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Partial collapses experienced for a steel space truss roof structure induced by ice ponds

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ABSTRACT

This paper presents investigations on the steel space truss roof of an industrial plant collapsed partially after exceptional snowfalls. This low sloped light weight roof structure supported on steel columns of 16.3 m height and covering totally 26,080 m^2 closed area in plan was constructed as Mero type double layer grid steel space truss system having a height of 2 m. Also, parapets of 90 cm height were placed along the perimeter of the building and siphonic system was used for roof drainage. To find out the main reasons of the partial collapse of the roof structure, a site investigation was conducted and findings were collected, then conformity of the structural members were checked with respect to the current Turkish steel building design codes. The material properties of the primary load carrying members of the roof were scrutinized by performing tensile tests. Finally, it was understood that two unexpected catastrophic collapses were experienced as a consequence of ice ponds that occurred on the edge regions of the roof due to discontinuously heated roof parts by the radiant heaters mounted on the roof structure and the freezing of the siphonic system.

1. Introduction

Buildings such as industrial halls, exhibition centers, airport terminals, and shopping malls are large span structures generally having a flat or low sloped light weight steel roof construction. In recent years, steel space truss roofs are preferred and commonly designed by architects in Turkey. However, structural failures or even catastrophic collapses based on improper design, underestimated design loads, unexpected extreme loads, improper manufacturing, poor workmanship, etc. are reported worldwide [1–4]. Similar to conventional steel structures, these light weight roofs can be subjected to extreme weather conditions such as incidental, short-lasting heavy rain showers as well as strong heavy snow falls. Additionally, these roofs subjected to unbalanced snow accumulation and ponding may experience failure or collapse if the current drainage system is not designed accurately or is not functioning properly due to maintenance issues. Furthermore, the same threat exists for these roofs surrounded with parapets whenever the regular drains are blocked and/or there are no secondary emergency drains such as gullets and scuppers which should be also designed to accommodate for the flow capacity that is not less than that of the primary drainage system [5,6].

Due to offering significant advantages to architects as well as mechanical engineers siphonic roof drainage systems for spacious flat or nearly flat roofs are widely used for approximately 30 years in Turkey. This system coupled with a network of horizontal and vertical pipes operate under the full bore flow, i.e. the steady state hydraulic pressure and has to be designed for sufficient capacity to accommodate for flow of the design storm considered. In this respect, the hyetograph expected for the geographical location of the building as well as the maintenance issues are very crucial, otherwise it may be possible to experience an

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inefficient operation of non-siphonic mode, or flood may occur due to insufficient drainage capacity. Additionally, it is also reported that when the intensity of the rainfall increases then partial unsteady depressurisation occurs on the system which can result in noise generation as well as in structural vibration. When the rainfall event occurs below the design consideration, then installation problems appear as a major disadvantage of the siphonic drainage system and can cause operational failures [7–11].

2. Description of the roof structure

The industrial factory located in a big city of West Anatolia is established for packaging of glass wares in November 2011. The load bearing system of this plant consists of 5 individual structural systems separated by expansion joints where each of the main 4 halls crosses a span of 160 m × 160 m in plan by covering a 25,600 m^2 area totally (see Fig. 1). The roof structure supported on steel columns of 16.3 m height has a Mero type double layer grid steel space truss system. While the height of the space truss is 2 m, the modular dimensions used for main halls are 333 cm × 333 cm. Roof 5 of the shelter adjacent to Roof 1 has modular dimensions of 300 cm × 333 cm and covers a small area of 480 m^2. Totally 84 steel columns resist these 5 roof constructions by using pin jointed supports attached on the top of the columns where the lateral movements in two horizontal directions are allowed to move freely, while the vertical displacements are not permitted.

Space truss bearing system is formed by the upper and lower chords and web members having tubular sections. To connect these members to each other by using steel spheres, screwed cones which are welded on the both ends of the pipes are used. In joint assemblies, hot-pressed forging spheres have flat facets and screw thread holes tapped for bolts. Tightening bolts by means of hexagonal sleeve and dowel pin arrangement for the straight truss members of tubular sections, it is possible to construct proper connections without showing any eccentricities. As a consequence, axial forces can only develop as expected in this design. The structural system of the Roof 1 and Roof 3 consists of 1297 joints and 4988 tubular members where 1324 joints and 5094 pipes are used for Roof 2 as well as Roof 4. For the Roof 5 of the shelter, 145 joints and 508 pipe members exist.

On the perimeter of the roof, parapet walls with a 90 cm constant height are designed continuously. The roof over the 4 main halls is constructed as a saw type two gabled roof with a slope of 2%. Totally 3 siphonic system lines on the lower parts of this roof are designed parallel to each other, just in the middle and along the two eaves of the roof so that the rain water will flow down from the ridge to the siphonic lines crossing 40 m distance utmost. No secondary gutters or scuppers are planned to be constructed for emergency situations. As the roof covering, trapezoidal steel sheeting with glass wool is used.

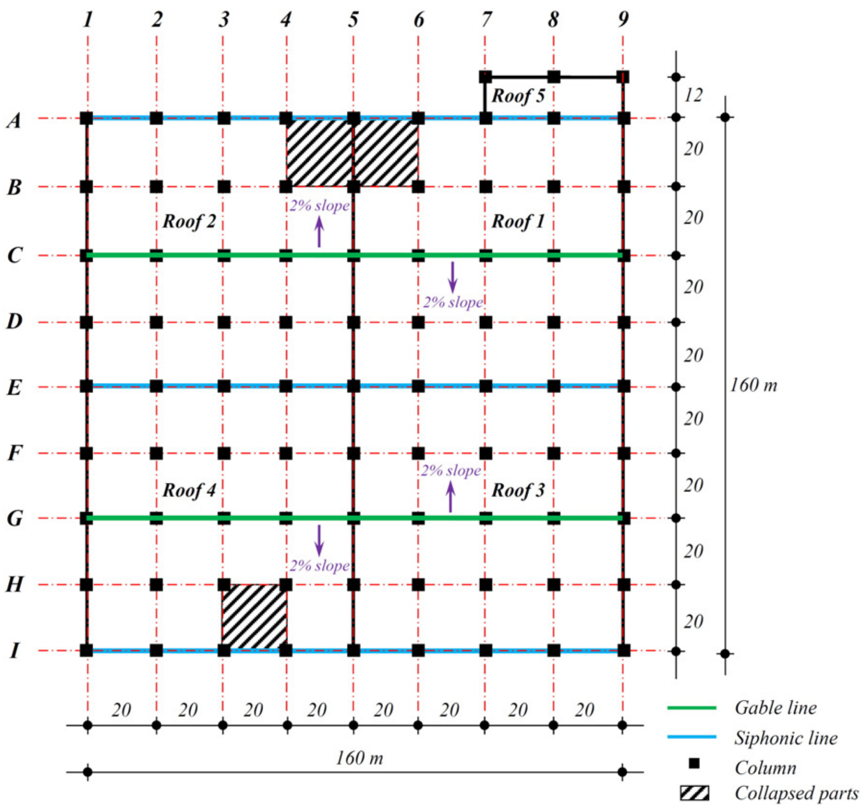

Fig. 1. Plan view of the roof of the industrial structure.