The behavior of composite dowels subjected to four-point bending test

Veronika Václavíková and Michal Štrba

Abstract**—**The article constitutes one of the modern methods of shear connection of composite steel-concrete beams, which is mainly used in bridge engineering where strength and fatigue durability is required. Such method using combination of rolled girders encased in a concrete slab and pcb (precast composite beam) technology is called pcb-W (precast composite beam – coupled in web) technology.

This solution has been developing since 2003 in Germany and is widely used in many European countries (including Poland, Germany, France and Czech Republic). The longitudinal shear force is transformed by composite dowels instead of headed studs.

The behavior of composite dowels is extremely complex. These connectors constitutes an integral part of composite beam, they are not only subjected to the global effects of bending and axial loading but to the local longitudinal shear acting between steel and concrete part as well. In order to understand the failure mechanism and verify the bearing capacity of composite dowels theoretical and experimental researches were carried out at the authors' workplace.

Keywords**—**Bending test, composite dowels, continuous shear connection, strain gauges, stress distribution.

I. Introduction

PRESENTED paper comes as a result of first author´s (hereinafter author) doctoral study as a part of doctoral thesis dealing with the problem of modern methods of shear connection of composite steel-concrete beams.

Based on the possibility of cooperation with Vladimír Fišer Company and on the processed parametric study, mentioned for example in [2-4], the method of shear connection was chosen using pcb-W technology.

The standard push-out test according to [1] was realized at the author's workplace to verify the bearing capacity of elements of shear connection and parameters of such shear connection. The experiment was carried out mainly to verify the bearing capacity of composite dowels calculated according to the design manual [7] and to test the suitability of using steel fiber concrete for pcb-W technology.

The results of the standard push-out tests were used to calibrate the FE models, which were needed for the optimization of the shape used for further destructive four-point bending test.

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II. Pcb-W technology

A. Pcb technology

The pcb technology, which is the abbreviation of "precast composite beam", can be applied to road bridges, railway bridges as well as pedestrian bridges. So far, about 300 bridges have been realized in Germany using this technology [6].

In Czech Republic two road bridges, one railway bridge and a pedestrian bridge have been realized so far.

Fig. 1 Pcb girder for pedestrian bridge in Czech Republic

The Vladimír Fišer Company bought know-how and rights to this protected solution in 2010 and continues with the development.

Pcb girders are composite elements that consist of an open or closed welded steel-section and a thin prefabricated concrete flange. Such elements are completed with additional concrete on the construction site which is especially economic and time-efficient since no formwork is required. The shear transmission between steel and concrete is accomplished by headed studs using short studs for the prefabricated concrete and longer ones for in-situ concrete [7].

The prefabricated concrete flange is engaged as structural concrete and as formwork for covering in-situ concrete plate. After setting the prefabricated girders on sub-structure the concrete deck is cast in-situ without any further formwork. This is a big advantage especially for bridges crossing existing railways or highways, because the closure of traffic ways underneath can be minimized to only a few minutes for the assembling of each girder.

B. Pcb-W technology

The pcb-W technology combines the advantages of pcb technology and the method of rolled girders encased in concrete (W). Pcb-W (precast composite beam coupled in web) uses rolled sections cut into two halves along the web using a specific cutting geometry that two T-sections arise, see Fig. 2. These T-sections are embedded into lower part of concrete deck or into a concrete beam which generates the composite dowels.

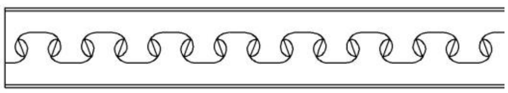

Fig. 2 IPE300 cross section cut into two halves by specific cutting geometry

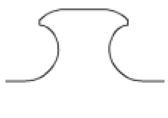

Fig. 3 steel dowel

The longitudinal shear force is then transformed by these composite dowels instead of headed studs. This system leads to great economic advantages compared to welded sections because material-consumptions for the upper flange, headed studs and effort for welding can be saved. Major advantage of external reinforcement elements compared to conventional concrete or pre-stressed solutions is an increased internal lever arm.

