FINITE MODELING OF A HIGH-RISE BUILDING RETROFITTING

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Abstract

The behavior of composite columns under gravity and lateral loading is a complex analysis, especially when the steel frames were under partial gravity dead load in advance. A new finite element model with double vertical elements was adopted for analyzing the stresses in existing steel columns and the new concrete columns as well. The double vertical elements, provides a unified approach to analysis the steel and concrete columns' stresses separately.

Keywords: Retrofitting, high-rise, finite element.

1. Introduction

1.1 Location and type of the structural frame

In a high-risk earthquake zone, there was a tall building under construction and after erecting the steel moment resisting frames, "X" bracings and placing floor slabs' concrete (composite beams), the quality control (QC) inspector reported unacceptable welding quality of the steel frames.

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. The steel box columns carried more than 60% of the total dead load (floor concrete slabs plus brick wall partitions).

To retrofit the structure, a composite column section along with additional bracing at different spans was considered to eliminate the problem. With this new configuration, the earthquake lateral forces will be distributed uniformly and will reduce the size of the footing retrofit.

1.2 Analysis requirements

Multistory rigid frames were determined as Ordinary Moment Frames (OMF), and the first step was performing a preliminary indeterminate frame analysis. All the columns connections on the footing were designed as fixed connection, but with very poor welding quality. Therefore it was suggested to consider pinned-base columns to eliminate the end moment on the foundation. In order to have better control on the steel structure's serviceability and behavior, drift control at the preliminary retrofitting design phase of the project was performed. After selecting vertical concrete member sizes for the columns, finite element analyses were performed to determine axial forces, moments, shears and deflections (both 1st-order and 2nd-order) for the load combinations required by the building code. The current American Institute of Steel Construction (AISC) Specification for Structural Steel Buildings [AISC, 2015] requires a 2nd-order analysis. Since the 2nd-order analysis is a non-linear analysis; the analysis must be performed for each required load combination. The amplification factor for the 2nd-order analysis based on the member effect is given as B_1 in the Specification and is shown in Eq (1).

$$B1 = \mathrm{Cm}/(1 - \frac{\alpha \mathrm{Pr}}{\mathrm{Pe1}}) \tag{1}$$

where C_m = equivalent moment factor;

$\alpha = 1.0$ 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.

Then the maximum moment on the beam-column will be amplified with Eq (2).

$$Mr = B1 * M \tag{2}$$

where M_r = amplified maximum moment;

M = maximum moment on the beam-column.

Columns were considered braced against lateral translation (braced frames) and the 2nd-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 as well and reinforcing columns at the connections was impossible. The most reliable option was using composite columns, so the third option was approved for retrofitting this building structure.

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 following describes the approved retrofitting process:

- 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 get better distribution of the vertical loads caused by the lateral earthquake forces on the footing and the columns at both sides of the bracings;
- 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% of the initial load. A finite element model was adopted for analyzing the existing structure with this new dead load in order to determine the existing stresses (Fig. 1).

