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ANALYSIS OF A STEEL-CONCRETE COMPOSITE GIRDER MADE WITHOUT THE USE OF WELDING

The work presents a solution for a steel-concrete ceiling girder made without the use of welding. Experimental and numerical tests carried out on a real-scale girder model were discussed, on the basis of which the value of the destructive load, the value of the of the destructive bending moment and the amount of girder deflection were determined. The results obtained from experimental tests were consistent with the results of numerical calculations. The bending load-bearing capacity was calculated for various variants of the girder structure, showing that it depends mainly on the height of the steel section and the type of steel from which it was made. The impact of the other analyzed parameters is less important. Eliminating the welding process during the construction of the girder allows for reducing the energy consumption of its production while maintaining strength parameters comparable to elements in which welding was used. Moreover, the connector attachment technique used (unlike welding) does not cause any microstructure transformations, allows maintaining the homogeneity of the material and avoiding internal stresses and deformations.

Keywords: Steel-concrete composite girder; non-welding methods; bending capacity; deflection

1. Introduction

The most commonly used materials in construction are steel and concrete. Each of them has its advantages and disadvantages – steel transfers tensile stresses well, while in compression the load-bearing capacity of steel elements is somewhat reduced due to the phenomenon of buckling. Concrete, on the other hand, behaves the opposite – it has a high compressive load capacity and a low tension load capacity. There are known solutions for both reinforced concrete and steel girders. A hybrid of these two solutions, which uses the high load-bearing capacity of concrete in compression and steel in tension, are composite steel-concrete girders. Their cross-section is designed in such a way that the concrete component carries mainly compressive stresses and the steel component carries tensile stresses, which is especially the case in single-span elements. This allows for larger spans or smaller cross-sections than with traditional steel or reinforced concrete girders.

Work is also undertaken to replace steel or concrete with other materials, resulting in new solutions for composite girders. An example of this would be steel/timber beams, where a steel section is connected to a wooden ceiling slab using screws [1,2] or pins [3]. Another proposal in which the steel section is replaced by a wooden element combined with the concrete ceiling slab are TCC (Timber-Concrete Composite) girders [4,5] or BCC (Bamboo-Concrete Composite) girders [6,7]. Instead of a steel section, a GFRP polymer profile cooperating with a concrete slab can be used [8,9]. All these solutions, under certain conditions, may constitute an alternative to steel-concrete composite girders. However, assuming the bending load capacity and element stiffness as the basic criteria, steel-concrete composite beams are the most effective solutions for composite girders.

In steel-concrete composite beams, the concrete component is the ceiling slab and the steel component is usually cold-formed [10], hot-rolled [11,12], welded [13,14] or grid elements [15,16]. An important factor ensuring proper cooperation between the concrete and steel parts of the cross-section is their proper connection. Most often, it is implemented using special connectors. In the girders used so far, the steel section is connected to the concrete slab most often by means of welded connectors: headed stud [17,18], C-shaped sections [19,20] or perforated steel plates [21]. Screw connectors [22,23] are also used, the installation of which requires drilling holes in the upper flange of the steel section, which affects the labor consumption of making this type of beams.

As a complement to the previously used solutions, a steel-concrete composite girder was proposed, made without the use of welding, in which the connection was achieved by using a cold-formed U-shaped connector, attached to the upper chord

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of the hot-rolled I-beam using shot-in nails. This solution can be used in building ceilings, especially when the concrete slab is made on profiled steel sheet.

2. Proposed solution

One of the most common applications of composite beams are ceiling beams used in buildings. The proposed girder consists of a hot-rolled I-beam connected to a reinforced concrete ceiling slab using a U-type connector. The connector is attached to the upper flange of the beam using four shot-in nails as shown in Fig. 1.

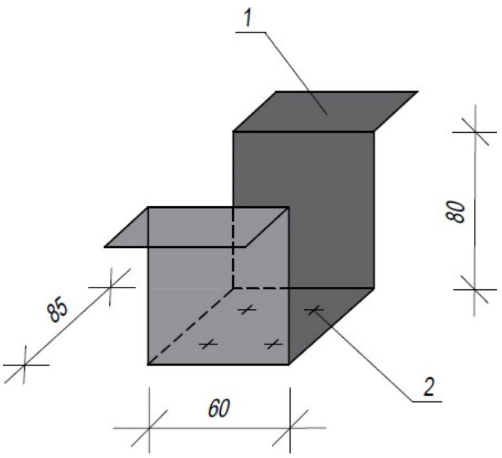

Fig. 1. U-shaped connector: 1 – connector, 2 – shot-in nails

The slab can be made on profiled steel sheeting or as a single slab on traditional formwork. An example solution of the girder structure is shown in Fig. 2.

