Innovative shear connection with composite dowels – verification using push-out test

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Abstract: - In recent years many research on composite beams with innovative shear transmission with composite dowels have been conducted and innovative composite constructions have been built. One of the common types of shear connection is the method of rolled girders encased in a concrete slab. The combination of such method and pcb (precast composite beam) technology is called pcb-W (precast composite beam – coupled in web) technology which has been developing since 2003 in Germany. The longitudinal shear force is transformed by composite dowels instead of headed studs. The standard push-out tests according to EC4 have been performed at the Brno University of Technology to verify the behavior of the composite connection. The bearing capacity of the concrete dowel is mainly affected by reinforcement area. The minimum or recommended area of the reinforcement is given by [7]. If greater bearing capacity of concrete dowel was required, it would be possible to employ more reinforcement bars or use reinforcement bars of greater parameter. However, we have to consider the armoring and mounting of the structure, which is more complicated the more reinforcement we use. For this reason, nine specimens were prepared for the standard push-out tests, 3 specimens with common concrete and recommended area of reinforcement, 3 specimens with fiber reinforced concrete and reduced area of reinforcement and 3 specimens with fiber reinforced concrete and no additional reinforcement. The reason of this research is to lower the area of reinforcement bars in composite dowels and make the process less laborious.

Key-Words: - Composite structures, push-out test, pcb-W technology, steel fiber reinforced concrete

1 Introduction

The paper author´s workplace deals with the problems of high-strength materials for composite steel and concrete structural members, see e.g. [10], and introduces the use of advanced, non-traditional materials in traditional structural members and also participates on the process of the development, structural design and experimental verification of steel and concrete composite columns composed of high-strength steels and high-performance concretes. Presented paper comes as a result of author´s doctoral study as a part of doctoral thesis dealing with the problem of modern methods of shear connection of composite steel-concrete beams.

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

One of the topics of the author´s workplace research field is the application of new progressive concrete types in composite steel-concrete structural members and structures. The author´s research is inspired, among other things, by the theoretical and experimental investigation of the usage of glass-fiber-concrete for slab of steel and concrete beams, mentioned for example in [11] and [12].

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 purposes of this experiment are especially two main points:

- Verification of bearing capacity of composite dowels calculated according to the design manual of SSF
- Testing the suitability of using steel fiber concrete for pcb-W technology, comparing the bearing capacity of steel fiber reinforced concrete and common concrete, in particular with the intention to reduce the required amount of reinforcement in composite dowels.

2 pcb-W technology

2.1 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, of which approximately 150 have been designed by SSF Company [6].

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

Figure 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, see Fig. 2. 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].

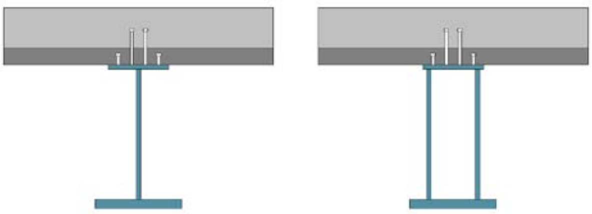

Figure 2: Open and closed pcb girder

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.

2.2 pcb-W technology

For the bridge spans up to 30 m and high slenderness of the bridge fields it is worth to leave out the upper steel flange and use the pcb-W technology, described also in [5]. It is the combination of pcb technology and a method of rolled girders in concrete (W), which is a traditional method used frequently for railway bridges since the 1st half of 20th century.

Load-bearing structures of deck railway bridges with encased filler beams have been used for short and middle spans of a maximum of 24 meters. For over a hundred years they have been designed in cases with little headroom. The first bridges were constructed with no interaction between steel beams and concrete floor slabs, the structural steel working as a bearing element and the concrete in the structure as a hardening and filling element. Later, in the second half of the 20th century, more developed bridge designs were introduced where encased steel beams were used acting compositely with a concrete floor slab – the concrete transmitting actions in compression and the steel acting in tension. These structural designs were based on the method of permissible stresses and have been in use up to present [13]. The encasement of the steel shapes in concrete is applied primarily for the following purposes: flexural stiffening and strengthening of compression elements, fire protection, potentially easier repairs after moderate damage and economy with respect both to material and construction [14].

