GIRDERS WITH PROFILED AND STRUCTURED WEB - ONGOING RESEARCH – PART 2

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Abstract: *In an ongoing research project, welded girders with I-section and thin "honey-comb" structured web will be investigated. A series of plate girders with different webs (flat, profiled or structured) are being modeled and analyzed under shear load. The numerical analysis will be based on nonlinear finite element method. Several plate girders were built for tests. The aim of the tests is to query if the structured web has a better buckling behavior than a normal flat web or even comparable corrugated web. Finally a comparison between numerical and experimental test results will be made. The paper describes former investigations on the shear capacity of the structured sheets, ongoing numerical analysis and experimental tests on global and local buckling.*

Key words: *shear resistance, buckling behavior,*

4. Shear Load Tests

To find the material properties of steel used for the web and the flange there were carried out tensile tests. Table 1 shows the average from all tests. Due to the difficulties of fabrication of the structured plates with a thickness of 1 mm it was decided to create a sandwich construction with 2 plates of 0,5 mm first. The geometry of all girders is shown in Table 2.

The static system of the girder is a beam with two bearings, one fixed and one moveable. Additionally the girder was also fixed in the horizontal direction for elimination tilting vertically to the moment plane. A concentrated force was put in the middle of the girder at the transversal stiffener. For analysis the horizontal deflection of the web, the vertical deflection of the girder, the strain in the web and the ultimate load were considered.

Table 1. Material properties from used parts (results in N/mm²)

Used parts	material	E	$R_{p0,2}$	R_{eH}	R_{eL}	R_m
Planar web	DC01	209141	183	x	x	327
Trapez web		180964	x	301	291	355
Sinus web		178687	x	319	298	332
Flat web	DC04		170	x	x	295
FQZ web	DC04		65	x	x	305
Flange	S355	215228	x	411	391	534

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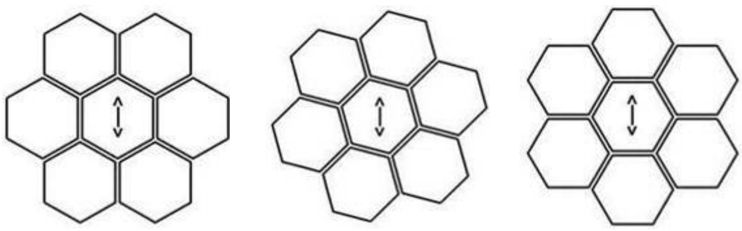
Table 2. Dimensions of the test girder (s-small comb, b- big comb)

Test No.	web	Length (mm)	Height (mm)	Shear length (mm)	Thickness (mm)	Shear height (mm)	Shear aspect ratio	Buckling curve
1.1.1	flat				1			
1.1.2	flat				1			
1.2.1	trapez				1			
1.2.2	trapez				1			
1.3.1	sinus				0,88			
1.3.2	sinus				0,88			
1.3.3	sinus	1194	432	520	0,88	416	1,25	1
1.4.1	FQZ 0°				2 x 0,5			
1.5.1	FQZ 90°				2 x 0,5			
1.6.1	Borit 0°s				2 x 0,6			
1.7.1	Borit 90°s				2 x 0,6			
1.7.2	Borit 90°s				2 x 0,6			
1.8.1	Borit 0°b				2 x 0,6			

Fig. 1 shows 3 possible orientations of the structured web related to the load direction.



a) 0° b) 45° c) 90°

Fig. 1. Orientation of the structured web in dependence to the load direction

Before the tests started the geometrical imperfections of the girders with planar and structured plates were measured. The imperfections of the web have an influence on the buckling behavior. Table 3 shows all initial imperfections of the tested girders. For the test specimen with a trapezoidal or sinusoidal corrugated web the horizontal geometric imperfection were not measured because of the local buckling behavior.

Table 3. Measured imperfection of the girders

Specimen	Imperfection shear field 1 in mm	Imperfection shear field 2 in mm
VK1.1.1	2,3	3,2
VK1.1.2	1,51	1,58
VK1.4.1	2,4	1,4

The test speed was 1 mm/min. It is an acceptable value for having comparable test results in reference to the buckling time and regarding the relation between buckling and shear load.

