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Case Study on Seismic Performance of Soft Stories in Short Steel Structures and Replacement of Braces with Equivalent Moment Resisting Frame

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ABSTRACT: Many of changes in ground floor of buildings may result in elimination of braces.This phenomenan, which called “soft story”, decreases the stiffness of stories and leads to collapse of building under severe earthquakes. Study of last earthquakes such as Bam on December 26 ,2003 and Chichi-Thaiwan on September 20 ,1999 shows that many peaple missed their life because of soft stories created due to elimination of structural infills by changing residential buildings to commercial or architectural reasons.
In this research, the soft story studied in short steel buildings with four stories by removing X-braces at first and second stories using non-linear static and dynamic analyses. After removing braces, the stiffness of soft story increased gradually by providing rigid connections and using moment resisting frame and the replacement of braces with equivalent moment frame (with different stiffnesses) studied. The seismic design parameters such as transient and inherent dissplacements, ductility and energy dissipation capacity calculated and compared in various diagrames. In addition, the sttiffness of X-braced and moment resisting frames calculated using classical relations of solid mechanics and discussed. According to obtained results, the replacement of X-braces by an equivalent moment frame in a building leads to excessive drifts and less energy dissipation capacity. In addition, the findings of this paper is coin with specification requirements to avoid soft stories in buildings by avoiding stories with stiffness of 70 percent relative to above story.

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1- Introduction

The soft story happening limits the deformation and energy dissipation capacity of that story and increases its seismic demands. As a result, the columns of the story collapsed because of excessive demand capacities.
The soft story is more susceptible to failure compared with the other stories. When the earthquake excites a building, the behavior of soft story is similar to inverted pendulum that looks like a rigid mass, which forms a Single Degree of Freedom System (SDOF) that by moving in the opposite direction of the earthquake excitation, the story collapses due to concentrating deformations and excessive induced stresses [1].

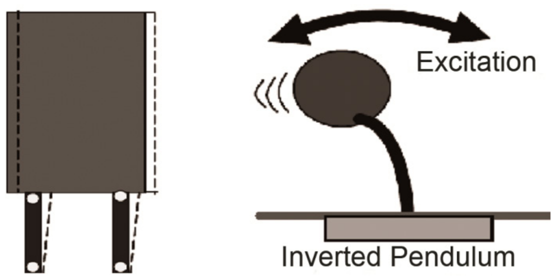

Figure 1: SDOF simulation of soft story (Wibowo et al. 2010)

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Moehle and Alarcone [2], Valmudsson and Nau [3], Chintana pakdee and Chopra [4], Trung and Lee [5], Pirizadeh and Shakib [6], Ghale-Noei and Golkari [7] studied the soft story in different researches and investigated the behavior of steel and concrete structures with different heights.

2- Methodology

The effect of the growth of the soft story in a four story steel building with special X-bracing studied using classical formulas and analytical tools. This building designed using the AISC specification for steel buildings (AISC360 2010) and AISC seismic provisions (AISC341 2010). The behavior of the structure studied in two phases after removing the braces from the stories. In the first phase, only the braces of the first story, and in the second phase, the braces of the second story removed. Then, the braces in the soft story substituted with the beam-to-column moment resisting connections and the stiffness of the story increased gradually using bigger column and beam sections. The behavior of each frame studied separately using the non-linear static analysis (pushover) method. In other words, the possibility of substitution of the braces with equivalent moment-resisting frames in the soft story studied. The behavior of each frame also studied under four sever earthquake records of Chi-Chi-Taiwan, Tabas-Iran, San Fernando-The U.S., and Northridge-The U.S using the non-linear time history analyses.