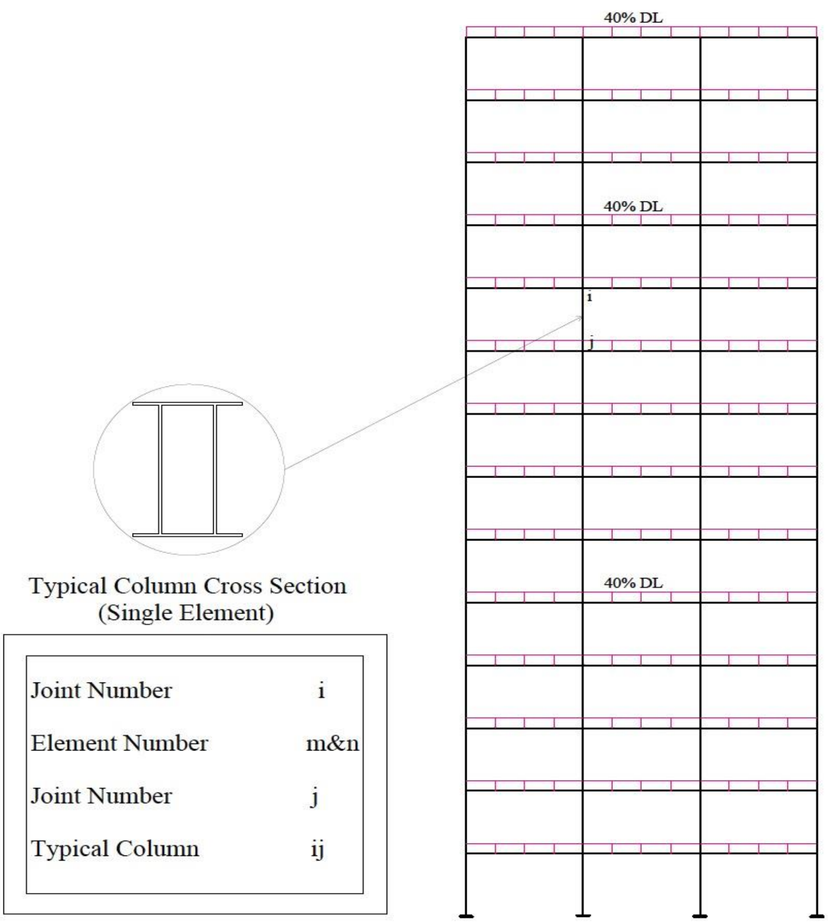


Fig. 1 - Typical Steel Frame (with or without "X" Bracing)

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 to be able to calculate axial, shear and bending moments of the steel and concrete columns separately (Fig. 2). The double columns were constrained at three points along the height to act like a single column.

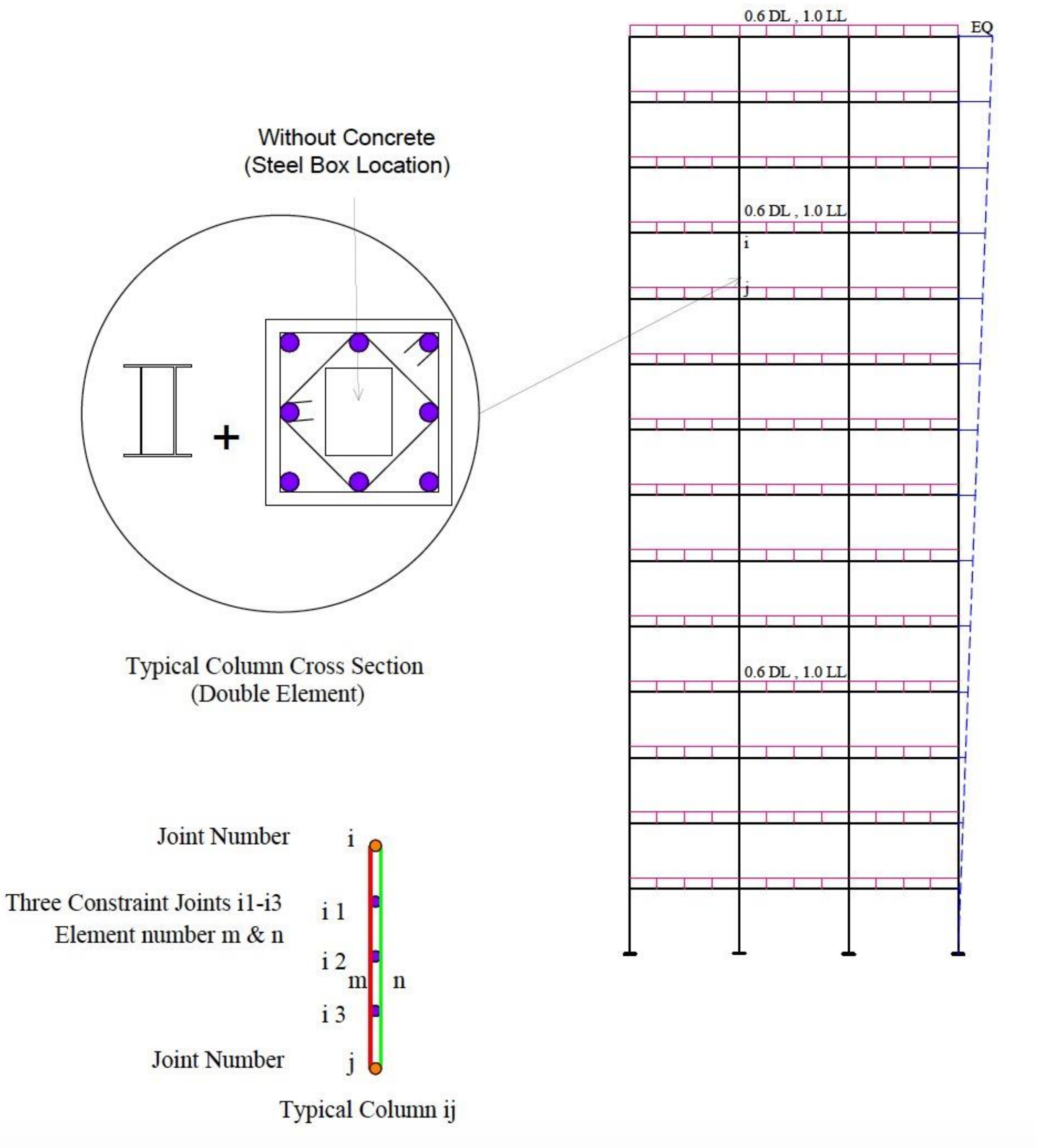
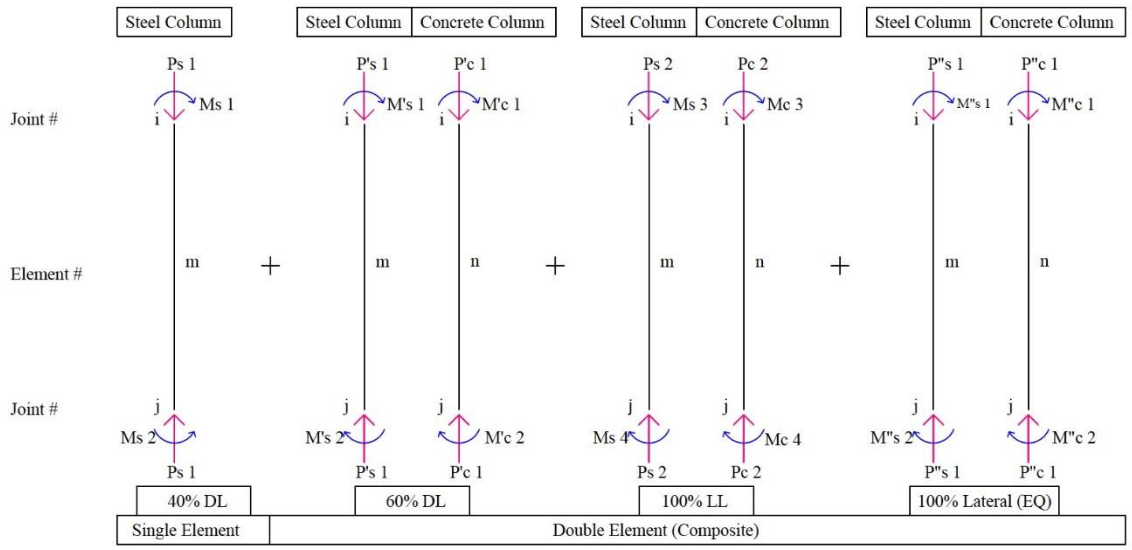


