Optimal Knee Bracing System and Orientation for High Rise Steel Buildings under lateral loads

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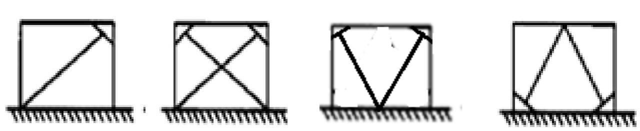
ABSTRACT

In knee brace frame System (KBFS) the non-buckling diagonal brace provide most of the lateral stiffness, the flexural yielding of knee element provides the ductility under a severe earthquake. In this way damage is concentrated in a secondary member which can be easily repaired/replaced at minimum cost. This paper aimed at investigating and comparing various types of knee bracing systems. A regular floor plan of 16 m x 12 m is considered for 15 storey steel frame building. To study the performance of 15 storied steel frame building with different bracing systems - single diagonal knee braced (SDKBF), X knee braced (XKBF), V knee braced (VKBF), Chevron knee braced (CKBF) and X braced frame(XBF), nonlinear static pushover analysis is performed in SAP 2000(V17.2) based on ATC 40 and FEMA 356 guidelines. Parametric study for knee element angle variation (30°, 45°, and 60) is carried out. The results are compared for the seismic parameters - capacity curves, displacement, performance point, and ductility factor with different bracing systems.

Keyword: - *knee braced frame, capacity curve, push over analysis, performance point, ductility factor.*

1. INTRODUCTION

Structural system opted under seismic load must satisfy stiffness and ductility criteria. The moment resisting frame possesses good ductility through flexural yielding of beam element but it has limited stiffness. The concentrically braced frame on other hand is stiff, but because of buckling of diagonal brace its ductility is limited. Knee braced frame (KBF) system efficiently satisfies both this requirements simultaneously. Aristizabal Ochoa[1] has proposed a framing system which combines the stiffness of diagonal brace with ductile behavior a knee element. The knee element is a fuse-like element that dissipates energy by the formation of plastic flexural hinges at its ends and mid-span when the building is subjected to severe lateral loads [2]. Knee braced frames (KBFs) are the modified form of the structural system in which consists of a conventional diagonal braces, with one end connected to a knee anchor instead of beam-column joint. In KBF the non-buckling diagonal brace provide most of the lateral stiffness, the flexural yielding of knee element provides the ductility under a severe earthquake. In this way damage is concentrated in a secondary member which can be easily repaired/replaced. at minimum cost [2]. In Fig. 1 different types of Knee braced frame (KBF) systems are shown.



(a) (b) (c) (d)

Fig.1 Different types of knee braced frame

(a) Single diagonal knee brace frame (SDKBF), (b) X knee brace frame (XKBF), (c) V knee brace frame (d) Chevron knee brace frame(CKBF)

2. PUSH OVER ANALYSIS

In this method, analysis is carried out under constant gravity loads and gradually increasing lateral loads to estimate deformation and damage pattern of structure. The first would apply gravity load to the structure, the second would apply one distribution of lateral load over the height of the structure, and the third would apply another distribution of lateral load over the height of the structure.. Static push over analysis is one of the analysis technique used for performance based design. Pushover analysis produces pushover curve or capacity curve that presents relationship between base shear (V) and roof displacement (Δ). Recently, there are some codes such as ATC-40, FEMA 273, FEMA 356, FEMA 440 adopted standards and guidance provisions regarding the assessment of existing structures as well as design of new structures. Some programs used for pushover analysis are SAP2000, ETABS, and DRAIN-2DX

Pushover analysis requires the development of the force-deformation curve for the critical section of beams and column by using the guideline in [6]. It is good to permits to identifying the critical members likely to reach limit states during earthquake for which attention should be given during the design and detailing process.

3. SCOPE OF WORK:

In present study, an attempt is made to assess the seismic behavior of different knee braced systems in multistory steel building using nonlinear push over analysis. A regular floor plan of 16 m x 12 m is considered for 15 storey steel frame building. Five structural configurations are analyzed and compared: Single diagonal knee brace frame (SDKBF), X-knee brace frame (XKBF), V-knee brace frame (VKBF), chevron knee brace frame (CKBF) and X brace frame (without knee) as shown in fig 4, 5, 6, 7 and 8. Parametric study for knee element angle variation (30^{0}, 45^{0}, and 60) is carried out. Non linear Push over analysis is done SAP2000 v.17.2. as ATC-40 guidelines

A. Loading Data

- Floor finish: 1 KN/m^2
- Slab thickness: 125mm
- Live load: 3 KN/m^2 on typical floor
  1.5 KN/m^2 on typical floor

- Earthquake load : As per IS-1893 (Part 1) – 2002
- Zone factor : III
- Importance factor: 1 [As per IS 1893(Part 1): 2002 table 6 clause 6.4.2 for office building]
- Response reduction factor: 5 [As per IS 1893
- (Part 1): 2002 for knee braced frame]
- Response reduction factor: 4 [As per IS 1893
- (Part 1): 2002 for X- braced frame.

