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Geometrical and Structural Imperfections of Steel Member Systems

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Abstract

The paper is focused on the influence of geometrical and structural imperfections in selected load-bearing steel structures from the point of view of the whole load-bearing system. Implemented member steel structures show a varying degree of shape and structural deviations from the presumed idealized state. As a rule, these imperfections arise in manufacture of the structure, its assembly and in use of the structure. These imperfections can have a considerable impact on the structure behavior. Impact analysis of these imperfections is made using selected examples of particular types of load-bearing steel structures as for their load-carrying capacity and serviceability.

Keywords: Geometrical imperfections; structural imperfections; steel structures; industrial buildings; static design; diagnostics.

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1. Introduction

In previous decades a large number of halls with steel load-bearing structures were realized. The buildings were mostly designed for industry, but also served as sports and exhibition halls and pavilions. The need for modernization is gradually emerging for these objects - both in connection with the related units (including roof covers), the installation of new technological equipment, and the technical condition of load-bearing steel structures, including the elimination of defects and failures. In these cases it is necessary to verify the static function of the load-bearing structure as a whole as well as its individual parts. In recent years there has been a transition to a new system of standards ČSN EN [1], together with the determination of standards that change the climate loads on the structures. Generally, a higher intensity of these effects leads to a search for and use of reserves in individual parts of the structure. However, all relevant factors must be considered as well – particularly the imperfections that have an adverse effect on the operation of load-bearing system as a whole

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and its individual members and structural details. Thus the imperfections may limit the load-bearing capacity of the structure.

Using specialized software, current design procedures enable to make a sophisticated analysis of the structural system, leading to a more objective evaluation of the behavior of the structure under load. Moreover, slender members were often used in the second half of the 20th century. Together with real (and often occurring) imperfections they can substantially influence the behavior of the structure.