In multi-story buildings, ceiling slabs are often made on profiled steel sheets, which constitute the formwork that is lost during the construction phase, which reduces the workload of constructing the ceiling (no need to dismantle the formwork). Moreover, if an appropriate profiled steel sheet is used, it can

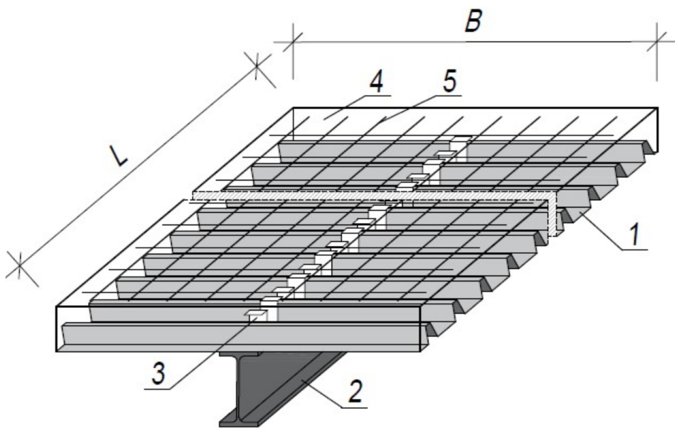

Fig. 2. Steel-concrete composite girder made without the use of welding: 1 – profiled steel sheet, 2 – steel I-beam, 3 – U-shaped connector, 4 – concrete slab, 5 – reinforcing bars

constitute the external reinforcement of the slab and transfer tensile stresses, limiting or eliminating span reinforcement. Therefore, a structural solution for the girder with a slab made on profiled steel sheet was chosen.

3. Experimental and numerical analysis

In order to check the correctness of the adopted solution, numerical simulations and experimental tests of the girder on a natural scale were performed. The span of the girder was 7.5 m and the width of the concrete slab was 1.80 m. An IPE 200 I-beam made of S235 steel was used as a steel section, the slab was made of C30/37 concrete, reinforcement in the form of 10 mm diameter steel bars with a yield strength of 355 MPa, T55×188 thick profiled steel sheet was used. 0.75 mm. The connector is made of a U-shape profile, 80 mm high, 85 mm wide, 60 mm long, and 3 mm wall thick, of S235 steel, fastened with four Hilti shot-in nails with a diameter of 4.5 mm. The girder on the test stand is shown in Fig. 3.

Fig. 3. Girder model on the test bench

The tested model was subjected to bending, measuring the values of vertical displacements for subsequent load levels. The total value of the destructive load at which the first crack in the slab was observed was 212 kN, which corresponds to the value of the destructive bending moment of 204.30 kNm. The value of maximum normal stresses in the elastic range for the steel section was also calculated, which amounted to 218.60 kN. The maximum deflection value in the elastic range was 26.72 mm.

A numerical model of the girder was made using the ADINA System program. 3D-solid, 27-node finite elements were used for the steel IPE profile, concrete and nails, and 3-node finite elements for reinforcing bars. The results of numerical calculations showed convergence with the results obtained on the basis of experimental tests – the difference for deflection was 1% and for stresses 0.4%. A detailed analysis of the results is presented in [24].

4. Analytical calculations – results and discussions

In order to determine the practical scope of use of the analyzed solution as an element of the beam-slab ceiling structure, analytical calculations were performed, the aim of which was to determine the bending load capacity $M_{pl.Rd}$ for various variants of the girder structure. The scheme of a single-span beam, simply supported, and the spacing of girders in the ceiling equal to 2.0 m were adopted. The variables were the height of the steel section, the type of steel from which it was made, the thickness of the concrete slab, the class of concrete and the span of the girder. The remaining parameters of the girder were assumed the same as in the experimental tests and did not change. The calculation results for C25/30 class concrete are presented in TABLE 1 and for C30/37 class concrete in TABLE 2.

