Optimal versions of braced girder used in civil engineering, by Finite Element Method

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Abstract: This paper presents two optimized versions of a steel structure used in civil engineering obtained thru a process of structural optimization using Finite Element Method. The main advantage of these optimized structures is the cost which is 50% smaller than the cost of a standard version of this steel structure. The optimization process was made using Finite Element Method and Ansys program. The paper presents the results of structural optimization process and the static analysis of these optimized steel structures in two load cases: the snow weight and the seim simulation.

Key-Words: Finite Elements Method, Steel Structure, Civil Engineering, Structural Optimization, Ansys

1 Introduction
Steel offers much better compression and tension than concrete and enables lighter construction. Steel structures use three-dimensional trusses, so they can be larger than reinforced concrete counterparts. Computerized, high-precision stress analysis and innovative jointing allow an array of structures and shapes. Steel frame construction now predominates. Examples include the 200-meter Astro/Dome and Super Dome in the United States and Japan's Fukuoka and Nagoya domes. This paper analyzes the steel structures used for manufacturing buildings. These buildings are made from I section beams with large dimensions of the I section (78cm x 26cm), as in figure 1.

This kind of structure has multiple disadvantages because the weight of the steel is bigger and the welding process is difficult. So, the costs of these types of structures are bigger than they should be. Basically the optimization process, in this case, consists in improving an initial shape of the braced girder and the columns which sustain it. This searching was made by making different types of structural modifications of shapes and improving those which had a good behavior at snow and seismic loads. These behaviors were determined using linear structural static analysis in Ansys program. The initial shape of the braced girder, which was subjected to the process of structural optimization is presented in fig.2.

Fig.1 The present version of the steel structure

Fig.2 The initial shape of the braced girder
2 Problem Formulation

The overall equilibrium equations for linear structural static analysis are:

\[ [K] \{u\} = \{F\} \]

or

\[ [K] \{u\} = \{F^0\} + \{F^p\} \]

where:
- \([K]\) = total stiffness matrix
- \([u]\) = nodal displacement vector
- \(N\) = number of elements
- \([F^r]\) = reaction load vector
- \([F^a]\), the total applied load vector, is defined by:

\[ [F^a] = [F^{rd}] + [F^{ac}] + \sum_{e=1}^{N} \left( [F^{pe}] + [F^{pe}] \right) \]

where:
- \([F^{rd}]\) = applied nodal load vector
- \([F^{ac}]\) = \([M]\) \{ac\} = acceleration load vector
- \([M]\) = total mass matrix
- \{ac\} = total acceleration
- \([F^{pe}]\) = element thermal load vector
- \([F^{pe}]\) = element pressure load vector

For our case the two load cases are the snow weight and the seismic load:

\[
S = 1,3 \cdot G + 1,5 \cdot G_s + 1,05 \cdot U_k
\]

\[
E = 1,3 \cdot G + 1,05 \cdot U_k
\]

where:
- \(S\) – snow load;
- \(G\) – the weight of the steel structure including the roof
- \(E\) – seismic load;
- \(G_s\) – the weight of the snow (2000 N/m²)
- \(U_k\) – the effect of the structure exploitation
  \(U_k = 0,75\) [N/m²]

3 Problem Solution

The initial shape of the braced girder subjected to the process of optimization has an opening of 15 m and the height of the two columns of 4 m. The structure optimization steps are presented below. The results of static analysis of the braced girder are presented only on half of the structure because of the geometric symmetry.
Fig. 8 Forth version of the braced girder

Fig. 9 – Von Mises stress for the forth version during snow case load

Fig. 10 – Von Mises stress for the forth version during seism case load

For the forth version in the snow case load the Von Mises stress is uniformly distributed over the entire structure and the maximum value is 200MPa. The same situation is achieved during the seism load.

Fig. 11 Forth version of the braced girder

Fig. 12 – Von Mises stress for the forth version during snow case load

Fig. 13 – Von Mises stress for the forth version during seism case load

The fifth version has the advantages of the forth versions but the values of Von Mises stress in both load cases are a little bit higher. The maximal values of the stress are distributed on bigger areas.
Both optimized versions (forth and fifth) are made by beams with small sections:
- 40mm x 30mm x 2mm
- 15mm x 15mm x 1,5mm
- 20mm x 20mm x 1,5mm
- 60mm x 40mm x 2mm.
The joint of the beams is made by welding.

4 Conclusion
The optimization process has been successful and the final two versions of the braced girder (forth and fifth) can be used for steel structures. The analysis for the optimized structures show that the fifth version of braced girder has a little bit less rigidity then the forth version but is using less material because it is manufactured using only 3 trusses. Both optimized versions of braced girders have good behaviors for both load cases (snow and seismic) and they can replace the standard steel structures which use heavy beams with large dimensions I sections.
The main advantage of these lighter optimized versions is: 50% smaller costs because the weight of the steel structure is 3 times smaller then the standard structure, so we use 3 times less steel!

References: