High Rise Building Retrofitting In a High Risk Earthquake Zone

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SUMMARY:
In south west of Tehran (high risk earthquake zone) there is a tall building that after constructing the steel frames with moment resisting connections and placing the floor slabs concrete, the inspector reported a poor construction quality for the steel frames. After investigation and checking the whole steel frames especially box plate columns and checking the connections welding visually and by PT and x-ray tests, it was obvious that the steel box plate column welding would not strong enough to tolerate the required load combinations including lateral earthquake loads. In order to retrofit the structure, a composite column section is considered along with additional bracing at different spans. With this new configuration, the earthquake lateral forces distributed uniformly that reduced the size of the required retrofitting footing.
The concrete box columns (around the steel plate box column) were designed based on a portion of stresses caused by live load and the rest of the dead load (forty percent) on the composite column. Two finite element models were considered for this structure in order to be able to separate the existing and new stresses in the frame elements. In this paper besides considering the prefabricated frame element quality along with the welding, the analytical method that used for retrofitting this structure will be presented.

Keywords: Retrofitting, composite section, finite element modelling

1. INTRODUCTION

1.1 Location and type of the structural frame

In the south west of Tehran (high risk earthquake zone) there was a tall building under construction. The fourteen story building has three 8m span at one direction and five 6m span in other direction as shown in Figure 1.1. After erecting the steel moment resisting frames, the “X” bracing systems and placing concrete of the building floor slabs (composite beams), the quality control (QC) inspector reported the unacceptable welding quality of the steel frames.

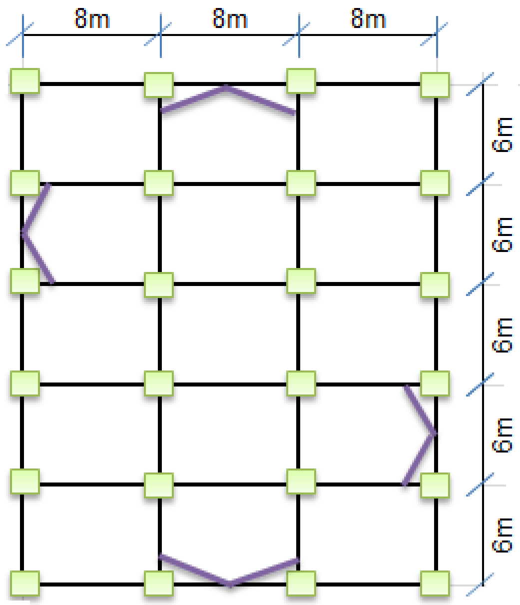


Figure 1.1. Steel frame structural plan

A visual, PT, and X-ray test investigation of the whole steel frame welding (especially box plate columns and connections) revealed that the steel box plate column welding is not strong enough to tolerate the code required load combinations, including lateral earthquake loads. To retrofit the structure, a composite column section along with additional bracing at different spans was considered to retrofit the structure. With this new configuration, the earthquake lateral forces will be distributed uniformly and will reduce the size of the footing retrofit. The steel box columns carried more than 60% of the total dead load (floor concrete slabs plus brick wall partitions).

1.2. Analysis requirements

Multistory rigid frames determined as an Ordinary Moment Frames (OMF). As with all indeterminate frames, the first step in the design process is to perform a preliminary analysis.
It is suggested that the OMF (steel frame) be considered as a pinned-base frame in order to eliminate the end moment of the steel column on the foundation. The Specifying Professional is encouraged to consider serviceability criteria and drift control at the preliminary retrofitting design phase of the project. After selecting trial concrete member sizes for the columns, finite element analyses was performed to determine forces, moments, and deflections (both 1st -order and 2nd -order) for the load combinations prescribed by the applicable building code. The current AISC Specification for Structural Steel Buildings [AISC, 2005a] requires a 2^{nd}-order analysis. Since a 2nd -order analysis is a non-linear problem; the analysis must be performed for each required load combination. The amplification factor for the 2^{nd}-order analysis based on the member effect is given as B_1 in the Specification and is shown in Equation 1.

$$B_1 = C_m / \left(1 - \frac{\alpha P_r}{P_{e1}}\right) \geq 1 \tag{1-1}$$

Where C_m = equivalent moment factor; α = 1.0 for LRFD to account for the nonlinear behavior of the structure at its ultimate strength; P_r = required compressive strength; P_{e1}= Euler buckling load.

$$M_r = B_1 . M \tag{1-2}$$

Where M_r = amplified maximum moment; M = maximum moment on the beam-column.