Fig. 2 - Typical Steel Frame (with or without “X” Bracing) with Composite Columns

The final stresses are a combination of the first and second models’ results per load and resistance factor design (LRFD) and strength method for the steel and concrete elements respectively. A computer program was written to collect the axial, and moment at top, bottom and mid height of all columns from the output file. Figure 3 shows the different loadings on single and double elements, and a sample of the AISC and American Concrete Institute (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

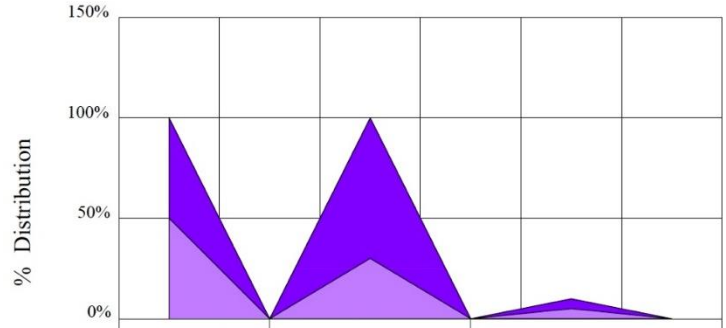
Fig. 3 - Loading on Single and Double Elements, and a Load Combination Sample

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

3. Conclusion

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 of the 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 made:

- 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 (Fig. 4);
- Increment of the concentrated loads on the footing caused by the new bracing systems, led to the footing reinforcement as well.



	Dead	Live	Earthquake
Concrete Column	50%	70%	10%
Steel Column	50%	30%	5%

Fig. 4 - Stress distribution on composite columns

4. Copyrights

5. References

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