TABLE 1

Bending load capacity $M_{pl.Rd}$ of the girder for concrete class C25/30

Steel	I-beam	Concrete ceiling slab C25/30					
		Girder span [m]					
		7.50			9.00		
		Slab thickness [mm]					
		60	70	80	60	70	80
		$M_{pl.Rd}$ [kNm]					
S235	IPE 200	136.12	142.81	149.51	136.61	143.31	150.00
	IPE 240	201.10	210.29	219.47	202.02	211.21	220.40
	IPE 270	249.22	260.01	270.80	250.50	261.29	272.07
	IPE 300	306.96	319.60	332.24	308.71	321.36	334.00
S355	IPE 200	199.54	209.66	219.78	200.67	210.79	220.91
	IPE 240	292.34	306.22	320.10	294.46	308.34	322.20
	IPE 270	360.72	377.01	393.31	363.63	379.93	396.22
	IPE 300	431.44	461.14	480.27	441.27	465.14	484.24

TABLE 2

Bending load capacity $M_{pl.Rd}$ of the girder for concrete class C30/37

Steel	I-beam	Concrete ceiling slab C30/37					
		Girder span [m]					
		7.50			9.00		
		Slab thickness [mm]					
		60	70	80	60	70	80
		$M_{pl.Rd}$ [kNm]					
S235	IPE 200	137.43	144.13	150.82	137.84	144.54	151.23
	IPE 240	203.57	212.76	221.95	204.34	213.53	222.72
	IPE 270	252.63	263.42	274.20	253.69	264.48	275.27
	IPE 300	311.64	324.28	336.92	313.10	325.74	338.39
S355	IPE 200	202.54	212.66	222.78	203.48	213.59	223.71
	IPE 240	297.98	311.87	325.75	299.75	313.63	327.51
	IPE 270	368.49	384.79	401.08	370.92	387.21	403.51
	IPE 300	452.72	471.82	490.92	456.06	475.16	494.26

The value of the bending load capacity $M_{pl.Rd}$ increases with the increase in the height of the steel section. The difference in load capacity between the smallest (IPE200) and the largest (IPE300) analyzed I-beam ranges from 116% (span equal 9.0 m, S355 steel) to 127% (span equal 7.5 m, S235 steel) and is approximately proportional to the difference in cross-sectional areas of IPE 200 and IPE 300.

Also, an increase in the value of the yield strength of the steel from which the steel section is made translates into an increase in the bending load capacity of the composite girder. The difference in load capacity between the smallest and the largest analyzed I-section ranges from 45% to 48% and corresponds approximately to the difference in the yield strength of S235 and S355 steels, which is 51%.

The influence of concrete class on the bending load capacity is minimal and amounts to approximately 1% with a difference in concrete compressive strength of 20% (between class C25/30 and class C30/37). Similarly, increasing the girder span by 20% (from 7.5 m to 9.0 m) resulted in a very small increase in bending capacity, which ranged from 0.3% to 2.3%.

Increasing the thickness of the slab also has a small effect on the increase in the load-bearing capacity on the bending of the girder. The difference in load-bearing capacity between the slab with the smallest thickness (60 mm) and the largest thickness (80 mm) is from 8% to 11%.

5. Conclusion

The height of the steel section and the type of steel from which it was made have the greatest impact on the bending capacity of the analyzed composite girder. An increase in the thickness of the concrete slab and an increase in the concrete class results in only a slight increase in load-bearing capacity. This is due to the location of the neutral axis of the composite cross-section in the slab (for the vast majority of cases), which results in partial use of the compressive strength of the concrete while fully utilizing the tensile load-bearing capacity of the steel section.

Increasing the span of the girder results in only a slight increase in the effective width of the concrete flange of the composite cross-section, which translates to a minimal increase in the bending load capacity of the girder.

The proposed solution can be used in building ceilings, especially with ceiling slabs made on profiled steel sheets, where during one assembly operation the sheet and the connector can be simultaneously attached to the steel section.

Eliminating the welding process when constructing a girder allows to reduce the energy consumption of its production while maintaining strength parameters comparable to elements in which welding was used.

The fastening technique used (as opposed to welding) is an advantage in terms of microstructure transformations, material homogeneity, and the avoidance of internal stresses and deformation.

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