Columns were considered braced against lateral translation (braced frames) and the 2^{nd}-order analysis based on the structure effect (B_2) did not apply based on the code.

2. RETROFITTING PROCESS

Three options were suggested for retrofitting of this building. The three options were:

- Redoing all the welding;
- Reinforcing the columns with new steel plates along with additional "X" bracing;
- Reinforcing the steel columns with reinforced concrete (composite columns) and additional "X" bracing.

The first option had workability problem, and most of the welding had vertical position and some without access at connection locations. The second option had workability problem too, and column reinforcement at the connections were impossible. The easiest option was composite column that had none of the other options problems, so the third option was approved for this building.

The design methodology described in the paper will be limited to steel structures subjected to seismic loads; however, these procedures are also directly applicable to concrete structures as well.
The approved retrofitting process was as follows:

- Dead load reduction on the existing steel frame elements by removing the heavy partitions to reduce the vertical loads on the existing steel columns;
- Adding new "X" bracing in both directions to reduce the vertical loads caused by the lateral earthquake loads on the footing and the bracing columns;
- Strengthening the vertical elements with reinforced concrete (composite column);
- Replacing the partitions with a lighter material;

By removing the heavy partitions, the dead load on the existing structure was reduced to almost 40%. A finite element model was adopted for analyzing the existing structure with this new dead load in order to determine the existing stresses Figure 2.1.

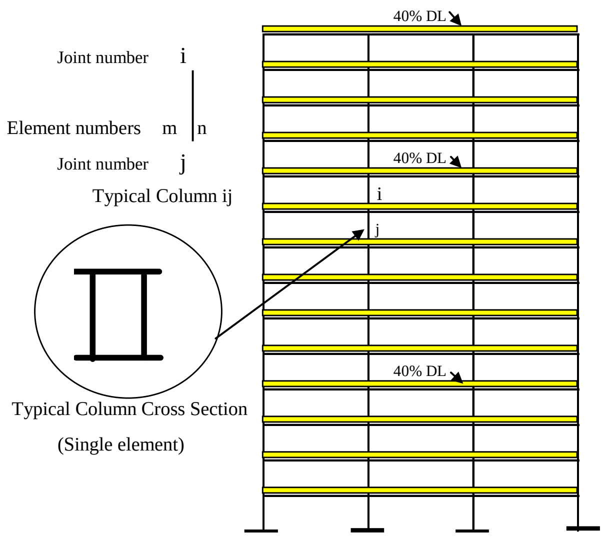


Figure 2.1. Typical steel frame (with or without "X" bracing)

For considering the remainder of the loads (including the rest of the dead load, and 100% of the live load, and the lateral load) a second model was adopted with the new "X" bracings and double vertical elements (composite columns) at each joint for an analysis of the stresses of the steel and concrete columns separately Figure 2.2. The double columns were constrained at three points along the height to act like a single column.

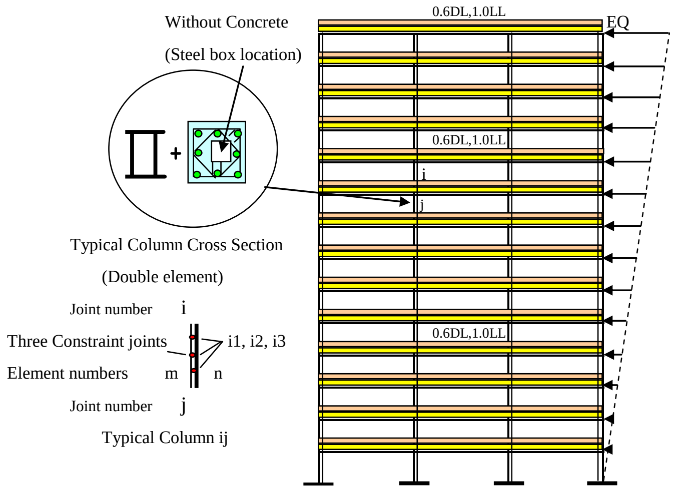
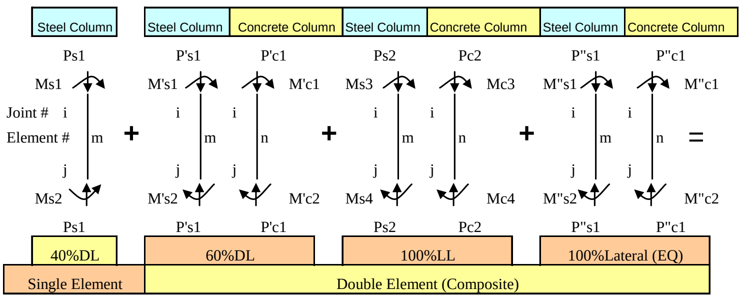