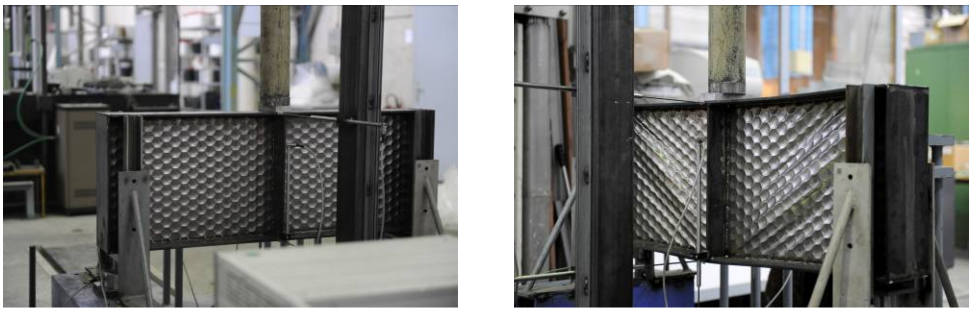


Fig. 2. Test girder 1.4.1 during the shear load test

Fig. 3 shows the test: two load cells, four strain gauges (linear or rosette) in all girders with a flat web as well as 10 displacement transducers.

Fig. 3. Test girder 1.6.3 during the shear load test

Two different test series are made with different length, aspect ratios and rigid or non rigid end post. Up to this date, 17 tests have been carried out in series 1 and two tests in series 2. Obviously, the shear area ratio has an influence on the ultimate force and the stiffness of the rigid end post has an effect, too. But for further data interpretation we only use all test with the same length 1,194 m and a shear ratio of 1,25 to show the influence of the thickness and the design of the different webs. Fig. 2 and 3 shows 2 girders with a structured web with a sheet plate from FQZ and Borit®.

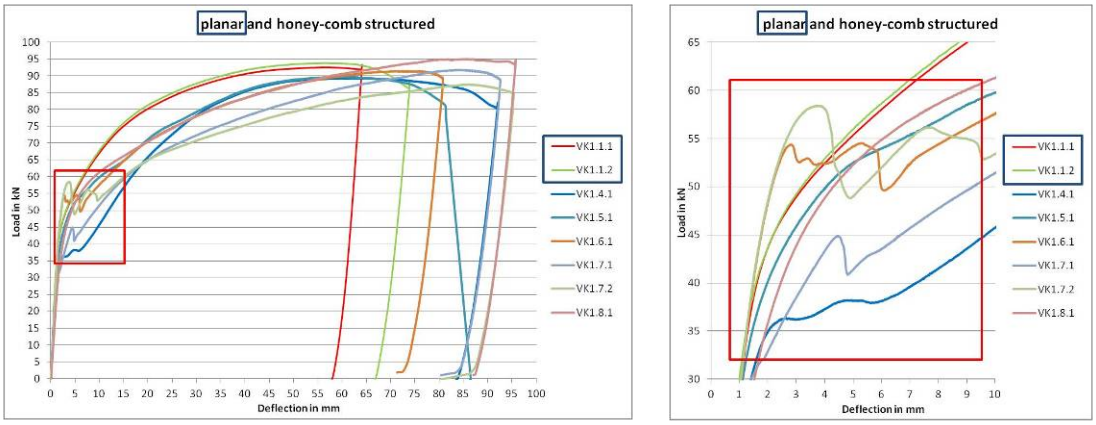


Fig. 4. Load- vertical deflection curves (1)

In comparison to all tests it can be seen, that the experimental tests of the girders with a plane and a structured web have a similar behavior and those test of the girders with a trapezoidal or sinusoidal corrugated web. Fig. 4 shows the load-vertical deflection curves (1) for girders with a planar and a structured web.