Pcb-W girders can be used in industrial buildings and bridges due to their high strength, high stiffness and large slenderness at the same time. Mainly for railway bridges the high strength and convenient slenderness providing small deformation is desirable.

C. Push-out test

In order to recognize the behavior of composite dowels under variable load, several experiments were carried out at the author´s workplace. The standard push-out test simulates the effect of vertical loads on composite steel-concrete beams.

Fig. 4 push-out test, the failure of the specimen

The experiment included three groups of specimens, each group contained three specimens.

The identical steel strip was designed for all three groups of specimens; steel S355 and the axial distance of composite dowels 250 mm as it is common in practice. The thickness of the steel strip was 20 mm.

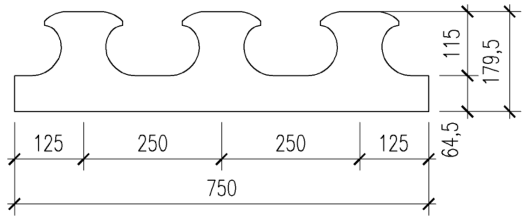

Fig. 5 dimensions of the steel strip

The concrete decks in the first group of specimens were made of common concrete and reinforced according to the design manual [6, 7]. The concrete decks in the second group of specimens were made of steel fiber reinforced concrete and the area of reinforcement was reduced. The decks in the third group of specimens were made of fiber reinforced concrete with no additional reinforcement, as you can see in Table I.

Table I groups of specimens

Group	Specimen	Concrete	Reinf. in dowel	Reinf. out of dowel	Number of gauges
S1	V1	C30/37	2 R12	R8	4
	V2	C30/37	2 R12	R8	2
	V3	C30/37	2 R12	R8	2
S2	V4	C30/37 + fibers	2 R6	R8	4
	V5	C30/37 + fibers	2 R6	R8	2
	V6	C30/37 + fibers	2 R6	R8	2
S3	V7	C30/37 + fibers	-	-	4
	V8	C30/37 + fibers	-	-	2
	V9	C30/37 + fibers	-	-	2

The measured parameters were: stress on the steel dowels measured by strain gauges LY11 3/350 (3/120) HBM, loading force measured by strain gauge force transducer C6/100t HBM, displacement of the steel profile measured by induction position sensor WA 50 HBM. To generate the adequate loads, we used two parallel hydraulic cylinders with the capacity of 940 kN.

Thanks to the parameters measured by strain gauges we have got the better idea about stress distribution on the steel dowels. The obtained map of connector´s strains employing the electro-resistance strain gauges enables the both verification and calibration of the numerical models.

The numerical models were used for the optimization of the shape used for further destructive test on beam members.

The greatest stress was measured on the steel dowels of the group S1. However, the values of stress of the groups S2 and S3 are high as well.

In the range between approximately 400 and 600 kN, the values of stress of the group S2 are even higher than the values of the group S1.

The bearing capacity of all the specimens is much higher (approximately 3 times) than it was calculated according to the design handbook. The results of the tests show relatively good consistency of fiber reinforced concrete with the steel strip. However the results cannot be used due to bad concreting of one specimen of the group S3. Therefore the author recommends dealing further with the specimens of steel fiber reinforced concrete and with lower degree of additional reinforcement, than it is recommended by design manual, it means with the specimen of group S2.

III. Determining the Location with the Greatest Value of Stress – Hot Spot

To identify the right position for the strain gauges location, the numerical model was created in FEM software RFEM of Dlubal Software Ltd. Company.

The main aim of the model was to specify the stress distribution on the steel dowel and determine the place with the greatest value of stress, so called HOT SPOT. These are the places where the strain gauges are placed before concreting the specimens.

The values measured during the experiment will be compared with the values given by the numerical model and the model will be calibrated.

