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Analysis of longitudinal skylights structure made of rectangular tubes in industrial hall

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ABSTRACT

Based on the example of an existing industrial hall, an analysis of the behaviour of longitudinal skylights made of rectangular tubes with different types of beam-to-column bolted erection joints has been performed. The following types joints of tubular members has been investigated: existing according to execution design, recommended and implemented during its overhaul. The analysis has been undertaken due to the faulty design of an industrial hall's longitudinal skylights made of rectangular tubes which caused cracking of skylight wired glass panes. The static behaviour of the skylights as space structures interacting with the roof structure was subjected to analysis. Also the behaviour of the joints between the tubular members of the faulty and correct (recommended) skylight structures, and that of the hall's joints after their stiffening were analysed. Finally, conclusions and recommendations concerning the repair and proper design of skylights of this type, with a special focus on skylight joints, are presented.

1. Introduction

Steel frame structures made of square and rectangular tubes are becoming increasingly popular in the building engineering. The members of such structures are most often joined directly by welding. In such cases, one cannot avoid joining tubes differing in their dimensions directly to tube walls. Due to the specific characteristics of the tubes the walls deform inwards or outwards. This effect depends on the load transmitted from the connected element, and it is the stronger, the larger the difference in width between the joined elements. In the case of standard joints, it is necessary to take into account the compliance in them, which was discussed in [1] as well as in [2,3]. This can be avoided through a different design of the joints between tubular elements [4–6]. In the proposed solutions by rotating the elements along their longitudinal axis a joint with the square tube corner is made, whereby deformability in the joint is considerably reduced. In this way a joint similar to the ones used to join steel circular tubes can be obtained. Unfortunately such a solution of the joint is not always practicable in the case of square or rectangular tubes.

The analyses carried out in [1–6] dealt with welded joints. However, the concept presented in [4–6] could not be applied to the considered skylight design. Furthermore the joints between the tubular elements had to be made as erection joints, which made the use of bolts in the joints preferable.

Many of the wired glass panes in the skylights of the considered industrial hall became cracked (Fig. 1). The cracks ran vertically (Fig. 2a) or obliquely (Fig. 2b) and were caused by the excessive mutual displacement of the skylights' structural members, i.e. the frames and the longitudinal girts. The faulty design of the joints between the tubular elements, made as erection bolted joints, contributed to the displacements. Neither the interaction with the roof structure nor the compliance in the joints between the tubular elements had been taken into account in the computational model.

In tubular elements joined with bolts it is sometimes possible to use, as in [7], gusset endplates. However, this was not possible in the case of the considered structure. Therefore bolted joints with a similar structure as that of the welded joints described in [1] were made, but the effect of the compliance of the tubes' walls on the stiffness of the joints, having a significant bearing on the distribution of internal forces in the bars of the skylights, was neglected.

This paper discusses the cause of the failure condition of the skylights, to which the faultily designed joints and the incorrect static system of the structure contributed. The skylight structure is analysed as a space (3D) structure. A finite element analysis (FEA) of the joints is carried out. A correct solution of the joint and a way of repairing the joints are proposed.

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Fig. 1. Long skylights in industrial hall bay A–B between transverse systems 2–6.

2. Condition of industrial hall's steel frame structure, its skylights and joints

The considered industrial hall is a two-bay structure rectangular in plan, with the following dimensions between the axes of the external columns: length – about 175.6 m and width – 40 m (Fig. 3). Along its length the hall is divided into two unequal segments (one about 125 m long and the other 50 m long) by an expansion gap (0.6 m). In the transverse direction the hall has two bays with column axes A, B, C spaced at every 20 m. Crosswise the roof over each of the bays is a gable roof with its eaves and valleys running along the axes of the columns of the transverse systems. The above-ground height of the hall in the eaves and valley zone is about 8 m and in the roof ridges (in which longitudinal segmental skylights are situated) it amounts to about 12 m.

The hall transverse systems are plate-girder frames with bay spans of 20 m, spaced at every 15 m. The frame systems located near the expansion joint and the end frame system (situated at a distance of 20 m from the end wall) were designed differently. Single-span truss purlins with their span adjusted to the spacing (15 or 20 m) of the transverse systems rest on the rafters of the frames. The purlins are spaced at every about 2.5 m or 5.0 m on the roof (see Fig. 3).

The truss purlins (both 15 m and 20 m in span) were made as: under-skylight purlins, intermediate purlins and valley (eaves) purlins, differing in the dimensions of their top flange and in height. The valley (eaves) purlins are spaced at every about 2.5 m and their top flanges are joined together by a longitudinal roof bracing. The under-skylight purlins are spaced at every 5.0 m and constitute, among other things, the support structure for the transverse frames (spaced at every 1.2–1.25 m) of the longitudinal segmental triangular skylights located in the roof ridges of each of the bays. The skylights located along the hall differ in their length. At the beginning of the hall there are 45 m long skylights (Fig. 1), followed by 22.5 m long intermediate skylights and 12.5 m long "short" skylights.

The supporting structure of the skylights (Figs. 4 and 5) was designed to be made (and was actually made) of steel St3S (S235) rectangular tubes (cold-formed hollow sections). The grade of the steel was experimentally verified by tensile testing. The skylight transverse frames made of 100 × 50 × 3 mm tubes, spaced at every 1.2–1.25 m along the purlins, were joined together in the side walls by girts made of 50 × 30 × 3 mm tubes and in the roof ridge by girts made of 50 × 50 × 4 mm cold-formed L-sections. The glazing of the skylights is made of insulated glass units consisting of a 6 mm thick

Fig. 2. Cracks in skylight panes: (a) vertical, (b) oblique.