Robustness of airport space frame structure

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Abstract

We present a robustness analysis of an airport space frame structure. A finite element model was implemented which reflects geometry, material and section properties, constraints and loads as specified in the original design documents. The structure was modeled as a spatial truss composed by perfectly hinged bars, made of elastic material. Five main loading conditions were extracted from the original structural design report, which include the following actions: self-weight, other permanent loads, snow and temperature gradients. For each one of these loading conditions, the most stretched bar and the most compressed bar among the top layer, the bottom layer and the diagonals, were alternatively removed, and the stress variations in the remaining bars monitored. The same was done by removing the most compressed bar among the support diagonals. A total of 15 analyses with removal of the most stretched or the most compressed bar were run. The study gives basic information about the general behavior of the structure in case of accidental loss of a key element.

Keywords: metal spatial structure, space truss roof, airport, robustness, extreme event, buckling, tensile failure

1. Introduction

Space truss roofs are lightweight, convenient and economic solutions to cover large areas. Their structural efficiency makes them working with low safety margins even with respect to regular loading conditions. At the same time, their public function requires a maintenance plan including structural health inspections and checks for robustness against extreme events, like fire, explosion, accidental failure of an element, etc. [1-2]. As regards the latter, loss of tension bars can happen due to bolt failure, while loss of compression bars could happen due to flexural buckling induced by overloading or differential support settlements [3].

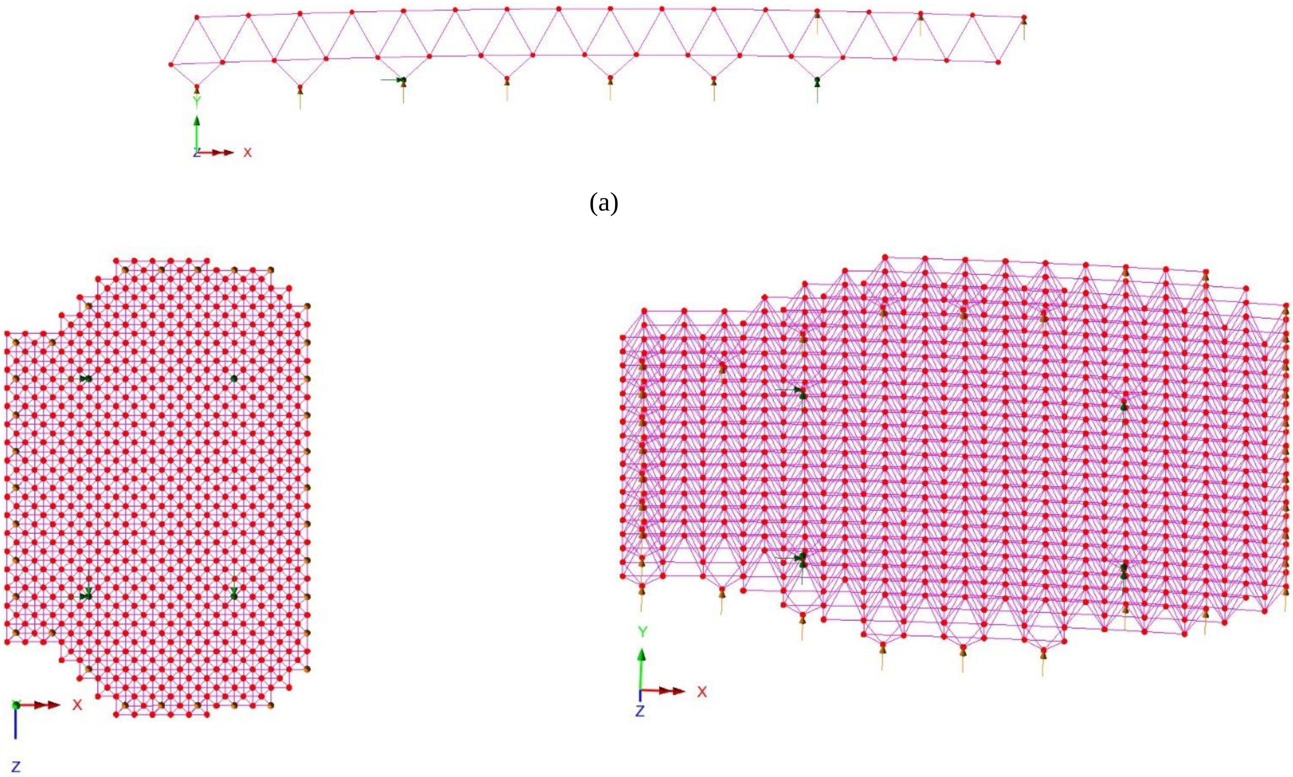
Here, we present a robustness analysis of an airport space frame structure. A finite element model was implemented based on the original design documents. The structure was modeled as a spatial truss composed by elastic, perfectly hinged bars. With respect to five main loading conditions, the most stretched bar and the most compressed bar among the top layer, the bottom layer and the diagonals, were alternatively removed, and the stress variations in the remaining bars monitored.