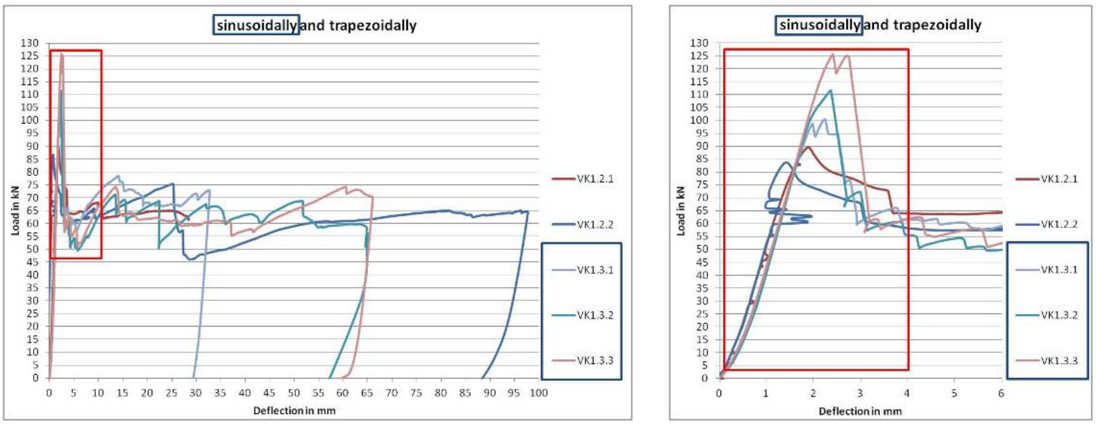


Fig. 5. Load- vertical deflection curves (2)

In Fig. 5 are shown load-vertical deflection curves (2) for girders with trapezoidal and sinusoidal corrugated web.

The right diagram on Fig. 4 shows that the behavior at the beginning of buckling is different for girders with a planar and a structured web. This phenomenon appears due to the deformation of the sheets (plane of the structure) without of the load. If the structure is nearly complete planar the load rise to the ultimate load. Differences between the directions of the structure (comb 0° → 90°) are also recognized. That's why one can define there is a big influence for reaching a higher critical buckling load (buckling behavior) between the direction of the comb and the load direction. Based on the stiffness of the different structured web from FQZ and Borit® the graphs of the ultimate load are different. The behavior of the girders with the trapezoidally and sinusoidally webs are similar as shown in Fig. 5.

Based on the beginning of the test the load- deflection curve steeply rising until the critical buckling load (local buckling). After this load one can see a big load drop. At the same time the web have an abrupt local buckling of the trapezoidal or sinusoidal corrugated web. There was the variant of buckling in the near of the middle rigid and also buckling in the near of the rigid end post. Furthermore one can note that the horizontal deflection in the center of the shear field depends on the stiffness of the sandwich web.

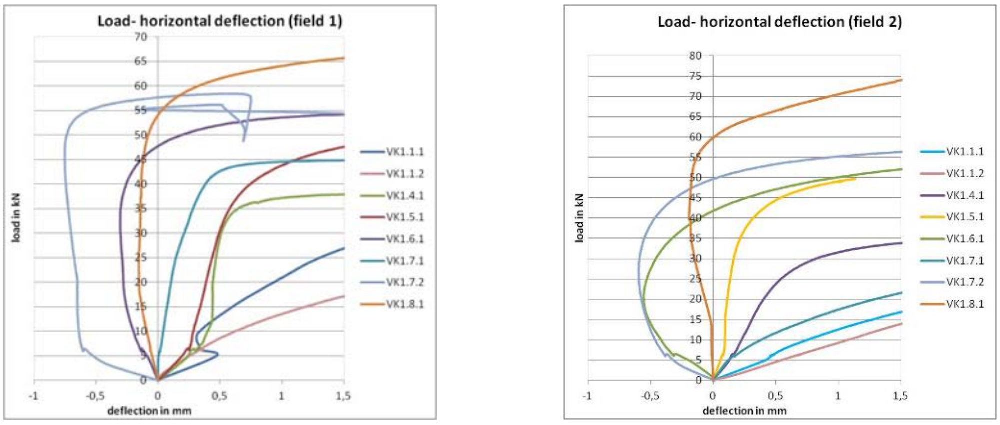


Fig. 6. Horizontal deflection Shear field 1 and 2

Fig. 6 shows the different behavior of the girder with the planar web and the structured web with regard to the horizontal displacement of the center of the two shear fields. It can be seen that the structured plate has a higher stiffness than the planar web. That means that the buckling behavior of a girder with a structured web is much better than the girder with a flat web. Figure 7 shows the different tension fields from test VK1.4.1- VK1.8.1. It can be observed that the comb structure does not exist partially.