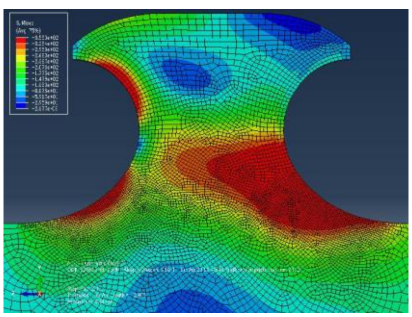

Fig. 6 stress distribution under the load of 100 kN

Fig. 7 the location of strain gauges

The strain gauges were placed on the third steel dowel where the biggest effect of longitudinal shear force is expected, see Fig. 8.

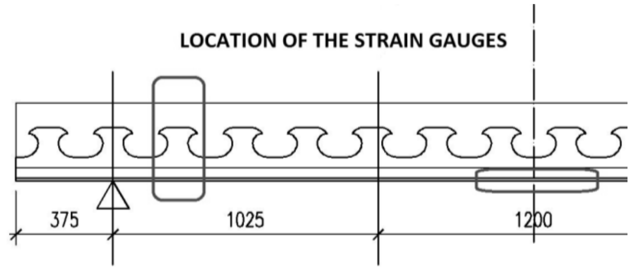

Fig. 8 the position of strain gauges

In addition two strain gauges were placed on the concrete deck in the middle of the beam´s span and one strain gauge was placed on the steel flange in the middle of the beam´s span as well.

IV. Four Point Bending Test

The composite dowel constitutes an integral part of steel component and its stressing affects the global stress state in the entire unit. Thus, it is not possible to separate the problem of dimensioning of the composite beam (due to effects tied with the distribution of normal stress in the composite cross section) from the dimensioning of the connector itself under the longitudinal shear between the steel and concrete. The computational approach should comprehensively describe both issues mentioned above.

Additionally the degree of complexity of such connection is forcing into applying the non-linear analyses (FEM) taking into account the material and geometrical nonlinearities resulting from the contact effects between steel and concrete. It is also essential to carry out extensive destructive tests for different types of elements. [10]

The most widespread destructive test, which is confirming the resistance of composite dowels, is the beam examination under static or cyclic loads.

Simple four point bending test was realized at the author’s workplace in order to obtain the idea of stress distribution in the steel dowel. Based on the values of stresses measured by strain gauges at certain points the numerical model can be calibrated and afterwards the map of stresses gained numerically can be confirmed in the chosen discrete points. Thanks to the high number of gauges on the steel dowel it is possible to record an extra concentration of stresses at the geometric notches.

A. *Concreting of the test specimens*

Three test specimens were prepared on the premises of AdMaS center in scale similar to natural. The steel strips were cut out from steel beams IPE 300 made of steel S355JRG3.

The test specimens were concreted upside down. The concrete decks were made of concrete C30/37 reinforced based on the results of passed push-out tests, see Fig. 9.

Fig. 9 concreting of the test specimens

B. The experiment

Simply supported steel-concrete beams with the length of 4,0 m were prepared at the author´s workplace. Two concentrated forces F/2 were applied according to Fig. 11. The load was applied in increments ΔF = 50 kN up to the capacity of the beams. The load increments were imposed for 60 s.

When the load exceeded the value of approximately F = 430 kN, the load bearing capacity of all three specimens have been achieved. The audible failure occurred when some of the reinforcement bar has been torn.

There were visible cracks in the concrete deck in the middle of the beam´s span and the concrete deck was crushed at the points, where the force was applied, see Fig. 12. There is a visible vertical displacement of the steel strip on one of the specimens.

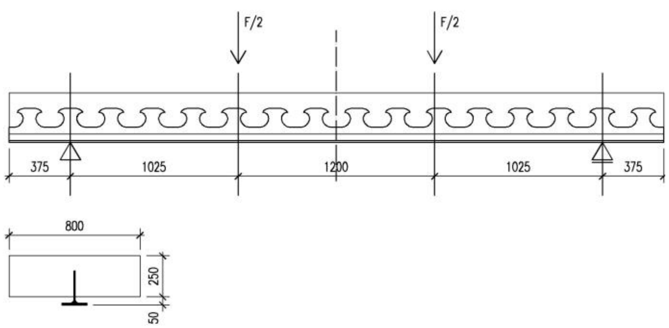

Fig. 10 the layout of the four-point bending test, beam´s cross section

The measured parameters were:

