observed.

The PBPD KBMFs exhibit superior performance in terms of base force as they have effective energy dissipation throughout the height of the frame, the elastic KBMF has lower base force as inelastic activities are concentrated in the column regions. The pushover curves show linear increase for all the frames but for the elastic KBMF and PBPD KBMF with constant ductility a considerable fall at the collapse can be observed. The increase in ductility of the frame beyond certain limits, i.e. $\mu_s > 5$, reduces its flexibility and increases its stiffness, too much of stiffness in a frame can make it brittle, which can be justified by the results of the NSPA where the KBMF with 2% target drift collapses at 0.3734 m and the KBMFs with 3% target drift collapses at 0.1590 m and 0.1256 m. Increase in energy dissipation increases the

base force of a structure which can be justified by comparing the base forces of all the frames corresponding to a particular displacement; i.e. for a displacement of 0.12 m, the elastic frame has base force of 2300 kN, PBPD frame with 2% target drift has base force of 11,000 kN, PBPD frame with 3% target drift and varying ductility has base force of 15,000 kN and PBPD frame with 3% target drift and constant ductility has base force of 16,600 kN. As it is observed from the plastic hinge formations of the frames under NSPA at collapse frames with higher ductility has higher energy dissipation and intern have higher base force at particular displacements. The inelastic activities in first and second storey beams of PBPD KBMF can be attributed to the higher ductility ratio, i.e. greater than 5 ($\mu_s > 5$) as no performance point exists for members designed with ductility factor 6, i.e. $\mu_s = 6$ [3]. In order to achieve desirable yield mechanism of fully elastic beams even at collapse condition strict drift controls such as 1.5% target drift can be employed in the design which restricts the ductility in frame to desired limit, i.e. $\mu_s < 5$.

6 Conclusions

This study evaluates KBMFs designed with current codes and by ductility-based seismic design approach. Steel structures have good ductile behaviour, the response of the frames under different target drifts and ductility conditions has been studied and the main findings are presented below.

- Knee-braced moment frames designed using ductility-based seismic design approach exhibit expected outcomes in terms of desired yield mechanism and effective drift control under strong ground motions.
- KBMFs designed using ductility-based seismic design approach exhibit global ductile behaviour as inelastic activities are thoroughly distributed throughout the height of the frame, but the elastic KBMF exhibit global brittle behaviour as the inelastic activities are concentrated in certain regions.
- Increase in ductility of the frame increases its strength and provides desirable and predictable structural response, but care should be taken to restrict the ductility to certain limit beyond which inelastic activities are observed in non-designated yielding members and it also causes adverse effect on the frame by making it stiffer which leads to brittle failure.
- Varying the ductility ratio (μ_s) throughout the frame leads to economical design of the frame.
- In the ductility-based seismic design of steel structures, for regions with high seismic activity low target drifts have to be used and for regions with moderate and low seismic activities relatively higher target drift values can be used.

References

1. Banihashemi MR, Mirzagoltabar AR, Tavakoli HR (2015) Performance-based plastic design method for steel concentric braced frames. *Int J Adv Struct Eng* 7:281–293
2. Belaladavar SC, Patil VB, Kharmale SB (2018) Ductility-based seismic design of knee-braced moment frame (KBMF). In: 16th symposium on earthquake engineering, vol 61
3. Dalal SP, Dalal PD, Desai AK (2017) Effect of increasing ductility factors on the performance of a steel moment resisting frame designed by performance based plastic design method attuned with Indian code of practice. *Proc Eng* 173:1862–1869
4. Goel SC, Liao WC, Bayat MR, Chao S (2010) Performance-based plastic design (PBPD) method for earthquake-resistant structures: an overview. *Struct Design Tall Spec Build* 19:115–137
5. Goel SC, Chao S (2008) Performance-based plastic design: earthquake-resistant steel structures. International Code Council, USA
6. Leelataviwat S, Suksan B, Srechai J, Warnitchai P (2011) Seismic design and behaviour of ductile knee-braced moment frames. *J Struct Eng* 137(5):579–588