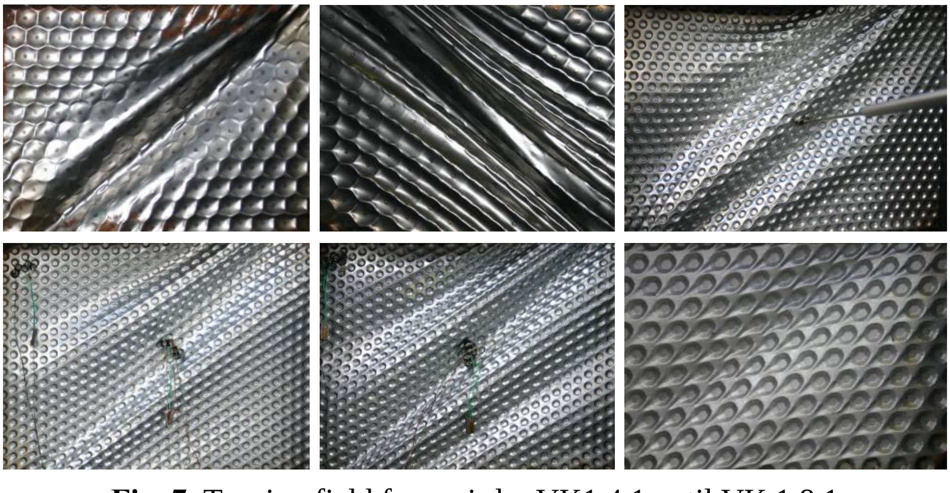


Fig. 7. Tension field from girder VK1.4.1 until VK 1.8.1

5. Analytical Results

The ultimate load is achieved when the load does not increase any more and only the deformation accelerates. Table 7 contains the measured load for all five types of girders. Furthermore for the first girders it was possible to calculate the ultimate load according to [1], [2] and [3]. In adaption of [4] it should be possible to find a design method of girders with structured web.

Table 4. Comparison of test and analytical results (s-small comb, b-big comb)

Specimen	Web	$F_{u,exp}$ [kN]	$F_{cal,ec3}$ [kN]	$F_{cal,dast15}$ [kN]	$F_{cal,Zem}$ [kN]	$F_u/F_{cal,ec3}$	$F_u/F_{cal,dast15}$ bzw. $F_u/F_{cal,Zem}$
VK1.1.1	Planar	92,6	44,5	72,9	X	2,08	1,27
VK1.1.2	Planar	93,8				2,11	1,29
VK1.2.1	Trapez	67,5	47,7	39,8	X	1,41	1,69
VK1.2.2	Trapez	65,1				1,36	1,63
VK1.3.1	Sinus	78,5	68,5	X	43,9	1,14	1,79
VK1.3.2	Sinus	69,3				1,01	1,29
VK1.3.3	Sinus	74,2				1,08	1,69
VK1.4.1	FQZ 0°	89,2	X	X	X	X	X
VK1.5.1	FQZ 90°	89,8					
VK1.6.1	Borit 0°k	91,4					
VK1.7.1	Borit 90°k	91,8					
VK1.7.2	Borit 90°k	87,4					
VK1.8.1	Borit 0°g	95,0					

In all girders with planar and structured web after shear buckling, a tension field developed (=post- buckling) and later plastic hinges were formed (=frame effect). A difference between the flat and structured web was observed: Parallel to the forming of a tension field, the comb structure was lost.