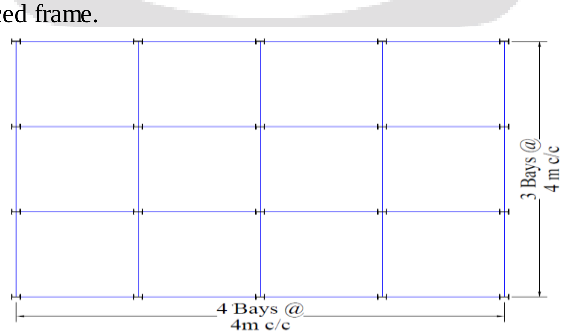
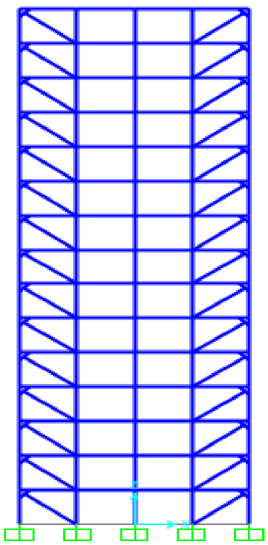


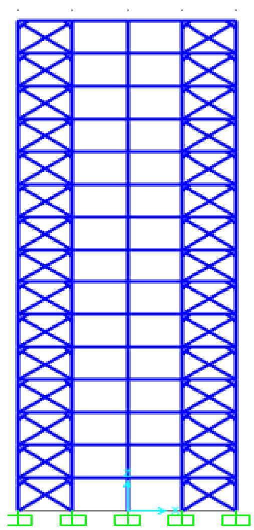
Figure 2 Typical Plan

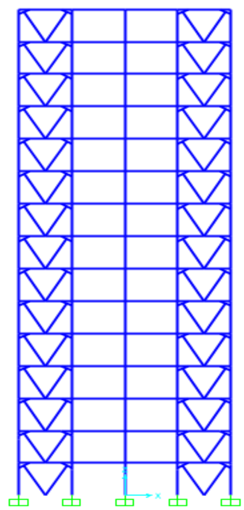
All the member are designed as per IS 800:2007 in SAP2000. Hinges properties for all sections has been taken as per FEMA-356.

B. Types of Model

Five braced frames are considered (a) Single diagonal knee braced frame(SDKBF), (b) X-Knee braced frame(XKBF) (c) V-knee braced frame(VKBF) (d) Chevron knee braced frame(CKBF) and XKBF(without knee) are considered. Seismic performance of all knee braced frames(SDKBF,XKBF,VKBF,CKBF) has been compared with X-brace frame without knee.







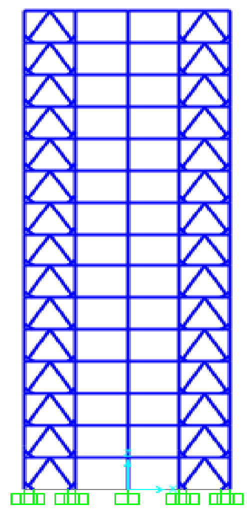


Fig.3 SDKBF Fig.4 XKBF Fig.5 VKBF Fig.6 CKBF

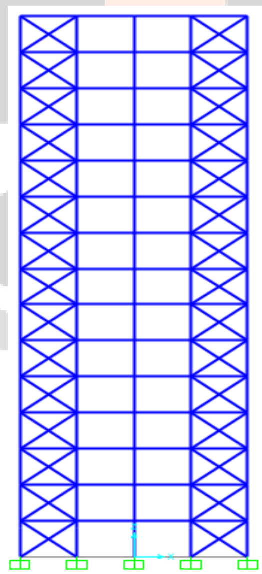


Fig.7 X-braced Frame(XBF)