However, the rate of bridges using this method has been degreasing for the last decades due to high consumption of steel, high costs and bad dynamic properties [8]. Since 2003 SSF Ingenieure GmbH has been developing the pcb-W construction method, which combines the advantages of pcb and W construction technologies. 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. These T-sections are embedded into lower part of concrete deck or into a concrete beam which generates the composite dowels, see Fig. 3.

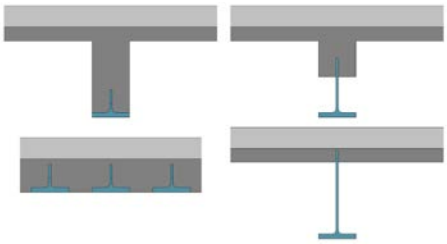

Figure 3: Cross-sections of pcb-W girders

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 (Fig. 4).

Compared to pre-stressed cross-sections an increase up to 20% can be realized for the internal lever arm which leads to more efficient cross-sections with considerably increased stiffness and more economical use of materials [7].

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.

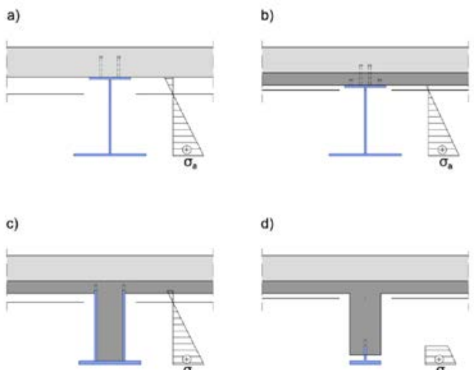

Figure 4: Stress distribution on: a) common composite steel and concrete beam, b) pcb girder, c) + d) pcb-W girder [5]

3 Description of the experiment

The standard push-out test simulates the effect of vertical loads on composite steel-concrete beams. The test specimens were arranged according to the Fig. 5. Both concrete decks should be concreted in horizontal position to correspond with the common practice. However it is impossible to concrete both decks at a time to achieve the same concrete age. For this reason, and also to simplify the casting, the specimens were concreted in a vertical position.

The reinforcement area of specimens with common concrete was designed according to the design manual [6, 7] with recommended reinforcement area in concrete dowels and in the area between the dowels.

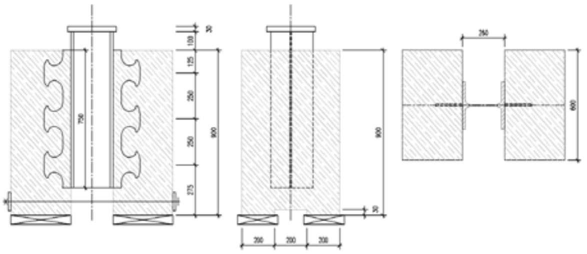

Figure 5: Push-out test scheme

The experiment includes three groups of specimens, each group contains 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 designed as 20 mm.

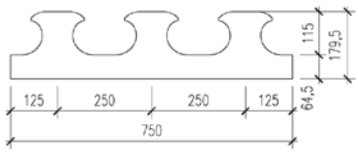

Figure 6: The diameters of the steel strip

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 1.

Table 1: 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 +	2 R6	R8	4
	V5	C30/37 +	2 R6	R8	2
	V6	C30/37 +	2 R6	R8	2
S3	V7	C30/37 +	-	-	4
	V8	C30/37 +	-	-	2
	V9	C30/37 +	-	-	2

The test specimens were designed according to the design book, so the failure would appear in concrete, more specifically the spalling of concrete cover would appear. The bearing capacity of the specimen with common concrete is with given geometry, strength grades of steel and concrete, and recommended reinforcement area 828,6 kN.