2. Structural model and analysis

A numerical model of the roof was implemented in LUSAS finite element code. Such model reflects geometry, material and section properties, constraints and loads as specified in the original structural report. The geometry has been inferred from the structural drawings. The structure was modeled as a space truss made of perfectly hinged, elastic bars. The model is composed by 796 nodes and 3013 bars (Figure 1).

The roof has maximum plan dimensions of (86.4×57.6) m and presents a small curvature in the transverse (shorter) direction (Figure 1a, b). The grid of the top and bottom layers is about (3.6×3.6) m, with slight differences in the transverse direction according to the curvature. The distance between the two layers is 3.2 m.

The roof is constrained in the vertical direction at 38 nodes, 34 of which are along the side dish and 4 are the in the central part; the perimeter constraints are able to react only in the upward direction, while the central ones are bilateral constraints (Figure 1). In the horizontal direction, the structure is constrained at 3 of the 4 central supports so to furnish two reaction points for each of two main directions (Figure 1b).



(a) (b) (c)

Figure 1. Finite element model of the analyzed space truss roof, a) side view, b) top view, c) axonometric view

The bars are constituted by circular hollow sections, made of steel S355, with the following eight diameters and thicknesses (in mm): 76.1/3.2, 88.9/3.6, 101.6/3.6, 114.3/3.6, 133.0/4.0, 159.0/4.5, 159.0/7.1, 193.7/10.0.

Referring to the structural report, the following load combinations were considered:

1. Self-weight + permanent load + snow.
2. Self-weight + permanent load + snow + uniform thermal variation.
3. Self-weight + permanent load + snow + non-uniform thermal variation.

The uniform thermal variation, applied to the whole structure, was equal to ±20 °C. The non-uniform thermal variation, applied to the top layer bars only, was equal to ±5 °C. The maximum nodal force, applied to the top layer nodes, was equal to about 29.808 kN for the inner nodes, and to its half for the edge nodes. Therefore, five main loading conditions were analyzed.

For each main loading condition, the most stretched bar and the most compressed bar among the top layer, the bottom layer and the diagonals, and the most compressed bar among the central support diagonals, were alternatively removed and the stress levels in the remaining bars checked. A total of 15 analyses with removal of the most stretched or the most compressed bar were run. The results of the analysis are summarized in the next section.

3. Conclusions

A robustness analysis of an airport space frame structure was conducted by a linear finite element model to investigate the global response to the accidental loss of a key element. With respect to five basic loading conditions, fifteen situations with alternative removal of the most stretched or the most compressed bar were considered. Based on the results obtained, the following conclusions can be drawn:

1. In none of the analyzed cases the removal of the most stressed bar is sufficient to transform the whole structure, or part of it, into a mechanism.
2. Among the loading conditions examined, there is always at least one case in which the removal of the most stretched or compressed element implies the overcoming of the tensile yield stress (355 MPa) and/or of the buckling load in the most stressed remaining bars.

3. Based on the previous Point 2, the situation of total absence of the most stretched or compressed bar is judged as not admissible, since it could impair bearing capacity in at least one other element.
4. Understanding whether or not the structure is able to withstand the previous extreme condition without collapsing would require a step-by-step nonlinear analysis.

References

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