TABLE.1 SECTION PROPERTIES

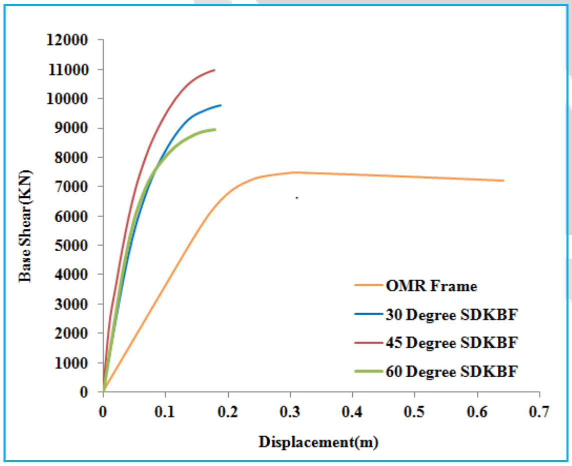
Specification	Knee brace frames
Columns	BU UC 305* 305 *240 + 2PLT 500 X 25 (1 to 4) BU UC 305* 305* 240 + 2PLT 450 X 20 (5 to 8) BU UC 305* 305 *240 + 2PLT 400 X 18 (9 to 11) BU UC 305* 305 *240(12 to 15)
Beams	ISMB600
Brace	ISLB350
Knee	ISLB250

TABLE 2. CONNECTIONS PATTERN

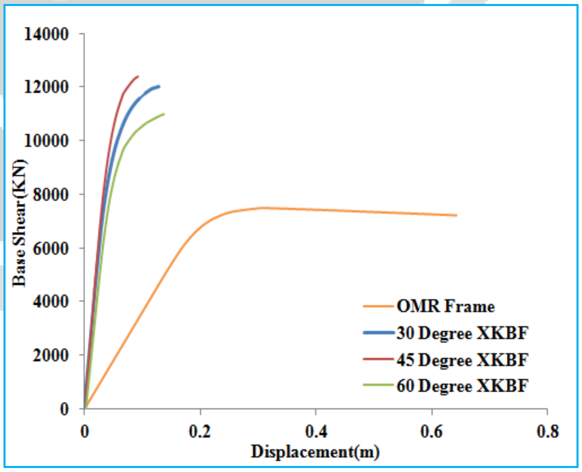
Beam-Column Connection	End of Braced Connection	Knee Beam-Knee Column Connections
Rigid	Pinned	Rigid

In present study displacement control push over analysis (using capacity spectrum as per ATC-40) is carried out. The target displacement used for building is 4% of the total height of the building (ATC-4) [1].

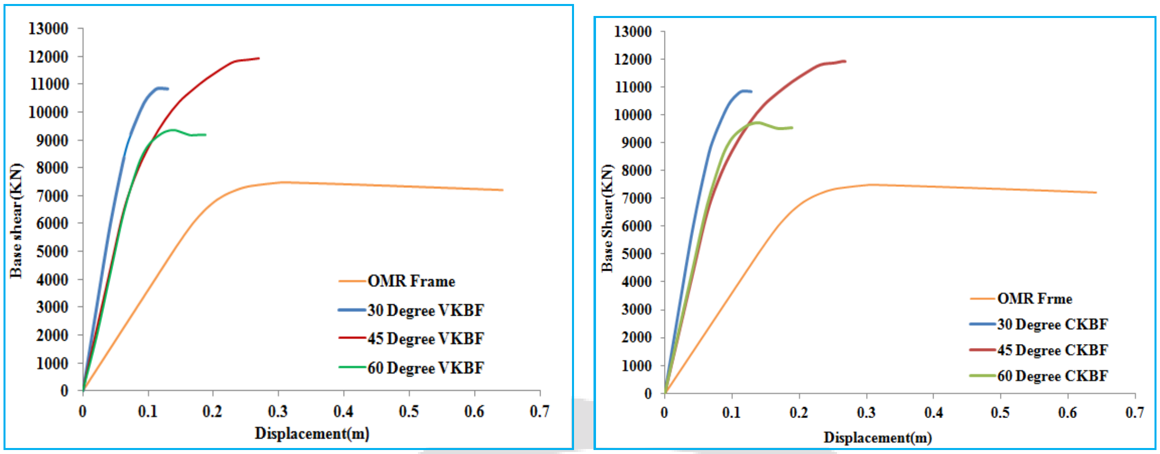
4. RESULT



(a) SDKBF



(b) XKBF



(c) VKBF (d) CKBF

Fig.8 Capacity curves of 15-Storey for angle Variation of knee element 30◦, 45◦ and 60 ◦