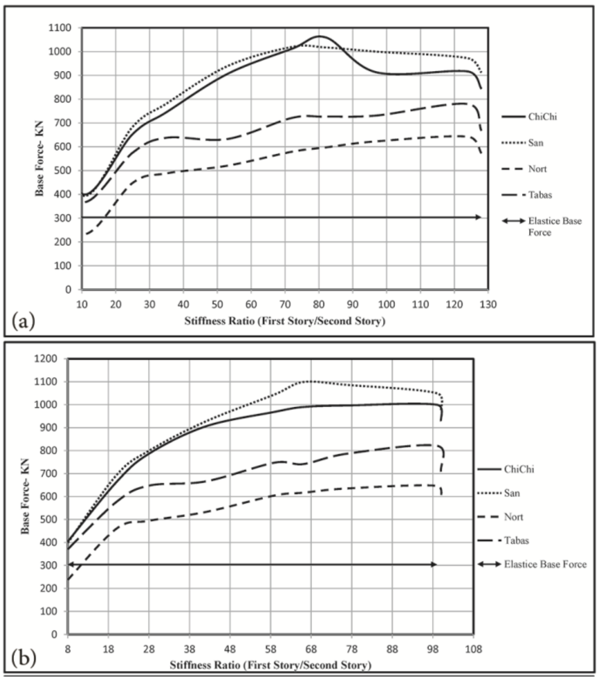
In this research, several four story steel frames designed and analyzed under non-linear static and dynamic analyses and the effects of removing braces in lower stories studied. The moment resisting frames in soft stories considered with different stiffness and replacement of X-braces with moment resisting frames in soft stories investigated.
The "soft story" developed in the first or second stories by removing braces. By replacing beam-to-column connections of the soft story with rigid connections, the simple frame converted to a moment resisting frame. Different stiffness's assigned to moment resisting frame. The non-linear static and dynamic analyses carried out to study 25 frames. The effects of removing braces in soft stories on seismic performance of structures studied. In addition, replacing braces with moment resisting frame with different stiffness's explored.

3- Main Contribution

By removing braces in soft story, ductility and energy absorption capacity of frames decreased compared with complete braced frame. Both parameters improved by the increase of stiffness of soft story using moment resisting frame.
Removing braces and development of soft story in second story is slightly more critical than first story due to interaction of near stories.

4- Maximum Base Shear

Comparison of the base shears of the frames under selected earthquake records of Chi-Chi, San Fernando, Tabas and Northridge given in Figure 2.
By removing braces in the soft story, the maximum story shear capacity decreased in all records. Especially in Northridge record with the soft story in the first story and in Chi-Chi record with the soft story in the second story that it become less than the equivalent base shear in static analyses.



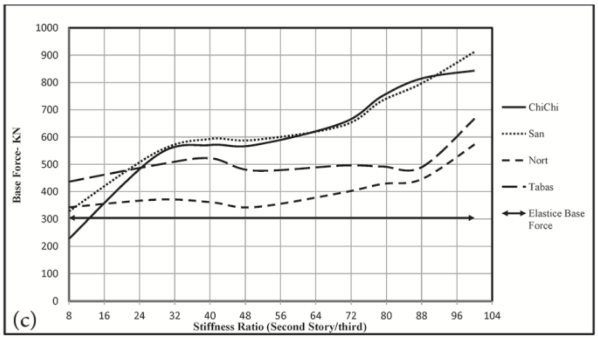


Figure 2: Comparison of the base shears under earthquake records for frames of groups; a) F4A, b) F4B, c) F4C

The base shear capacity increased by increasing stiffness of the first story of 70 percent of that in the second story under two records of Chi-Chi and San Fernando, while it decreased with a mild slope for stiffness of 70 percent and more. Similarly, by increasing the stiffness of the first story up to 80 percent of that in the second story, the maximum base shear of story remained stable under two records of Northridge and Tabas and did not increase any more.
Increasing the relative stiffness of second story to that of third story in frame class F4C by up to 28 percent (F4C28) led to increase in base shear capacity compared to frame F4C8 by 2.35, 1.66, 1.14 and 1.08 times under Chi-Chi, San Fernando, Tabas, Northridge records, respectively. However, it could not reach the equivalent base shear of complete braces frame.

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