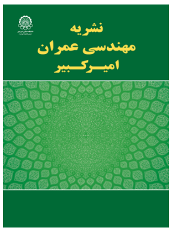

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Application of Lower Grade Steel on Dynamic Behavior of X-Braces in Shear Part 1: Classical Theory of Braces in Shear

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ABSTRACT: Using Lower Grade Steel (LGS) in design of buildings increases ductility and energy dissipation capacity along with load bearing capacity with decreased seismic demands. In addition, the performance of structures increases because of decreased target displacement. Nevertheless, the majority of seismic design codes follow an approach that is irrespective of steel grade. The procedures of structural design with different steel grades are typical independent of demand and capacity curves, as the related design codes have specified the seismic parameters based on the type of structural system and often recommend the same behavior factor and over-strength coefficient for steels of different grades. This comprehensive study includes two major parts. The first part includes design theory development of structures for X-Bracing system for different grades of steel and the classic formulas introduced to calculate main capacity and demand parameters. Then, the accuracy of proposed theory verified with nonlinear static analyses which leads to enough accuracy for buildings with shear behavior. Also, using LGS in seismic design of X-bracing buildings increases stability, ductility and energy dissipation capacity under severe earthquakes. In the second part, the comparative behavior of frames with different steel grades studied using advanced nonlinear static and Incremental dynamic analyses and the effect of height of the building emphasized.

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1- Introduction

Low Grade steel (LGS) is made with very small percentages of carbon and other alloys to achieve lower strength along with higher ductility and elongation [1-6]. The earliest work on low yield point steel (mild steel) was carried out by Saieki et al. (1986) [7]. LGS used more frequently as energy dissipative device in seismic resisting systems of high-rises after Kobe earthquake in 1995. Yamaguchi et al. (1998) studied the use of LGS in buckling restrained braces, shear walls, shear columns, and studs, and reported an improvement in seismic behavior [8].

This study presents a design theory for high performance X-braced systems made with different grades of steel and a series of seismic behavioral formulas developed. In addition, theoretical results for frames with 1, 3, 4, 7, 10 and 15 stories are compared with the results of nonlinear static analyses.

2- Design of X-braces with mild steel

2- 1- Classical Theory Of Shear Behavior Of X-Braces

To study the shear behavior of x-braces, the classical theory of behavior of this system under lateral loads is developed based on the demand and capacity curves and formulas of solid mechanics and structural analysis. For this purpose, a single-story frame consisting of beam, column and X-braces considered as shown in Figure 1.

2- 2- Theory Of X-Braces For Lgs

Assuming yield strengths of 250 and 90 MPa for structural steel and LGS, respectively and design of both systems for a constant base shear, the cross section of LGS brace will be 2.8 times greater than SS brace. In addition, stiffness of a LGS system will be 2.8 times SS system. Accordingly, natural period of the LGS system designed is about 60 percent of SS system.

It is shown that Target displacement of the LGS frame is expected to be 0.36 times that of SS frame.

By definition of ductility as the ratio of Target Displacement (S_{dp}) to Yield displacement (S_{dy}), the relationship of viscous damping with ductility can be expressed as follows:

$$\mu = \frac{63.7k}{63.7k - \beta_0} \tag{1}$$

Where, β_0 is hysteretic damping and k is defined according to ATC40 [9].

By definition of strain hardening slope as $K = \frac{Sa_y}{Sd_y}$, the relationship of target displacement (S_{dp}) and damping with hardening coefficient can be calculated as follows:

$$\alpha K = \frac{Sa_P - Sa_y}{Sd_P - Sd_y} \tag{2}$$

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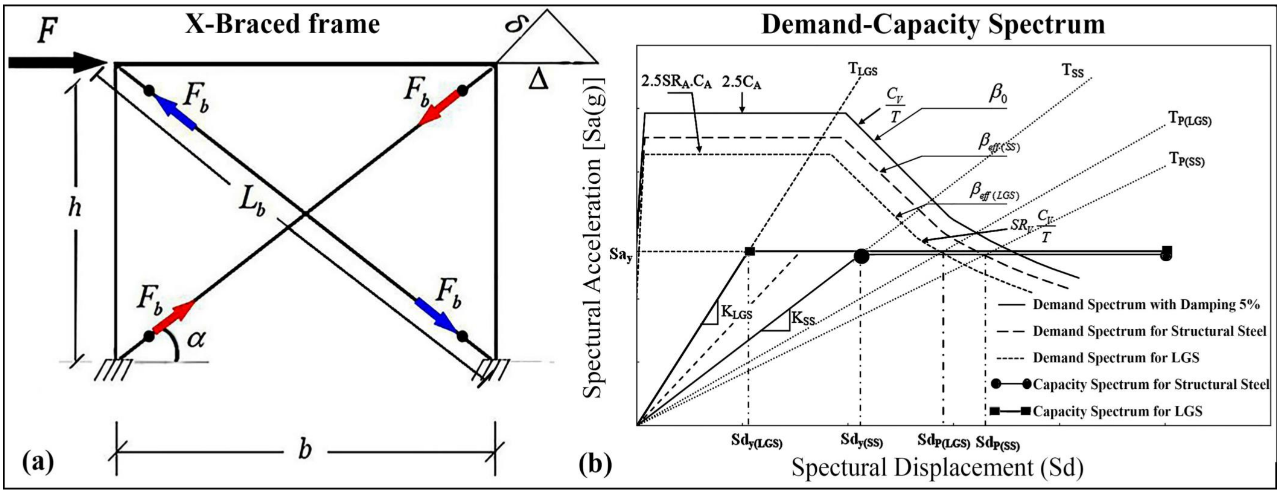