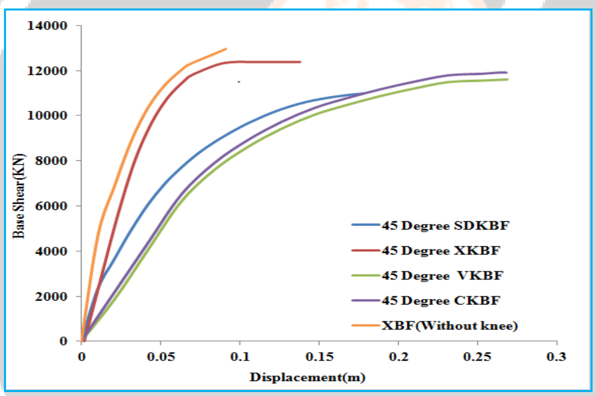
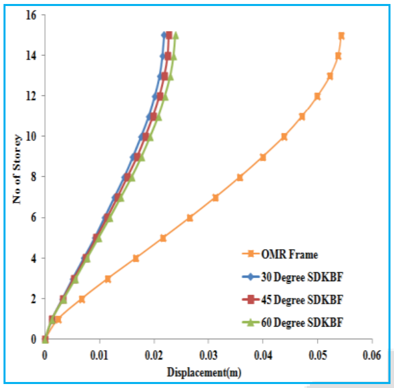


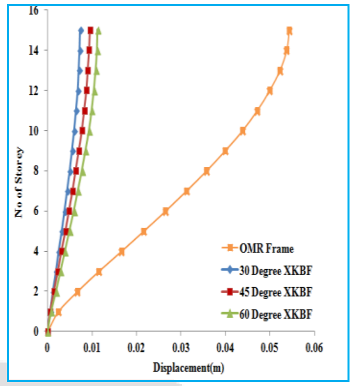
Fig 9. Capacity curves comparison for knee braced frames and X-braced frame

TABLE 3. PERFORMANCE POINT

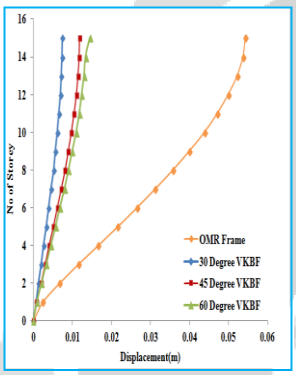
Bracing Type	Performance point	$\theta = 30°$	$\theta = 45°$	$\theta = 60°$	OMR Frame
SDKBF	Base shear(KN)	5809.595	**5863.710**	5773.710	4980.912
	Displacement(m)	0.067	**0.059**	0.071	0.107
XKBF	Base shear(KN)	7290.767	**7545.812**	7193.877	
	Displacement(m)	0.042	**0.043**	0.044	
VKBF	Base shear(KN)	6309.569	**6398.729**	6301.149	
	Displacement(m)	0.063	**0.066**	0.067	
CKBF	Base shear(KN)	6419.79	**7103.009**	6409.592	
	Displacement(m)	0.065	**0.063**	0.065	
XBF(without knee)	Base shear(KN)	7640.489			
	Displacement(m)	0.039			



