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EVALUATION OF THE ECONOMIC EFFICIENCY OF HONEYCOMB GIRDERS OF ROOFS OF INDUSTRIAL STEEL-FRAMED BUILDINGS

TOBIAS PETERSEN, MANUEL KRAHWINKEL, and MATTHIAS BEHRENS

Innovative Bauweisen und Baukonstruktion, HafenCity University, Hamburg, Germany

A honeycomb girder (HCG) is defined by a mirror symmetric composition of two trapezoidal corrugated steel sheets (TCSSs). Mechanical fasteners such as screws or rivets connect them. This connection creates a honeycomb-like profile, which permits double height and thereby explicitly improves the stiffness compared to a single TCSS. The present paper investigates the economic efficiency of HCGs in the application as a cladding of roofs and facades of industrial steel-framed buildings. The typical primary structure of industrial steel buildings consists of steel frameworks, which where arranged in an equidistant manner. Orthogonally to the span direction of the steel frameworks TCSSs span between them, catch wind and snow loads and conduct the forces in the primary structure. Based on a numerical parametric study on the load carrying behavior of HCGs under bending 30 different industrial steel-framed building systems where structurally designed due to the rules of Eurocode 3. The investigated systems differ in framework distances, framework width and snow loads. By comparing the determined steel tonnage of each system with the steel tonnage of a reference system, which is constructed with commonly used TCSSs, the economic efficiency of HCGs in the application as a cladding of roofs and facades of industrial steel-framed buildings becomes evaluated.

Keywords: Cold-formed, FEM, Thin-walled, Light gauge, Simulation.

1 INTRODUCTION

The present paper investigates the economic efficiency of honeycomb girders (HCGs) made of trapezoidal corrugated steel sheets in the application as a cladding of roofs and facades of industrial steel-framed buildings. On the basis of a numerical parametric study on the load carrying behavior of HCGs under bending, which is published in a first paper of these proceedings (Petersen and Krahwinkel 2015), 30 different steel-framed building constellations are designed in accordance to Eurocode 3 (DIN EN 1993-1-1 2010, DIN EN 1993-1-3 2010). By comparing the steel costs of steel-framed buildings constructed with a conventional TCSS-roof (reference systems) with the steel costs of steel-framed buildings constructed with an HCG-roof the economic efficiency of HCGs becomes evaluated. Firstly the reference systems and the parameters of the investigated systems with HCG roofs are described. After a detailed explanation of the structural analysis, on which the estimate of costs is based, the results of the evaluation are presented.

2 REFERENCE STEEL-FRAMED BUILDINGS

Kocker and Möller (2009) investigate different types of steel-framed buildings according to their economic efficiency. Therefore they define two structural basic systems, firstly a two-hinged frame and secondly a frame with fixed-ended columns. All investigated systems were constructed without purlins and with a warm roof section. Furthermore Kocker and Möller introduce three different snow load levels taken into account in the structural design (0.75 kN/m^2, 1.20 kN/m^2, 2.00 kN/m^2). Figure 1 illustrates the investigated geometric dimensions of three different steel frames in Kocker and Möller (2009). The distance between two frames is chosen constantly to 6 m in all systems of Kocker and Möller. The following investigations of this paper adopt the systems of Kocker and Möller as reference systems after updating their structural analysis from DIN 18800 (DIN 18800 Part 1 2008, DIN 18800 Part 2 2008) to Eurocode 3 (Petersen and Krahwinkel 2015). The following investigations focus on systems with two-hinged frameworks. (see Figure 1).

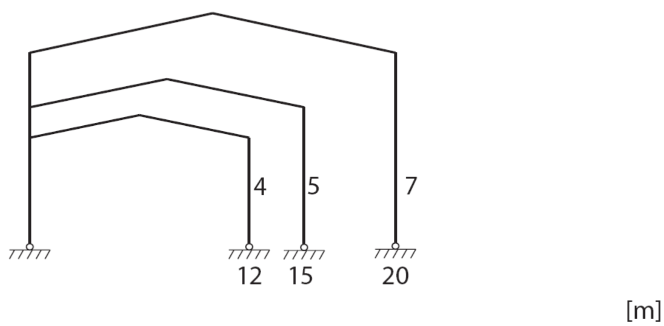

Figure 1. Systems with two-hinged frameworks.