3.1 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 is to specify the stress distribution of the steel strip 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 the experiment. The values measured during the experiment will be compared with the values given by the numerical model and the model will be calibrated.

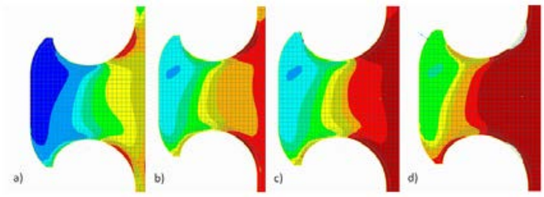

Figure 7: Stress distribution under the different load conditions

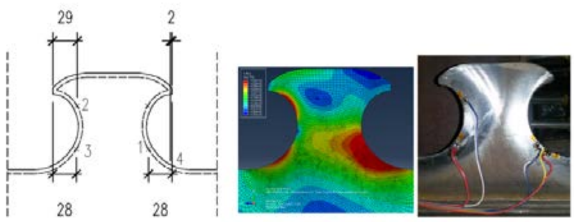

Figure 8: Identification of HOT SPOT, strain gauges

4 Preparatory work

4.1 Concreting of the test specimens

The test specimens were concreted on 23.9.2015 in the premises of the AdMaS center. The concreting was carried out in two phases; at first the group of test specimens S1 and then the groups S2 and S3 were cast.

Concreting of the first group of specimens was carried out without problems. During the casting of fiber reinforced concrete some of the specimens moved in the formwork. The biggest displacement occurred during concreting of the specimen V7, i.e. the sample without reinforcement, because of the lack of reinforcement did not hold the steel profile in the position.

5 The experiment

The first part of test specimens was tested on the premises of the AdMaS center on 26.10.2015. 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.

The test procedure is given by EC4. The load should be applied in increments up to 40% of the expected failure load and then cycled 25 times between 5% and 40% of the expected failure load. Subsequent load increments should then be imposed such that failure does not occur in less than 15 minutes.

Figure 9: Test equipment

The first specimen of the whole experiment was specimen V1. Expected failure load of the specimen is 828,6 kN. So the specimen was exposed to the 40% of such value, it means 331,44 kN and then according to the procedure given by EC4. However, we did not notice any signs of failure during the loading process up to the capacity of the hydraulic cylinder. That is why we repeated the test with two parallel hydraulic cylinders with the intention to save some time; we cycled the loading up to the 40% of the failure load only 3 times. Then the specimen was loaded up to the capacity of both hydraulic cylinders. The failure did not occur. There were small cracks at the ends of HEB flanges. The next tested specimen was V4, the failure did not occur as well. The cracks could be seen at the place of steel strip as well as in the case of specimen V8.

The last tested specimen was V9, the failure occurred in the place of steel strip as it can be seen on Figure 7.

Figure 10: Failure of the test specimen V9

The rest of the experiment was postponed with the hope to find better way to load all of the specimens up to the failure. However we did not find any facility with such equipment, so the second part of the test specimens was tested in AdMaS center as well. The test took place on 4. 10. 2016; the measured parameters and equipment were the same.

With the intention to save some time, we did not cycle the loading up to the 40% of the expected failure load; we loaded the experiments up to the capacity of the hydraulic cylinders. The failure did not occur, there were small cracks at the place of the steel strip and at the ends of HEB flanges.

5.1 Experiment evaluation

The tests were graphically processed. Several diagrams were made: loading force on time, stress on strain gauges on time and vertical displacement on time. Then the values of stress on strain gauges on applied force were graphically processed, see Appendix.

It can be seen on the stress/applied force diagrams, that 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.