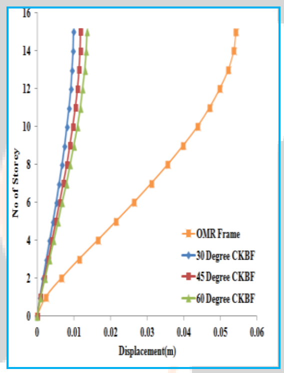
(a) SDKBF



(b) XKBF

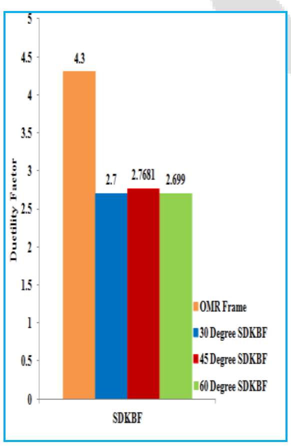


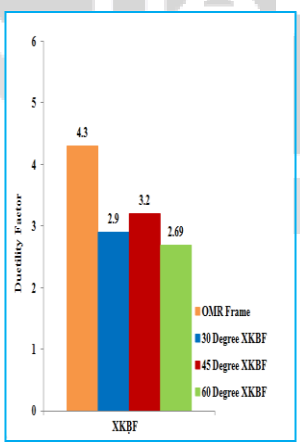
(c)VKBF

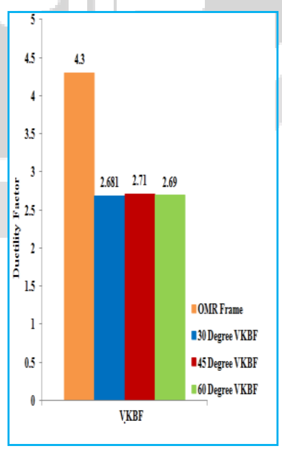


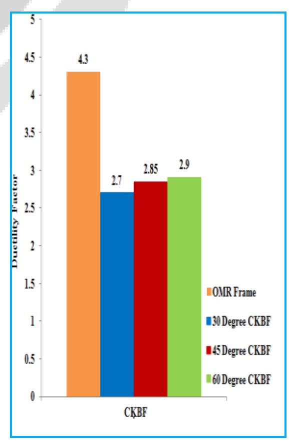
(d) CKBF

Fig.10 Displacement value of 15-Storey obtained from linear static analysis for angle Variation of knee 30, 45 and 60 Degrees









(a) SDKBF (b) XKBF (c) VKBF (d) CKBF

Fig.11 Ductility factor of 15-storey variation of knee 30, 45 and 60 degrees

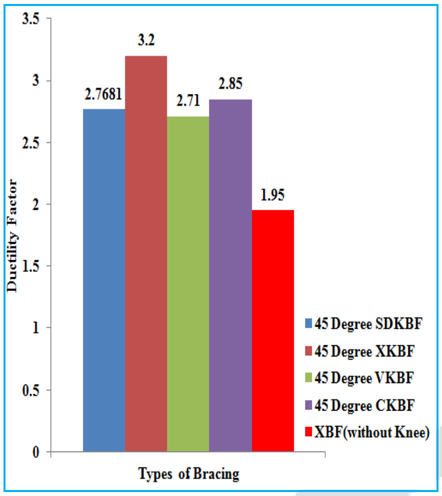


Fig.12.Comparision of Ductility Factor for knee braced and X-braced Frame Systems

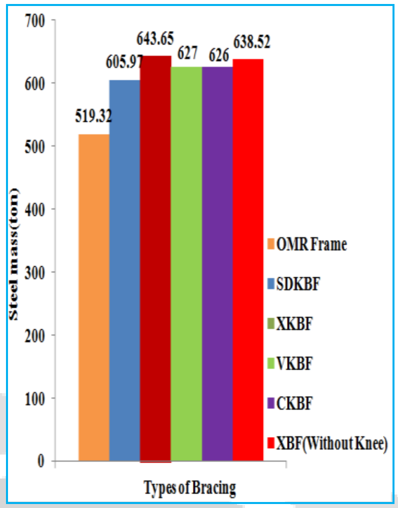


Fig.13 Amount of Steel Consumed

5. CONCLUSION

An analytical investigation of the seismic response of different braced frame has been undertaken by non linear push over analysis. The conclusions of present study can be summarized as follows:

- Capacity curves of all Knee braced frames having 45° knee element angle is found to be higher than of 30° and 60° knee element angle.
- Capacity curves of SDKF, XKBF, VKBF, CKBF and OMR frame shows that Capacity of XKBF is higher than other systems considered here. Base shear capacity increase 30 %, 47%, 36%, 37% for SDKBF, XKBF, VKBF, and CKBF than that of OMR frame respectively. Base shear capacity is found to be increase with increase in no of storey.
- Capacity of XBF (without knee) is higher than other knee braced systems considered here. However knee braced frames shows higher ductility.
- All Knee braced frames having 45° knee element angle shows higher performance point than that of 30° and 60° knee element angle.
- Under linear static analysis for seismic load Knee braced systems with 30° knee element angle shows least displacement.
- OMR frame has good ductility through flexural yielding beam elements, but it has less stiffness. Ductility Factor decrease 13%, 10%, 28%, 29% for SDKBF, XKBF, VKBF and CKBF then that of OMR frame respectively.
- Ductility factor of all knee braced frames having 45° Knee element angle is found to be higher than of 30° and 60° knee element angle for all storey knee braced Frames.
- Amount of material consumed in XKBF is higher than that of other knee braced frame systems considered.
- Optimal knee bracing layout can be selected according to the requirement of economy, ductility, stiffness etc.

6. REFERENCES

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