3 INVESTIGATED STEEL-FRAMED BUILDINGS WITH HCG ROOFS

The geometric dimensions of the steel frameworks of the investigated steel-framed buildings with HCG roofs are similar to the steel frameworks of the reference systems (see Figure 1). The installed HCG systems consist of two Hoesch T-150.1 profiles with a nominal thickness t_N of 0.88 mm which are connected with the self-drilling screw Hilti SMS01Z 4.8x20M. The fasteners are arranged affine to the shearing forces in a simple beam under bending. The load bearing capacities and bending stiffnesses of the HCGs can be derived from the results of the numerical parametric study in Petersen and Krahwinkel (2015). The varying parameter in the investigation on the economic efficiency of HCGs is the distance between steel framework of the steel framed buildings. It varies between 10.0 m and 14.0 m with a step size of 1.0 m. Smaller distances do not promise an economical benefit due to their small difference with the application distances of conventional TCSSs (up to 7 m). Numerical pre-investigations have shown that larger distances as 14.0 m are not realizable with HCGs because of their bending stiffnesses, not even if the HCG would be a gross section without composite effects. Independent of the framework distances all investigated steel-framed buildings, reference systems and systems with HCG roofs, consist of 10 equidistant spans. Figure 2 shows an exemplified illustration of the frame corners as a rigid, bolted joints. The length of the haunches was fixed to one-tenth of the framework width *B*. The beams and columns of the frameworks are constructed by hot-rolled profiles.

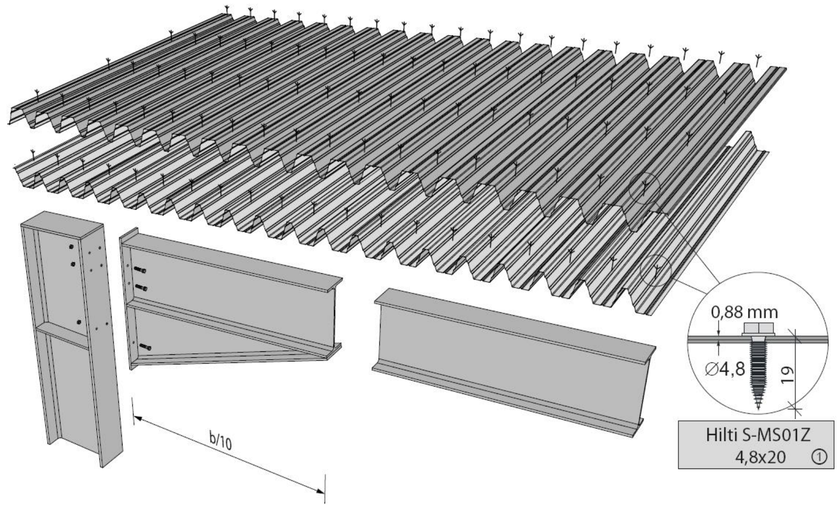

Figure 2. An exemplified illustration of the frame corners as a rigid, bolted joints.

4 STRUCTURAL ANALYSIS

The process of the structural analysis follows a detailed explanation of *Kindmann* in Kindmann and Kraus (2011). The structural analysis of all investigated systems, reference systems and systems with HCG roofs, were reduced to the design of an internal two-hinged framework. They were simplified considered as 2D beam structures. The proofs of wind bracing, joints, gable wall members and foundation elements are not investigated in the scope of the economic efficiency analysis. The dimensioning and calculations were carried out in accordance with the design rules of Eurocode 3 (DIN EN 1993-1-1 2010, DIN EN 1993-1-3 2010). The design loads are composed of wind and snow loads, in which the snow load is the leading variable action. Every system becomes investigated with three different snow load levels according to the investigations of Kocker and Möller (2009). Figure 3 shows qualitatively the single load cases of the leading combination of actions dead loads, snow loads, wind loads and equivalent geometric imperfections.