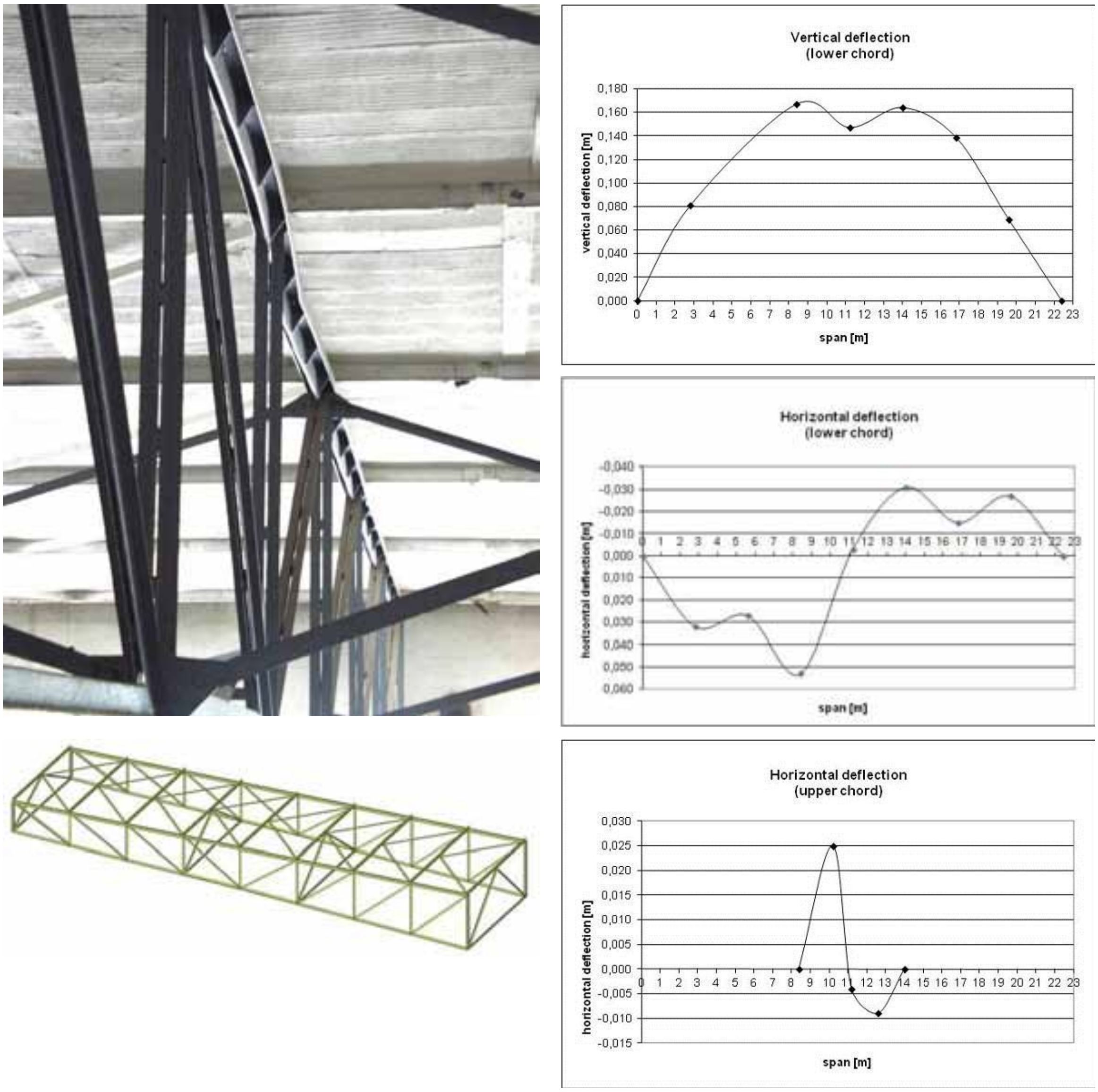

Fig. 1. (a) the geometrical imperfection of the roof girder; (b) the analysis model; (c) lack of verticality; (d) lack of straightness of the bottom chord; (e) lack of straightness of the upper chord [2].

2. Global imperfections of load-bearing systems

Global imperfections that occur in most load-bearing steel structures have largely a geometrical and structural character. Given the large variety in load-bearing steel structures, we are going to focus on the hall structures. A number of imperfections of the whole load-bearing system and local imperfections of individual elements belong to the group of geometrical imperfections as defined in [1]. The most important geometrical imperfections of the load – bearing system of the roof with trusses are excessive lateral deflections of compressed or compressed and bent chords of trusses in horizontal and vertical direction (see Fig. 1 and Fig. 3b). They may have static causes due to insufficient cross-section dimensions of members with respect to their strain. In a number of cases these can be attributed to an incorrect static calculation in combination with a low-quality of manufacture and an incorrect assembly. Typical geometrical imperfections include lack of verticality of truss girders and their initial lack of straightness. These factors result in increased additional stresses of individual members, especially compressed chords of trusses as well as their connections. They also lead to increased strains in the roof bracing systems. Geometry of the load-bearing system as a whole can be adversely affected by deformation and slip in connections.

In the Fig. 1 are shown geometrical imperfections of the upper chord of a roof truss [2]. According to geodesic measurements, maximum horizontal deflections of the bottom chord were up to 50mm, in the upper chord they amounted to 25mm and vertical deflections of the bottom chord reached up to 160mm. Local imperfections of the upper chord lead to occurrence of mostly bending moments in the horizontal plane and the resulting stresses are increased by 75MPa. Lack of verticality of truss girders, caused by different horizontal deflections of chords, is manifested by an increase of bending moments both in horizontal and vertical planes. The stress in the upper chord is increased by about 15MPa and in the bottom chord 95MPa.

Fig. 2. Deformation of chords of the longitudinal bracing at the gable wall [3]. The horizontal deviation measures 170mm, which makes about 1/50 of the span. The load-bearing capacity of the member fell under 20% of its original capacity. The deformation of the bracing indicates that it could be loaded by horizontal actions from the gable wall.

Imperfections can also occur as a result of roof cover failures, which contribute to ensuring stability of load-bearing members (mostly rafters, purlins, trusses and girders). The causes of roof cover failures may comprise damage to the integrity of the original roof cover by additional interventions (e.g. making holes in the cover), mechanical damage (local overloading), and unprofessional reconstruction (replacing the original cover by lightweight cover of a smaller stiffness). Some materials can be damaged due to leaking roofs (timber elements of the cover such as roof panels). These factors can also increase the strain of bracing members, including their connections, accompanied by a total roof deformation in the horizontal direction (see Fig. 2, 3a).

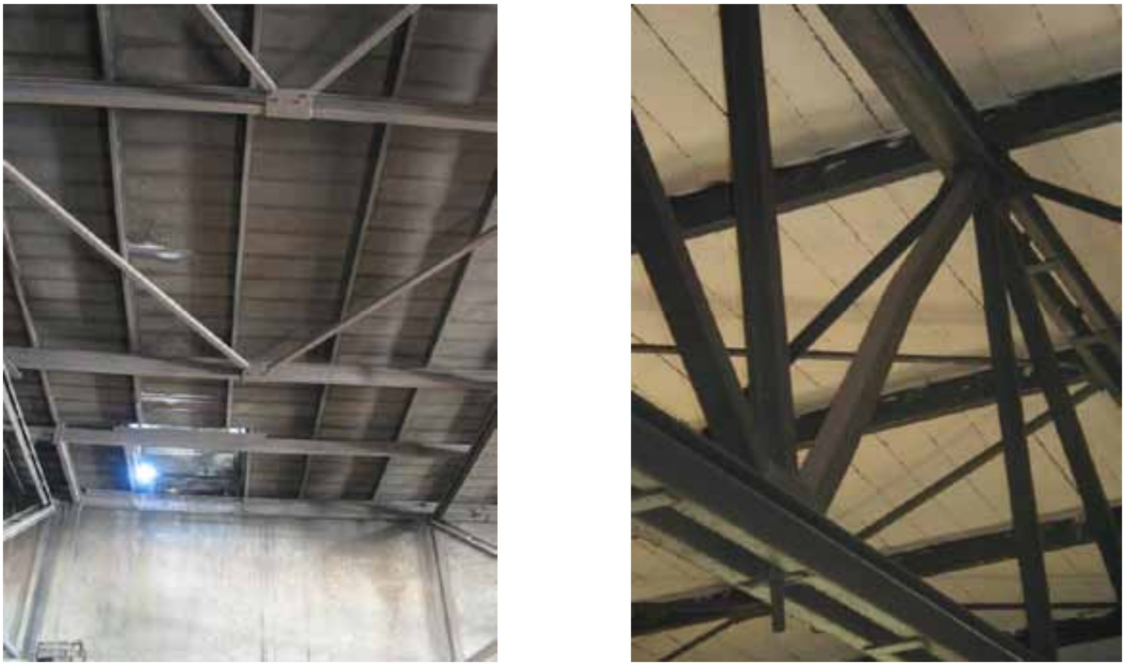

Fig. 3.(a) In the renovation of the roof structure, bracing diagonal members were removed without being replaced. Owing to this change the bracing lost its load-bearing and bracing function [3].

(b) Deviation of a compressed diagonal of the roof truss [4]. The measured imperfection 35mm (i.e. 1/130 of the length) causes additional bending stress of the member of about 100MPa.

This group of geometrical and structural imperfections may also include missing members of the load-bearing system that were removed from the original system. As a rule, it is a case of bracing members. There are also cases of removing internal members of trusses. Removal of members can constitute a significant, negative change in the static system of the entire structure and possibly it may lead to a loss of stability of the structure.

The geometrical imperfections of partial members of load-bearing steel structures include both imperfections caused by external factors and influences of the static character. Imperfections caused by external factors are often caused by mechanical damage or by incompetent interference while creating space for other parts of building. Static reasons may be caused by the influences which were not accounted for in the original design. For example, the snow drifts on the roofs with different height levels or additional loads from added technological equipment, distribution of ventilation or air conditioning. A replacement of the roof cover can also negatively impact on the structure behavior.

Truss imperfections are caused by applied loads acting contrary to original assumptions, both in terms of intensity or position. These loads cause additional bending moments in the members, or increase the values of normal forces, or there can be a change in the type of strain. This can be exemplified by a replacement of the original roof cover with a new, lower weight roof cover without corresponding static verification of the structure. In certain areas of the roof, the wind suction effect may give rise to the compressive forces in the bottom chords of trusses. Chord members are often made from slender built-up members. Given the high slenderness they are not able to withstand the increased compressive stresses and they can buckle. Purlins with unacceptable imperfections are frequently due to an increased intensity of loading (e.g. snow drifts), additional load from the changes in bracing effect (compressive forces in the purlins, which constitute a part of the bracing system) or local overloading (e.g. mounting points for repair or installation of technological equipment). A change in the intensity and the position of loading can generate additional strains from bending and torsion, particularly in purlins with open sections. If purlins are not efficiently secured against loss of lateral and torsional stability, the safe load-bearing capacity can be exceeded and the serviceability may not be satisfactory.

The introduction of geometrical imperfections in the static analysis requires a detailed geodesic surveying of the significant points of individual components of the load-bearing steel structure. The values of geometrical imperfections measured in the given cases significantly exceeded the values according to the standard [1]. The impact of geometrical imperfections was considered in computational models on the basis of the second order analysis. Increased stresses of the individual members have a direct impact on their joints and connections. Structural imperfections depend on real execution of structural details – connections, joints and support details. Welded joints are usually made simultaneously with the manufacture of the structure, i.e. their quality is reasonable. Problems can be posed by insufficient dimensions of welds, and the fact that the spacing of welded connections does not correspond to their strain.

Bolted joints in structures function mainly as assembly joints (see Fig. 4). They often have to compensate for an inaccurate assembly (including manufacturing) and this corresponds to the occasionally low quality of their execution. In the connections there are excessive bolt holes, holes in the elements and node plates are sometimes additionally re-drilled, which does not comply with the specified spacing between bolts and the distance of holes from the edges. As a consequence, these factors result in reducing the load-bearing capacity of connections in the transverse strain and especially in the slip of joints, which leads to an increased deformation of the structure as a whole.

Fig. 4. Wrong drilling of the bolt connection of a cross roof bracing diagonal as a consequence of inaccurate assembly of the structure [4]. The load-bearing capacity of this connection reaches only about 60% of the designed connection capacity.

Mutual member connections in nodes (including support nodes) are usually designed in a theoretical point of intersection. The real execution is frequently different. Thus, eccentricities are generated in the nodes, which cause additional strains in connected members. The problem can be posed by nodes with insufficient stiffness, which were sometimes designed and used for spatial roof structures erected in the 1950's or 1960's. The increased stressing of members by bending moments, due to eccentric connections, are particularly significant in the systems made of slender members with open sections.

Supporting of the roof structure is usually analyzed as rigid or sliding support. The possibility of sliding and rotation in the place of supporting becomes important in the systems with open, thin-walled cross sections. If the free sliding and rotation are not provided, or sufficient rigidity of rigid supports is not secured in the horizontal direction (for example, caused by deformation of the anchor elements) then it results in increased strains in the members located mainly in areas of support. These additional force and moment effects can be unfavorable namely for open, thin-walled cross-sections.

Therefore the computational models should take into account and reflect potential imperfections of load-bearing structures. This includes modeling of the geometrical shape of the structure, intensity of load actions, introduction of eccentricity in the connections and supports of the construction and above all interaction between the individual planar structural parts which together form the spatial system.

3. Conclusion

The aim of this article was to explore the geometrical and structural imperfections of the existing roof structures objects. They particularly comprise the structures of power generation facilities, which were the object of research and analysis at the Brno University of technology, Faculty of Civil Engineering, Institute of Metal and Timber Structures. The need to take into account geometrical and structural imperfections in the analysis of the statics arises primarily in the conversion of existing steel structures in connection with their rehabilitation or reconstruction. In many cases, these structures, which did not have regular maintenance for many years, are often in a bad state of repair. Neglect or inadequate attention given to the imperfections could have a serious impact on the safety and reliability of structures. Generally, the impact of individual imperfections on the resulting action of members and entire structure cannot be unambiguously quantified. The same type of imperfection can have a different importance, depending on a particular type of structure and its configuration.

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