Figure 2.2. Typical steel frame (with or without "X" bracing) with composite columns

The final stresses are a combination of the first and second models' results per LRFD and USD load factors for the steel and concrete elements respectively. Computer program was written to collect the axial, top & bottom and maximum mid height moment for each column (between four parts of each column). Figure 2.3, shows the different loadings on single and double elements, and a sample of the AISC and ACI load combinations that were used for the final design of the structure.



Steel Column (LRFD Method)

Ps= 1.2Ps1+1.2P's1+0.5Ps2+1.0P"s1

Msi= 1.2Ms1+1.2M's1+0.5Ms3+1.0M"s1

Msi= 1.2Ms2+1.2M's2+0.5Ms4+1.0M"s2

Concrete Column (USD Method)

Pc= 1.2P'c1+1.0Pc2+1.0P"c1

Mci= 1.2M'c1+1.0Mc3+1.0M"c1

Mci= 1.2M'c2+1.0Mc4+1.0M"c2

Figure 3.2. Loading on single and double elements, and a load combination sample.

The reactions caused by the vertical elements on the footing compared with the old steel frame analysis results in order to determine the additional stresses that must be carried by the footing.

3. CONCLUSIONS

The three dimensional finite element models with single and double vertical elements were considered for analyzing the existing stress in the steel columns (with 40% of the dead load) and the new stresses caused by the remainder dead load, the full live load and the lateral loads in the structure. Based on the results of these analyses, the following conclusions can be drawn:

- The stress distribution between the steel and concrete columns were monitored and approved during the construction by checking the vertical deformation of the structure at different stories;

- The final results indicated that the steel columns carried about 40% of the gravity load (Dead and Live);
- More than 85% of the lateral loading tolerated by “X” bracing system;
- Less than 5% of the reminder lateral loading carried by steel columns;
- About 10% of the reminder lateral loading tolerated by the concrete columns Figure 3.1;
- Increment of the concentrated loads on the footing caused by the new bracing systems, led to the footing reinforcement as well.

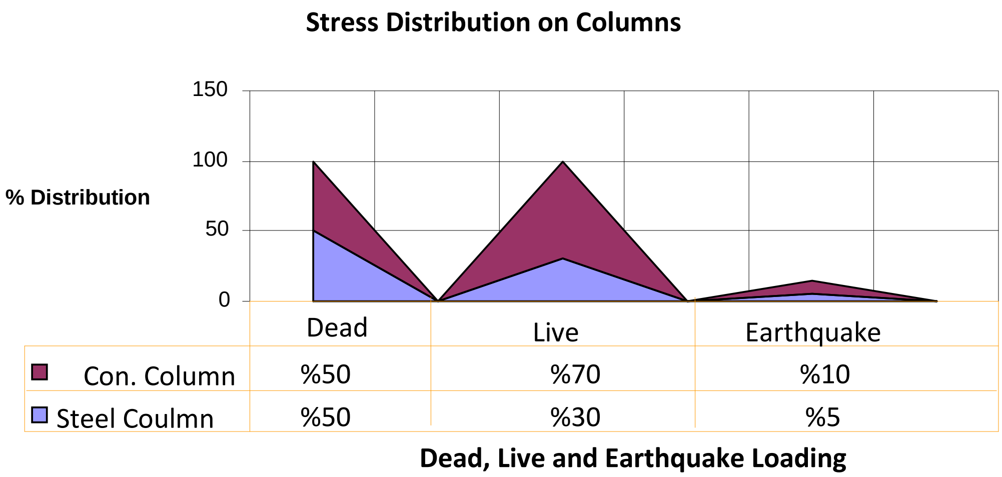


Figure 4.2. Stress distribution on composite columns

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