Seismic Performance Evaluation of Buckling Confined Braced Steel Frames Using a Model and Cyclic Pushover Analysis

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Abstract :

Buckling-constrained Braces (BRBs) are showed to have nearly the equal yielding stress and remaining strengthbelow tension and compression. The BRBs can undergo fully-reversed axial yield cycles without lack of stiffnessand electricity, whose seismic energy dissipation ability is superior. based on modal pushover analysis, thehave an effect on of better vibration modes of Buckling-confined Braced steel frame turned into taken into consideration. as compared tonon-linear static manner, the results of modal pushover evaluation agree better with that of nonlinear responsehistory analyses. based totally on cyclic pushover evaluation, the hysteretic conduct of Buckling-confined Bracedmetallic frame (BRBSF) changed into researched. After installed with BRBs, the energy dissipation of BRBSF is finishedby way of the hysteretic deformation of BRBs, the seismic responses of the structure may be ubstantially reduced andseismic overall performance could be advanced.

key phrases:Buckling-restricted Braces; Buckling-restrained Braced metal frame; modal pushover evaluation; cyclicpushover evaluation; seismic overall performance

1. INTODUCTION

Steel braces are used as an economic means of providing lateral stiffness to a steel structure. However, theenergy dissipation capacity of a steel braced structure subjected to earthquake loads is limited due to thebuckling of braces, which show unsymmetrical hysteretic behavior in tension and compression, and exhibitsubstantial strength deterioration when loaded monotonically in compression or cyclically. If buckling of a steelbrace is restrained and the same strength is ensured both in tension and compression, the energy absorption ofthe brace will be markedly increased and the hysteretic property will be good. So the Buckling- RestrainedBrace (BRB) is proposed. The capacity of resisting earthquake loads and energy dissipation of Buckling-Restrained Braced Frame (BRBF) is better than the frame with the installation of steel braces [1-3].Recently, Modal Pushover Analysis (MPA) has been developed to improve conventional pushover proceduresby including higher mode contributions to seismic demands [4]. This MPA procedure offers several attractivefeatures. Developed herein is an improved pushover analysis procedure based on structural dynamics theory,

which retains the conceptual simplicity and computational attractiveness of current procedures with invariantforce distribution common in structural engineering practice. In this MPA, the seismic demand due to individualterms in the modal expansion of the effective earthquake forces is determined by a pushover analysis using theinertia force distribution for each mode. Combining these ‘modal’ demands due to the first two or three terms ofthe expansion provides an estimate of the total seismic demand on inelastic systems [5].The accuracy of MPA have been evaluated for a wide range of structural systems and ground motions toidentify the conditions under which it is applicable for seismic evaluation of structures. To this end, it has beenapplied to code-esigned buildings [6], and generic frames [7] designed according to the static force distributionspecified in the International Building Code (IBC) [8]. By studying the bias and dispersion of this approximateprocedure, MPA has been shown to be accurate enough in estimating seismic demands for the seismicevaluation of many buildings.This Cyclic Pushover Analysis (CPA) procedure is that the structure is loaded horizontally and quasi-staticallyunder force or displacement control, the loading history consisted of stepwise increasing force or displacementcycles. The hysteretic behavior and energy dissipation capacity of structures can be researched with CPA, tostudy whether which exhibit substantial strength and stiffness deterioration.The objectives of this investigation are as follows: (1) To study the seismic demands of Bechmark BRBF, toevaluate the accuracy of MPA in estimating seismic demands and document the bias and dispersion of the ratioof the seismic demands on BRBF determined by MPA procedure to their ‘‘exact’’ values computed bynonlinear Response History Analysis (RHA), and (2) To study whether the good hysteretic behavior and energydissipation capacity of BRBs reflect on BRBF, the hysteretic behavior of BRBF is researched by CPA.

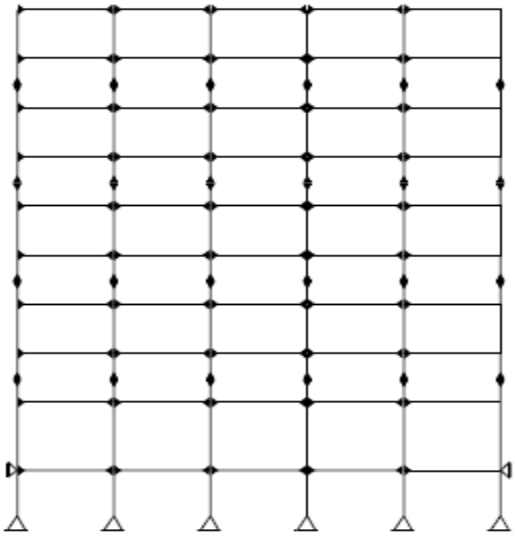
2. STRUCTURAL SYSTEM

The 9-story structure used for this benchmark study was designed for the SAC Phase III Steel Project. Althoughnot actually constructed, the structure meets seismic code and represents a typical mid-rise building designed forthe Los Angeles, California region. This building was chosen because it will also serve as a benchmark structurefor SAC studies and thus will provide a wider basis for comparison of the results from the present study.The Los Angeles nine-story (LA 9-story) structure is 45.53 m by 45.73 m in plan, and 37.19 m in elevation. Thebays are 9.15 m on center, in both directions, with five bays in the north-south (N-S) direction and five bays inthe east-west (E-W) direction. The building's lateral load-resisting system is comprised of steel perimetermoment-resisting frames (MRFs).The columns are 345 Mpa steel. The columns of the MRF are wide-flange.

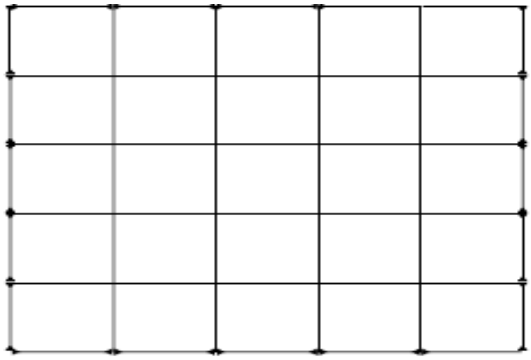
The levels of the 9-story building arenumbered with respect to the first story, located at the ground (first) level (see Fig. 1). The 10th level is denotedthe roof. The building has an additional one basement levels. The level directly below the ground level is thefirst basement (B-1). Typical floor-to-floor heights (for analysis purposes measured from center-of-beam tocenter-of-beam) are 3.65m. The floor-to-floor heights for the basement level are 3.65 m and for the first floor is5.49 m .

The column lines employ three-tier construction, *i.e.*monolithic column pieces are connected every three levelsbeginning with the second story. The column bases are modeled as pinned (at the B-1 level) and secured to theground. Concrete foundation walls and surrounding soil are assumed to restrain the structure at the first floorfrom horizontal displacement. In accordance with common practice, the floor system, which providesdiaphragm action, is assumed to be rigid in the horizontal plane. The floor system is comprised of 248 Mpa steelwide-flange beams acting compositely with the floor slab. The inertial effects of each level are assumed to becarried evenly by the floor diaphragm to each perimeter MRF, hence each frame resists one half of the seismicmass associated with the entire structure.The seismic mass of the structure is due to various components of the structure, including the steel framing,floor slabs, ceiling/flooring, mechanical/electrical, partitions, roofing and a penthouse located on the roof.

Theseismic mass of the first story is 1010t, for the second story to 8th level is 989t, and for the 9th story is 1070t.The seismic mass of the entire structure is 8041t.This benchmark study will focus on an in-plane (2-D) analysis of one-half of the entire structure. The framebeing considered in this study is one of the N-S MRFs. The height to width ratio for the N-S frame is 0.82:1.The Bechmark MRF are installed with BRBs, the layout of BRBs in Bechmark MRF is depicted in Fig. 2. TheBRBs are 235 Mpa steel, in ANSYS which are modeled by LINK8 element, columns and beams are modeled byBEAM189 element, and floor mass is modeled by MASS21 element. The elastic modulus after yielding is 1percent of which before yielding for all steel. The finite element model in ANSYS of N-S BRBSF is alsodepicted in Fig. 2.