All stability verifications for the framework in the frame plane are carried out with the linear summation of the utilization ratios for each stress resultant on the basis of a second order determination of stress resultants under influence of equivalent geometric imperfections. The equivalent geometric imperfections were considered as initial sway imperfections by applying equivalent loads. Initial bow imperfections have not been taken into account.

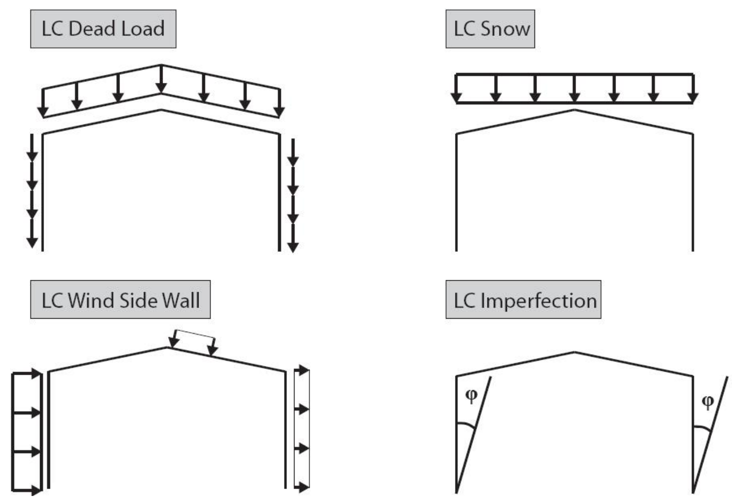

Figure 3. Qualitatively single load cases of the leading combination of actions.

Possible stability failures of the framework perpendicular to the frame plane, such as flexural buckling around the weak axis or lateral torsional buckling become separately investigated by dividing the framework into the subsystems frame column and frame beam. It is assumed that the corners of the subsystems are supported perpendicular to the frame plane. The bearings are assumed to be fork bearings (see Figure 4).

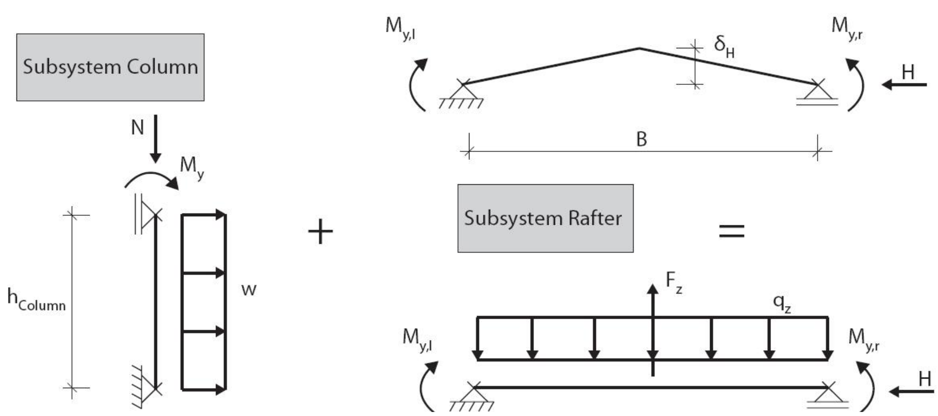

Figure 4. Subsystems of the framework.

5 RESULTS

Table 1 gives an overview of the steel-framed buildings investigated in the scope of this paper. It shows the results of the structural analysis as determined profiles for the steel frames. The upper profile relates to the beam section and the lower profile to the column section. The systems with a distance of 6 m are reference systems. The systems with a distance from 10.0 m to 14.0 m are systems with HCG roofs. For

Systems without a profile description a construction made of hot-rolled profiles was not possible. To keep the comparability the usage of welded sections has been avoided. To enable the comparability of the economic efficiency between steel-framed buildings of different sizes the ratio of steel cost and base area has been formed. Other material costs have not been taken into account. Approximately it is assumed that higher assembly cost of HCGs compared to TCSS equal less assembly cost for less frameworks. The cost estimate for the steel frameworks based on the delivery program in 2013 of a steel company (Brühler Stahlhandel GmbH 2013). The costs for the Hoesch T-150.1 TCSS with a thickness of 0.88 mm are estimated to 10 €/m^2.