Fig. 1. a) X-braced frame, b) Demand-Capacity Spectrum curves for structural steel and LGS

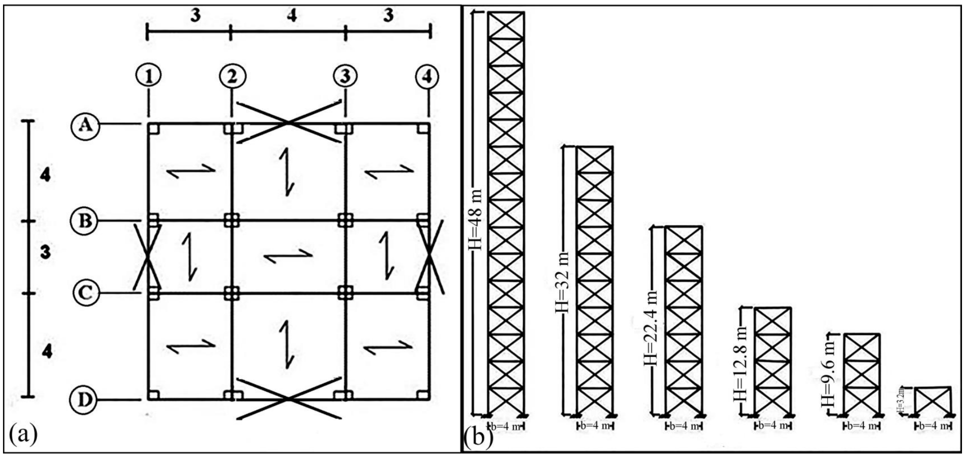

Fig. 2. a) Plan of buildings, b) studied X-braced frames

Finally gives the following relationship:

$$\beta_0 = 63.7k\left[\frac{1}{\alpha(\mu-1)+1} - \frac{1}{\mu}\right] \tag{3}$$

3- Design of specimens

To study the accuracy of the classical theory developed for the seismic behavior of x-braces in structures with different number of stories, its outputs were compared with the results of nonlinear static analysis. For this purpose, buildings with 1, 3, 4, 7, 10 and 15 stories were designed and analyzed by the common seismic design methodology. The plans of analyzed structures are shown in Fig. 2.

4- Nonlinear Static Analysis

The lateral force versus inelastic displacement diagrams can be obtained by Pushover analysis. In this analysis (named as N2 method in ATC40), capacity curves defined as elastoplastic.

Comparing the yield and target displacements of the studied samples, it is observed that the ratio of the yield and target displacement of LGS to SS specimens is close to the values obtained in theory for short buildings with shear behavior (see Table 1). While, increasing the height of building and governing bending deformations in the overall behavior of the structure, the difference between the results of the theory and the analysis increased.

Table 1. comparison of seismic behavioral parameters of pushover analysis with proposed theory

Specifications	Theory	4 story	7 story	10 story	15 story
$Sd_{y(LGS)}$	-	1.6	4.06	8.9	16
$Sd_{y(SS)}$	-	4	4.9	10.55	17.3
$Sd_{y(LGS)}/Sd_{y(SS)}$	0.36	0.4	0.82	0.84	0.92
$Sd_{P(LGS)}$	-	10.4	10.25	13.9	19.85
$Sd_{P(SS)}$	-	12.5	13.95	15.28	21.9
$Sd_{P(LGS)}/Sd_{P(SS)}$	-	0.83	0.73	0.89	0.9

* All numbers are based on millimeters.

5- Conclusions

In this paper, a theory for seismic behavior evaluation of X-braced systems with shear behavior proposed. In addition, effects of different grades of steel on seismic parameters discussed using capacity- demand spectral diagrams and proposed classical relations. Also, the relationship of damping with ductility of the structure determined and observed that the steel grade has an impact on seismic parameters of the system. Next, the frames with different number of stories were subjected to nonlinear static analysis. Comparison of the software results with the results of the theory showed that in the low-rise frames, because of dominance of shear displacement effects, the results are close to those predicted by the theory. Higher stability and ductility of the structure obtained by using Lower Grade Steel in design of X-braces.

6- Acknowledgement

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