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Progress in Steel, Composite and Aluminium Structures

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Fire resistant optimum design of a steel frame

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Keywords: Steel frames, optimization, minimum cost design, fire resistant design, beam-to-column connections, fabrication cost calculation.

In order to study the effect of fire, a relatively simple frame is selected as shown in Figure 1. This is simplified model of a central part of a three-storey building frame structure. The frame is unbraced. The column are constructed from welded square box section and the beams have a rolled universal beam (UB) profile. The frame is subject to vertical permanent and live loads (Fig. 1). In the fishbone model the beam ends are considered to be built up for vertical loads and pinned for horizontal ones.

The bending moment and axial forces acting on beams and column parts, together with the inner forces due to vertical loads have been calculated. The design constraints are as follows:

- Stress constraints for beams of UB profile (I beam without fire resistance),
- The stress constraint for the beam (with fire resistance),
- Stress constraints for welded box column parts (without fire resistance),
- Stress constraint for columns (with fire resistance),
- Local buckling constraint for welded box column profiles.

We have calculated the evolution of steel temperature and thermal properties at elevated temperatures, also the steel mechanical properties at elevated temperatures. The objective function is the total cost including material and fabrication costs also for beam-to-column connections.

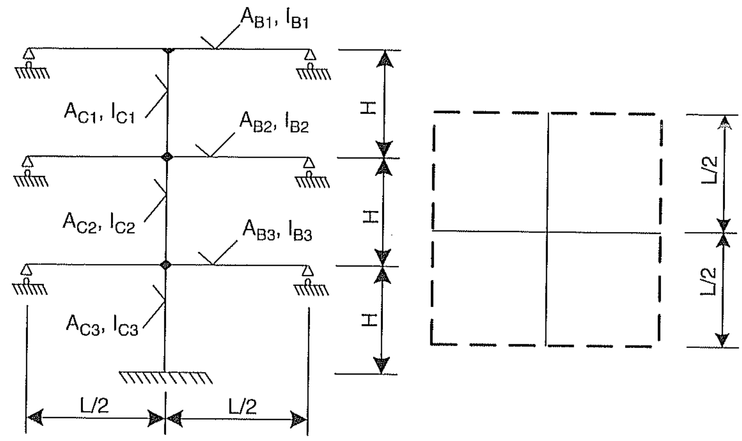

Figure 1. The investigated frame consisting of a column and 4 beams in each storey. The frame is a central part of a building as it is seen in the top view.

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Table 1. Optimum values of the three welded box columns and the three UB type beams without fire resistance.

b_{c1}/t_{c1} (mm)	b_{c2}/t_{c2} (mm)	b_{c3}/t_{c3} (mm)	h_{b1} (mm)	h_{b2} (mm)	h_{b3} (mm)	Cost ($)
241.9/7.3	266.4/8.1	378.2/11.5	419.0	393.9	418.8	**3884.3**
250/8	260/10	350/12	457	406	457	4180

Table 2. Optimization results for the frame (with fire resistance considerations).

Fire resistance time (sec)	b_{c1}/t_{c1} (mm)	b_{c2}/t_{c2} (mm)	b_{c3}/t_{c3} (mm)	h_{b1} (mm)	h_{b2} (mm)	h_{b3} (mm)	Cost ($)
0	283.0/10.9	331.1/10.3	363.4/12.4	419.3	394.9	419.3	4335.3
3600	193.1/31.8	258.7/23.4	258.7/30.4	443.6	416.6	425.4	5528.6
7200	182.8/66.3	193.8/69.9	227.2/61.7	450.3	401.0	434.9	6940.0

The cost function of the frame including the cost of connections are as follows: material, cost of design, assembly and inspection, cost of cutting, cutting of column parts, beams, diaphragms and shear plates, cost of welding.

A new and promising optimization technique is introduced, the particle swarm optimization (PSO). In this evolutionary technique the social behaviour of birds is mimicked. The technique is modified in order to be efficient in technical applications. It calculates both the continuous and discrete optima, uses dynamic inertia reduction and craziness at some particles.

Data of the calculated frame are as follows: the beam length $L = 6$ m, $H = 3.6$ m.

Optimization of steel frames for fire safety is a relatively new area. Using a relatively simple frame model it is shown how to apply the optimum design system for the case of fire. The cost function to be minimized is formulated on the basis of detailed cost calculations, including the fabrication cost of beam-to-column connections. The connection type is selected from several seismic resistant types by cost comparison. The calculation shows that optimization has a large effect. Due to the high material cost and the cost calculation method that the design, inspection and erection costs are proportional to the weight, the mass minima do not differ from the cost minima.

When we consider fire resistance, the time after which its elements still work, needs more material (steel) to be built into the structure. The present example shows, that about one hour increment in fire safety needs 42% more cost at the structure. For a designer it is important to know the relation between structural mass and fire safety. Further investigation will be the application of fire resistant paintings or other materials and to optimize for the cost of the structure. Also the next step is the combination of fire resistance and earthquake resistance design.

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