Table 1. Overview of the steel-framed buildings investigated in the scope of this paper.

frame width	snow	distance between two frames					
		reference	HCG roofs				
		6,0	10,0	11,0	12,0	13,0	14,0
[m]	[kN/m²]	[m]	[m]	[m]	[m]	[m]	[m]
12,0	0,75	IPE 270 HEA 240	IPE 360 HEA 280	IPE 360 HEA 300	IPE 360 HEA 300	IPE 360 HEA 320	IPE 400 HEA 320
	1,20	IPE 300 HEA 260	IPE 360 HEA 320	IPE 360 HEA 340	IPE 360 HEA 360	IPE 400 HEA 360	
	2,00	IPE 330 HEA 300	IPE 400 HEA 400	IPE 450 HEA 400			
15,0	0,75	IPE 330 HEA 280	IPE 400 HEA 360	IPE 450 HEA 360	IPE 450 HEA 400	IPE 450 HEA 400	IPE 450 HEA 450
	1,20	IPE 360 HEA 320	IPE 450 HEA 400	IPE 450 HEA 450	IPE 500 HEA 450	IPE 500 HEA 450	
	2,00	IPE 450 HEA 360	IPE 600 HEA 450				
20,0	0,75	IPE 400 HEA 360	IPE 500 HEA 500	IPE 550 HEA 500	IPE 550 HEA 550	IPE 600 HEA 550	IPE 600 HEA 600
	1,20	IPE 450 HEA 450	IPE 600 HEA 550	IPE 600 HEA 600	IPE 600 HEA 650	IPE 600 HEA 700	
	2,00	IPE 500 HEA 500	IPE 600 HEA 700				

Figure 5 shows the difference between the ratios of steel cost and base area of the systems with HCGs and the reference systems in dependence on the investigated framework distances. The systems with HCG roofs are up to 5.0 €/m^2 more expensive than systems with a conventional TCSS roof. It can be observed, that with a rising load influence area the systems with HCG roofs become more efficient. The systems with a framework width of 20.0 m and a characteristic snow load of 1.20 kN/m^2 are more efficient as their reference system. The possible savings in this case are up to 3.0 €/m^2.

Former investigations should focus on the bending behavior of HCGs as continuous beams. Therefore it is necessary to develop a joint component between to connect the HCGs in support areas. It is also necessary to investigate the assembly costs of HCGs more in detail to evaluate the assembly costs more realistic.

6 CONLCUSION AND OUTLOOK

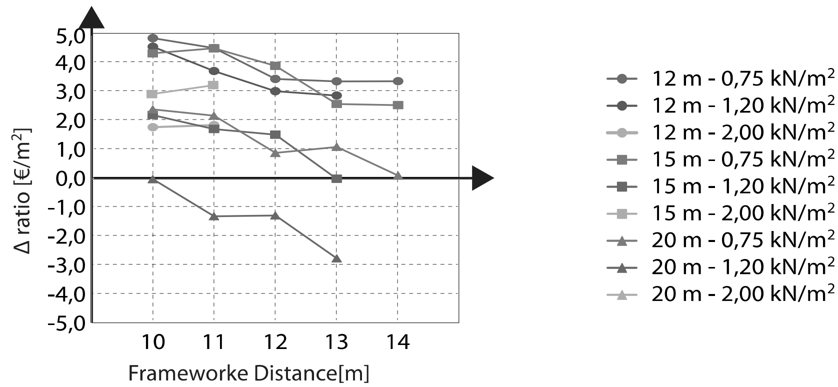

Figure 5. Difference between the ratios of steel cost and base area.

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