(a) Steel frame elevation



(b) Standard floor plan

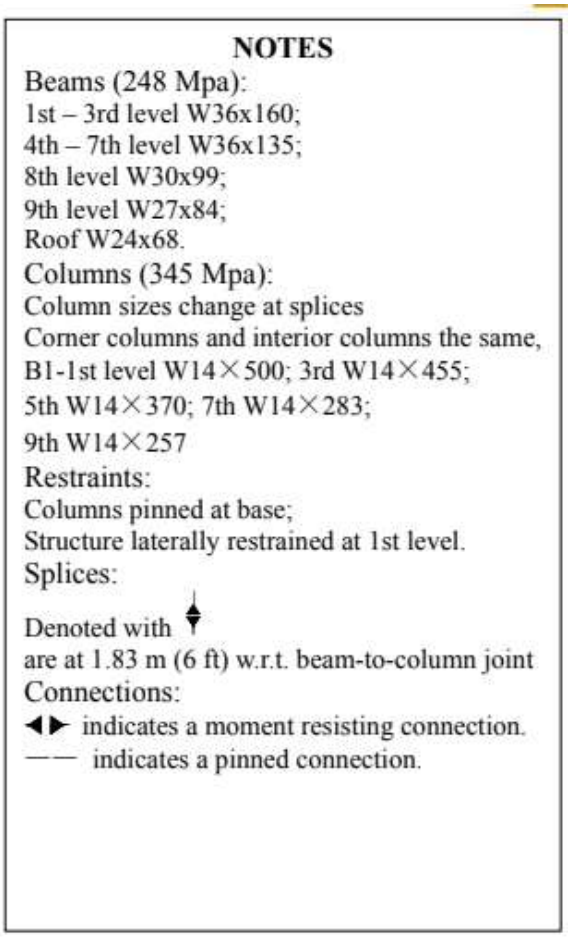


Figure1 9-story Bechmark MRF

Figure 2 Finite element model of 9-storey BRBSF

3. CALIBRATION OF FINITE ELEMENT MODEL

The first five natural frequencies of Bechmark MRF are get by Finite Element (FE) analysis in ANSYS, thecomparison of the results in ANSYS with the datas in papers of ASCE is listed table 1. The dispersion of theresults is very little, so the final "corrected" FE model in ANSYS was refined and calibrated to match theidentified structural natural periods. It was found that a FE model in ANSYS can be calibrated to give a goodprediction of earthquake response.

Table 1 Comparison of natural frequency

Mode	1	2	3	4	5
Paper	0.443	1.18	2.05	3.09	4.27
ANSYS	0.435	1.14	1.99	3.06	4.18

4. MODAL PUSHOVER ANALYSIS

Estimating seismic demands requires explicit consideration of inelastic behavior of the structure. Whilenon-linear response history analysis (RHA) is the most rigorous procedure to compute seismic demands, whileRHA quire longer computational time and encounter convergent difficulties. Current civil engineering practiceprefers to use the non-linear static procedure (NSP) or pushover analysis. The seismic demands are computed bynon-linear static analysis of the structure subjected to monotonically increasing lateral forces with an invariantheight-wise distribution until a predetermined target displacement is reached [9, 10]. Both the force distributionand target displacement are based on the assumption that the response is controlled by the fundamental modeand that the mode shape remains unchanged after the structure yields. Obviously, after the structure yields, bothassumptions are approximate, satisfactory predictions of seismic demands are mostly restricted to low-andmedium-rise structures provided the inelastic action is distributed throughout the height of the structure [11, 12].The fact that MPA is able to estimate the response of buildings responding well into the inelastic range to a
similar degree of accuracy indicates that this procedure is accurate enough for practical application in buildingretrofit and design. The MPA procedure was developed based on structural dynamics theory that includes thecontribution of several modes of vibration [4]. This procedure was further refined and systematically evaluated[6] using six buildings, each analyzed for 20 ground motions. It was found that with sufficient number of"modes" included, the height-wise distribution of story drifts estimated by MPA is generally similar to trendsnoted from nonlinear response history analysis (RHA).
To estimate the seismic demands, the contribution of the first three 'modes' were included in analysis of theBRBSF. The combined values of roof displacements were computed including one, two, or three "modal" pairs.Combining these peak modal responses by an appropriate modal combination rule (e.g. SRSS, CQC rule) leadsto the MPA procedure. Table 2 shows the floor displacements for the building by MPA and NSP together withthe exact value determined by nonlinear RHA of the system.For the comparison purpose, four recorded ground acceleration time histories were used. These four earthquakesinclude four types filed seismic acceleration records, the peak values of acceleration are 620gal, 140gal,respectively.