- T1 – T6, T1 – T10 - Stress on the steel dowels measured by strain gauges LY11-1,5/350 HBM Darmstadt (K = 1,90)
- BT1, BT2 – Stress on the steel strip measured in the middle of the beam´s span by strain gauges LY41-100/120 (K = 2,05)
- T7, T11 – Stress on the concrete deck measured in the middle of the beam´s span by strain gauges LY11-6/350 HBM Darmstadt (K = 2,0)
- F – loading force measured by strain gauge transducer Interface 500, USA
- z – vertical displacement of the steel strip measured by draw-wire displacement sensor WPS-250-MK30, Micro-Epsilon Bechyně
- the development of the cracks was recorded depending on the value of applied force

The signals were recorded by measuring center MGC plus, HBM Darmstadt with the frequency 20 Hz/channel. The recorded parameters were then processed using Microsoft Excel.

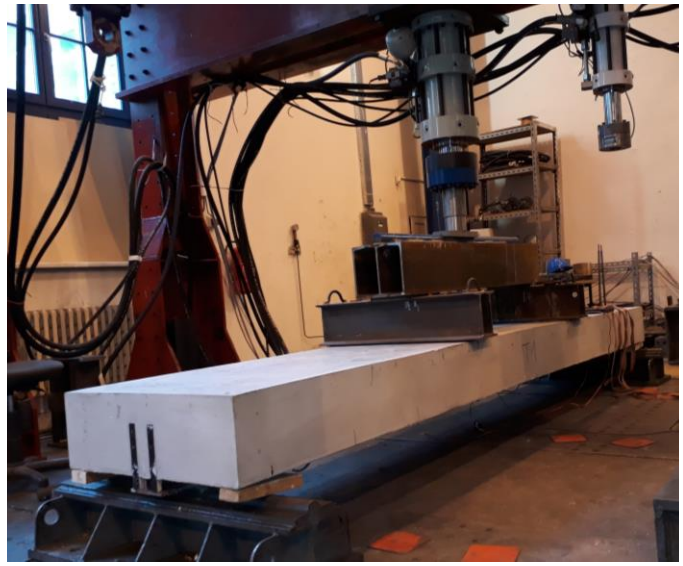

Fig. 11 four-point bending test, simply supported beam with visible shrinkage cracks

Fig. 12 the composite beam under the load of 400 kN; visible destruction at the point, where the force was applied; destruction in the middle of the beams span seen from the bottom of the beam

The tests were graphically processed, see Fig. 13. In order to visibly compare the values of stresses measured by strain gauges and calculated by numerical model, the values were inserted in the Table II.

This table shows the values of stresses at chosen points under the load of 100 kN. The stress distribution nearly corresponds to the stress distribution gained by numerical model. In this moment the numerical model can be calibrated and used for future parametrical studies and optimization of the composite cross section.