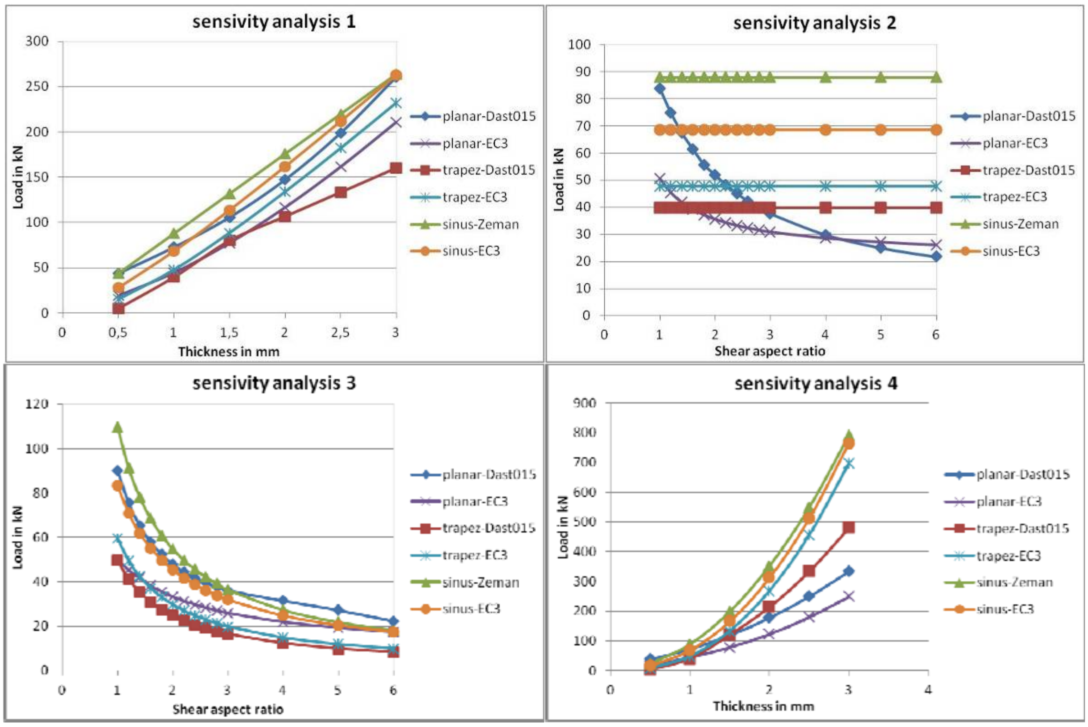


Fig. 8. Load over shear aspect ratio and thickness- analytical results

There was one difficulty in finding the comparable values for the definition of shear and tension load from [2] for the experiment and the FE method. The buckling load was defined as a load, which corresponds to the horizontal displacement of the web of 1 mm. It was difficult to recognize, when the frame effect started during the experiment. That's why the tension effect was given by an approximate value. In Table 4 are only shown the complete ultimate loads from the tests and the analytical analysis.

In Fig. 8 the comparison is shown considering the influence of the parameter thickness and shear aspect ratio. An overview of the differences is given in Table 3[5]. The thickness is directly linear to the ultimate load, as shown in sensivity analysis 1. The highest value for loads are calculated for a girder with a sinusoidally web. In the diagram for the sensivity analysis 2 has 4 graphs with the same value of load for different shear ratio aspects. More over the obtained results show, that the shear aspect ratio for analysis 3 is indirectly proportional to the ultimate load and the thickness is more than linear directly proportional to the ultimate load (analysis 4).

Conclusion(s)

The main conclusions are: The stiffness of the sandwich element is higher than the flat plate. (Because of the stiffness it is simplier to weld a sandwich element to the flanges than a thin flat web.) The ultimate loads of girders with planar and structured webs are comparable. The buckling behavior of the girder with a structured web is dependend on the orientation of the combs. Sin girders give the highest ultimate load.

Conclusions for further test samples: The direction of the structured web has to be changed (rotation about 45°).

Conclusions for the analysis: The calculation model is being developed according [4], [2] and [1]. The further refinement of structured web-model with geometry and material properties is necessary.

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