Engineering Failure Analysis 45 (2014) 245–251

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Steel roofing disaster and the effect of the failure of butt joints

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ARTICLE INFO

Article history:
Received 17 April 2014
Received in revised form 8 June 2014
Accepted 6 July 2014
Available online 12 July 2014

Keywords:
Building failures
Disasters
Failure analysis
Joint failures
Reinforcement

ABSTRACT

This article scrutinises the causes of a disaster of a pitched roof construction made of welded plate girders. The girder construction elements were assembled with bolted butt joints. The roofing was made of a folded sheet supported by steel purlins that transferred the load onto welded plate girders. The purlins had no roof bracings. In the analysed case, several days of abundant snowfall preceded the failure that caused a collapse of the roof of a production hall. The investigations that followed confirmed that the collapse started with the cracking of the bolts used to centrally join the roof girders. In the course of the analyses and calculations, it was established that the main cause of the disaster lay in a faulty design of the butt joints between the segments of the steel plate girders. Another factor having impact on the failure was the numerous mistakes in the design and fitting of the steel purlins. The excessive snowfalls were not the main cause of the disaster but were only an additional one. The article also provides a concept for the reconstruction of the damaged building and provides additional details concerning the refurbishment phase.

1. Introduction

Abundant snowfalls have often been identified as a common indirect cause of roofing failures throughout Europe. The average snow depths frequently exceed the values stipulated in the current construction standards [1], leading to emergency situations or even to construction failures in many buildings, e.g., the collapse described by Biegus and Rykaluk [2]. In the analysed case, several days of snowfall with temperatures of approximately 0 °C caused the collapse of the steel roofing of a production hall belonging to an industrial plant located in Poland, central Europe. Because the catastrophe occurred at night, there were no casualties and nobody was hurt. An overview of the roof construction damage is shown in Fig. 1.

2. Analysis of the constructional design

The destroyed building was one of the subsidiary units of an industrial plant. The facility had a frame construction that used precast reinforced concrete columns with variable cross-sections. In each of the columns, two brackets sustaining crane beams, and roof girders were used. The roofing was made of corrugated folded sheet supported on steel purlins that transferred the load onto welded plate girders with an I-beam cross-section. The purlins, which had a length of 9.0 m, were made of hot-rolled I-beams with a height of 200 mm and had no roof bracings. Double pitched roof girders with a span of 12.0 m, arranged with a 5% slope, were positioned every 9.0 m. Fig. 2 presents the arrangement of the construction elements in a chosen part of the building. The plate girders, formed from H-type welded structural steel, were joined centrally by means

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http://dx.doi.org/10.1016/j.engfailanal.2014.07.008
1350-6307/

Fig. 1. Overview of the collapsed roofing construction.

of four bolts with a M24 ISO metric screw thread (Fig. 3). The joints in the support zones were formed by anchoring steel girders in the brackets in the reinforced concrete columns. The anchors were formed by two ϕ 25 mm bars with M22 ISO metric screw threads. The strength of the concrete in the column support zones, as determined by non-destructive testing, corresponded to the C20/25 class. The designed socket-type spot footings were made of reinforced concrete. Autoclaved aerated concrete (AAC) blocks, each 38 cm thick, were used to build the external curtain walls. An expansion gap separated the entire structure of the discussed production hall from the main part of the industrial plant.

3. Damage extent

The extent of the damage caused by the disaster was preliminarily evaluated on the macroscopic scale by visual inspection. The damage affected the production hall but did not spread beyond the expansion gap to the main multi-storey brick part of the building. The catastrophe resulted from the cracking of the bolts joining the roof girders centrally. During the first stage of the disaster, the roofing construction, the principal structural elements of which were composed of plate girders, collapsed and broke into two parts under the strain of the snow layer. Fig. 4 presents the condition of the hall's interior several hours after the incident.

During the collapse, after the failure of the central butt joint, the pivot edges of the segments of the girders were located in the beam supports on the reinforced concrete columns (Fig. 5). The ends of the steel girders, anchored in the brackets of the short columns, damaged the reinforced concrete sustain zones during the course of their rotational movement. The steel anchors, 25 mm in diameter, underwent plastic deformation, which in turn led to local necking down, a decrease in the cross-section area, or severance of the bars. In effect, the concrete beam supports were completely destroyed. The various forms of the ensuing damage are presented in Fig. 6.

Note that the fragmented parts of the damaged roofing reached a state of unstable equilibrium as the roof beams found support on the non-bearing concrete floor and on the longitudinal walls of the building made from AAC blocks. Some of the roofing elements also rested on the equipment and devices remaining in the hall at the time of the disaster, causing their total destruction (Fig. 4).

Moreover, in the brick part of the facility, behind the expansion gap, cracks appeared on the partition walls supporting the central joints of the roof girders.

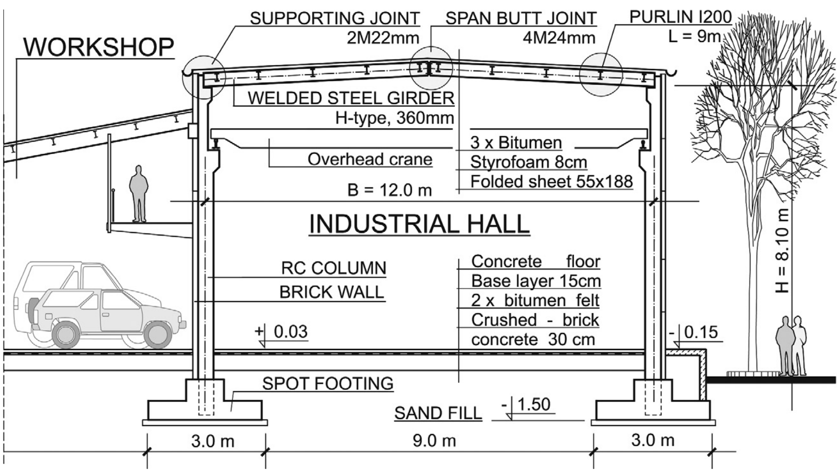

Fig. 2. Cross-section of the industrial hall and the arrangement of the structural elements.