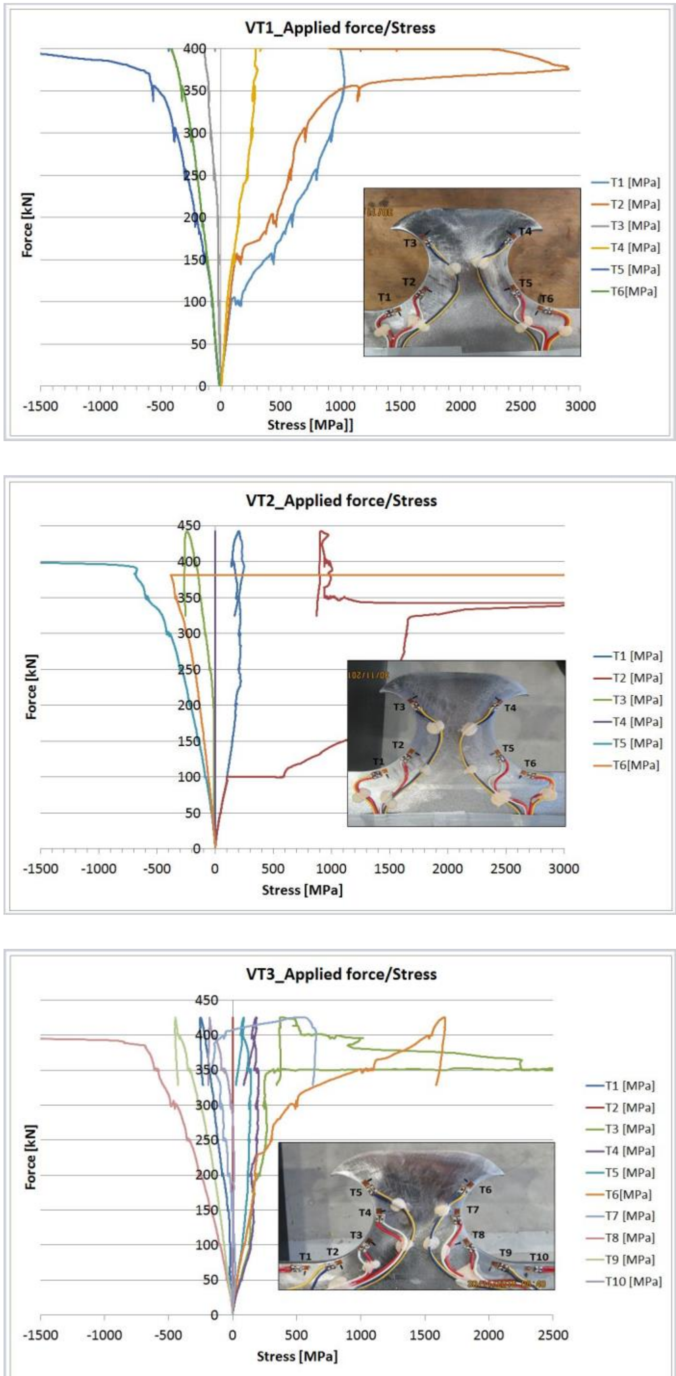

Fig. 13 the force/stress diagrams, test specimen VT1, VT2, VT3

Table II the values of stress measured by strain gauges under the load of 100 kN

VT1		VT2		VT3	
				T1	-21
T1	135	T1	103	T2	0
T2	78	T2	100	T3	137
				T4	142
T3	-17	T3	-12	T5	75
T4	56	T4	0	T6	89
				T7	15
T5	-72	T5	-83	T8	-98
T6	-69	T6	-60	T9	-67
				T10	0
	tension				
	compression				
0	dammaged gauge				

V. CONCLUSION

Presented paper deals with the problems of load bearing capacity of composite steel-concrete beam using pcb-W technology. To establish an elementary numerical model, it is essential to understand the behavior of each part of the complex composite beam.

The integral part of the composite beam constitutes the steel connector, in the case of pcb-W technology steel dowels. The author presents the process of examination of the behavior of these steel dowels under static load.

The results obtained from four-point bending tests are used for calibrating the numerical models of composite steel-concrete beams.

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V. Václavíková (M´15) was born in Olomouc, Czech Republic in 1987. She graduated in 2013 at Brno University of Technology and got the degree Master of Civil Engineering (Ing.). Her major was Steel structures and Building construction. She also got Bachelor´s degree in Law at Masaryk University in Brno. Her major field of study was Land law and Real estate register. In 2009/2010 she had an internship at Vilniaus Gedimino technikos universitetas in Vilnius, Lithuania. So far, the author continues with her studies to get the Doctorś degree of Civil engineering.

She gained work experience in Statika Olomouc Ltd. during her studies (2011 - 2014). Her occupation was designer of steel, timber and concrete structures. Then she worked in Vladimír Fišer Company in Brno as a research worker in steel and concrete bridges which enables her to continue with her studies at the university. Currently the author is on maternity leave. The author published some articles on conferences of PhD students in Czech and Slovak republic. She participated in the conference of Civil Engineering in London, Zakynthos and Bern.

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