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Collapse and Rehabilitation of Composite Trussed Structures

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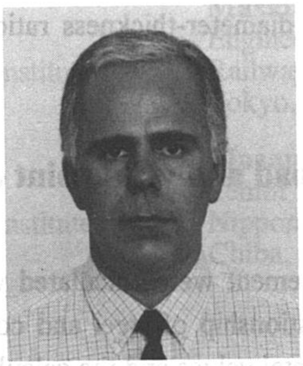

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Summary

A failure case of a 2.400 m^2 area of an industrial roofing structure is presented. The investigation leading to the cause of the disaster, the numerical and experimental study using reduced models the rehabilitation procedures for the remaining part of the structure are described. Conclusions are also drawn concerning the application of external tension reinforcements to restore the original load capacity of the structure.

1. Introduction

Composite steel-concrete trussed members are widely used in Brazil as supporting structures for roofing large industrial facility areas, and the complete lack of maintenance in such structures is for certain the main cause of serious problems of deterioration and corrosion.
The case in study concerns one of such structures, used to shelter an industrial area enclosing an environment with strong emissions of chemically active dust and vapours.
The whole building structure of 12000 m^2 is divided into four sections, constructed from 1960 up to 1987, and containing different structural models for the trusses.
Trusses of type I consist of a two span indeterminate structure of 51 m long. Trusses of type II are simply supported, 30 m long structures, covering the collapsed area. Both are constructed in reinforced concrete but have unprotected steel bars as the tensioned diagonals. The type II truss, however, has no diagonals in the central frame.
Trusses of type III and IV, more recently constructed, were in good conditions.

2. Investigation of the Collapsed Area

The collapsed structure was composed by seven type II trusses. Many nodes were ruptured and showed they were not properly reinforced as plane frame nodes.
Corrosion in the exposed bars was more evident near the lower nodes, where the bars were immersed in a thick layer of chemically active dust, accumulated over the years. One of the ruptured tendons had its cross sectional area reduced by almost seventy percent.
Four other trusses of the same type, however, were still standing. A weak connection was observed to link those two areas. Rupture at this point certainly occurred before any sufficient overload could be transferred to the neighbour trusses, and the collapsing wave was stopped.
The inspection was extended to the rest of the building and showed that trusses type I, covering the main building area, were also very deteriorated. It was further observed that some of the steel bar diagonals were completely loose, subjected to no tension.

3. Numerical Analysis

Considering the pre-cracking stiffness of the nodes, a plane frame finite element model was used for the analysis of the trussed structures.
A first analysis was made for trusses type I and II, considering the original design properties. It confirmed that two of the steel diagonals in trusses of type I had no tension whatsoever.
Further investigative analyses showed that if the continuous trusses type I were considered as two separate, simply supported spans, all member would have been well dimensioned and those diagonals properly tensioned.
All evidences pointed to the conclusion that the trusses were originally intended to be separated and, for some reason, constructed as continuous over the internal support.
A second analysis was performed for trusses type II considering the measured properties of the materials and the reduced sections of the steel diagonal bars. The result showed that the tensile force in the ruptured and deeply corroded diagonal was beyond its reduced area capacity. The remaining members were not overstressed.
Rupture was expected to have begun in that diagonal and caused failure of the whole structure.
A third analysis was made withdrawing that particular bar from the structure. The moments at the nodes of that frame raised up to extremely high values, far beyond its capacity That would certainly create a mechanism and destroy the structural symmetry, leading to a unavoidable failure mechanism of the whole structure.

4. Design of the Reinforcement

The continuous trusses type I and the remainig and trusses type II, not affected by the collapse, were completely rehabilitated and strengthened for restoring their original load capacity.
An external reinforcement was devised using epoxy glued steel plates around the nodes, also fixed with bolts, in which steel bars were welded. The reinforcement was placed parallel to the tensioned diagonals and as new crossed diagonals at the central frame of trusses type II.
Reinforcement was also positioned at the bottom cord of trusses type II and the top central cord of the continuous trusses type I, to help supporting its constructively created continuity.

5. Experimental Analysis

Reduced models have been very didactic for the learning process of engineering students.
The case in study would perfectly fit its purpose and two reduced models made of microconcrete and galvanised wire were built. One to reproduce failure of trusses type II and another, exactly alike, to test the effectiveness of the reinforcement.
Both 400 by 38 cm models were positioned in a testing frame and instrummented for the measuring of nodal displacements and strains at the bars, nodes and reinforcement.
The first model was loaded, at each nodal point, and behaved very linearly. To reproduce the corrosion rupture of the steel diagonal a thin saw was used to slowly reduce its cross section.
After cutting over half section, the bar suddenly ruptured and the moments at the nodes of the same frame increased abruptly. The very same, numerically predicted, failure mechanism was formed and the structure suffer an immediate collapse.
The second model was subjected to service load, as the first one, and behaved alike. Maintaining the load, the reinforcement was placed, as it would be done in the prototype structure.
The external loading was eventually increased by fifty percent. The model responded stiffer and tension was properly transferred to the reinforcement, as expected.
Like in the first model the diagonal bar was also cut, and now its force was adequately transferred to the reinforcement. The external load was again increased by fifty percent and the reinforced model was able to sustain it very adequately.

6. Conclusions

The strengthening procedure was considered adequate and built in the real structures. The most convenient feature of this technique consist on its economy and simplicity. The structure may be strengthened while supporting the service load and there is a minimal disruption on the production process in operation.