Table 2 Comparison of results based on several methods

Types of Acceleration	Analysis Methods	Roof Displacement/m	Bias
Acceleration Records in Field I 620gal/140gal	RHA	0.1025/0.02275	
	NSP	0.0774/0.0175	24.4% / 23.1%
	MPA	0.0865/0.0195	15.6% / 14.3%
Acceleration Records in Field II 620gal/140gal	RHA	0.246/0.083	
	NSP	0.199/0.0608	19.1% / 26.1%
	MPA	0.2403/0.0558	2.3% / 32.7%
Acceleration Records in Field III 620gal/140gal	RHA	0.321/0.07324	
	NSP	0.2904/0.0545	9.5% / 25.5%
	MPA	0.3403/0.0776	6% / 6%
Acceleration Records in Field IV 140gal	RHA	0.083	
	NSP	0.1611	15.2%
	MPA	0.1779	6.3%

Table 2 shows the bias in these estimates relative to the exactresponse from non-linear RHA. The bias in the MPA results for two or three modes included are generally significantly smaller than in NSP only considering of the first one "mode". The first 'mode' alone is inadequate, especially in estimating the displacements. Significant improvement is achieved by including response contributions due to the second and third'mode'. The higher "modal" pairs contribute significantly to the seismic demands for the selected systems and MPA is able to capture these effects. With sufficient number of "modal" pairs included, the height-wise distribution of peak roof displacements estimated by MPA is generally similar to the "exact" results from nonlinear RHA, and much superior to the first "modal" pair result. However, because MPA is an approximate method, it does not match the "exact" demands determining by nonlinear RHA. Instead MPA has the goal of estimating seismic demands to a useful degree of accuracy for practical application with the advantage of much less effort than required for nonlinear RHA.

5. CYCLIC PUSHOVER ANALYSIS

One reversal load pattern is proposed for the pushover analysis of BRBSF, that is Cyclic Pushover Analysis (CPA). The reversal loading is considered as an earthquake event, and the hysteretic behavior indicate the seismic performance to resist the earthquake load and dissipate seismic capacity of BRBSF.

Based on the push-over analysis and reversal load pattern analysis for the structure, the hysteretic curve is depicted in Fig. 3, Fig.3 shows the BRBSF shows stable hysteretic behavior without pinching and strength, stiffness degradation and the energy dissipation is large. It is seen that the BRBs are able to develop the steel strength to its full capacity and show dramatic strain-hardening behavior, good hysteretic behavior and

energy dissipation capacity of BRBs reflect on BRBSF. At the same time, the energy dissipation is completed by the hysteretic deformation of BRBs, the seismic responses of the structures will be greatly reduced and seismic performance will be improved.

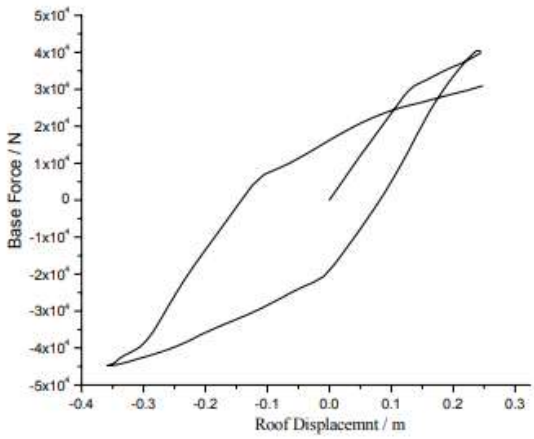


Figure 3 The Cyclic Pushover Analysis curve of BRBSF

6. CONCLUSIONS

It is an evident that the MPA and CPA procedure is an improved tool for estimating seismic demands on buildings. Using the MPA and CPA procedure, the structural behavior can be examined during seismic loading. RHA were computed to measure the bias and dispersion of MPA estimates, which indicate the dispersion values of the ratio of roof displacement demands determined by MPA considering of the first three "mode" is smaller than NSP only considering of the first one "mode". MPA provides adequate predictions of peak roof displacement of BRBSF when higher mode contributions are significant. It was also shown that NSP based on

invariant load vectors cannot capture the changes to the dynamic modes resulting from inelastic action. CPA is a good method to evaluate the hysteretic behavior of a structure, the BRBSF shows stable good hysteretic behavior and energy dissipation capacity because of the installation of BRBs, the seismic performance of which is markedly improved simultaneously. 7. ACKNOWLEDGEMENTS The support of National Science Foundation of China through projects (Grant No. 90715021, 50678057, 50108005), Nation `Eleventh Five` Technology Sustain Foundation and Heilongjiang Science Foundation (Grant No. ZJG0701) is greatly appreciated. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of these Foundation of China.

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