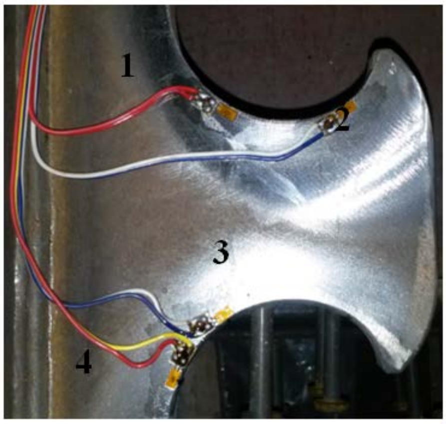

Figure 11: The positions of strain gauges

6 Conclusion

The aim of this experimental research is to contribute to knowledge about the behavior of simple supported composite steel-concrete beams exposed to bending using modern shear connection such as pcb-W technology. The work is focused on the use of fiber reinforced concrete with the intention to reduce the percentage of additional reinforcement in the concrete dowels and thereby reduce labor intensity of pcb-W technology. 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 I recommend 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. The next step of author´s research is to evaluate the test, calibrate the numerical models and realize the bending test.

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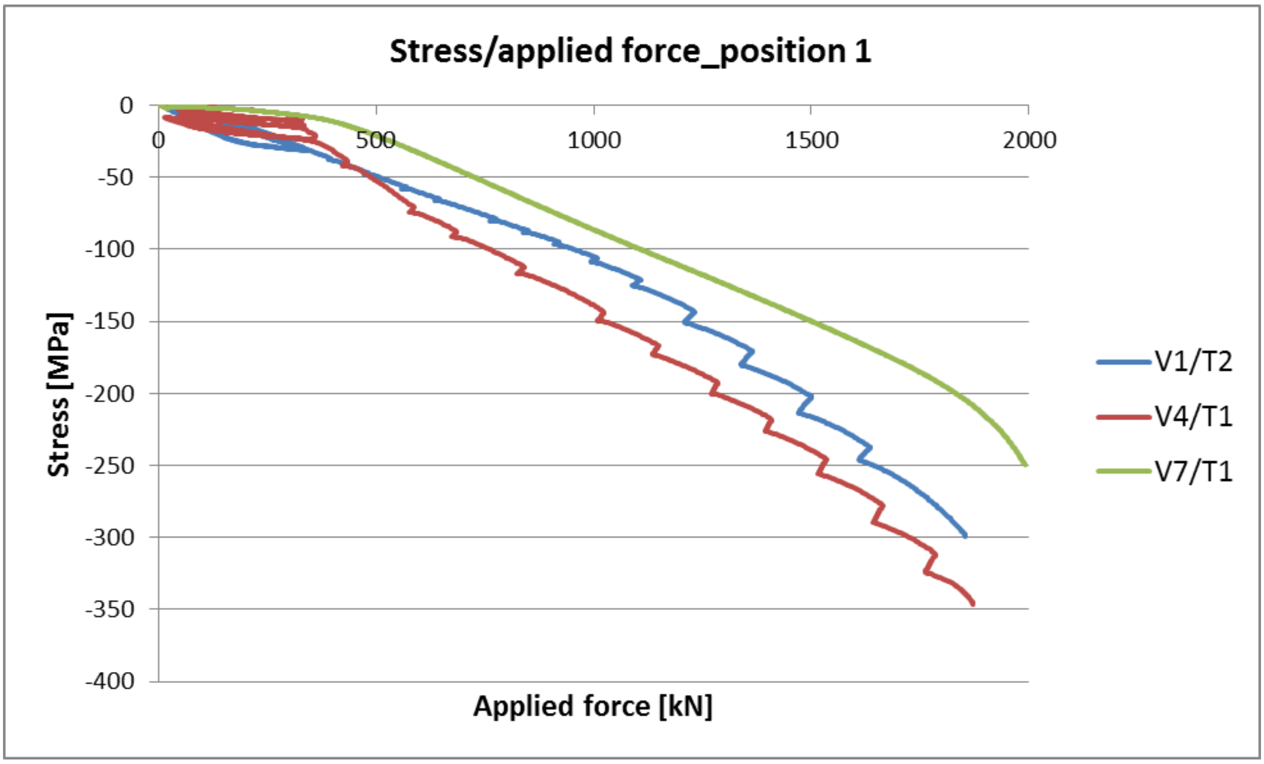
Appendix: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-100
-150
-200
-250
-300
-350
-400
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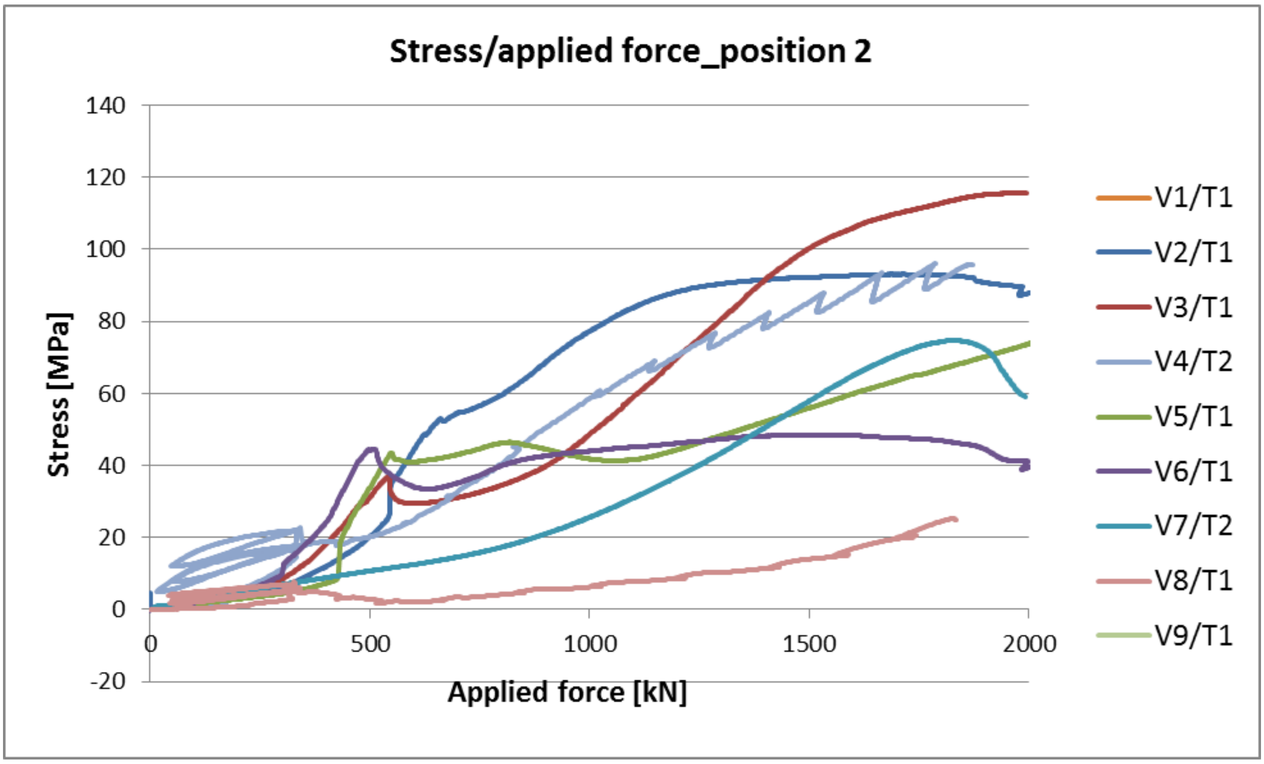
500
1000
1500
2000
Applied force [kN]
V1/T2
V4/T1
V7/T1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100
80
60
40
20
0
-20
0
500
1000
1500
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Applied force [kN]
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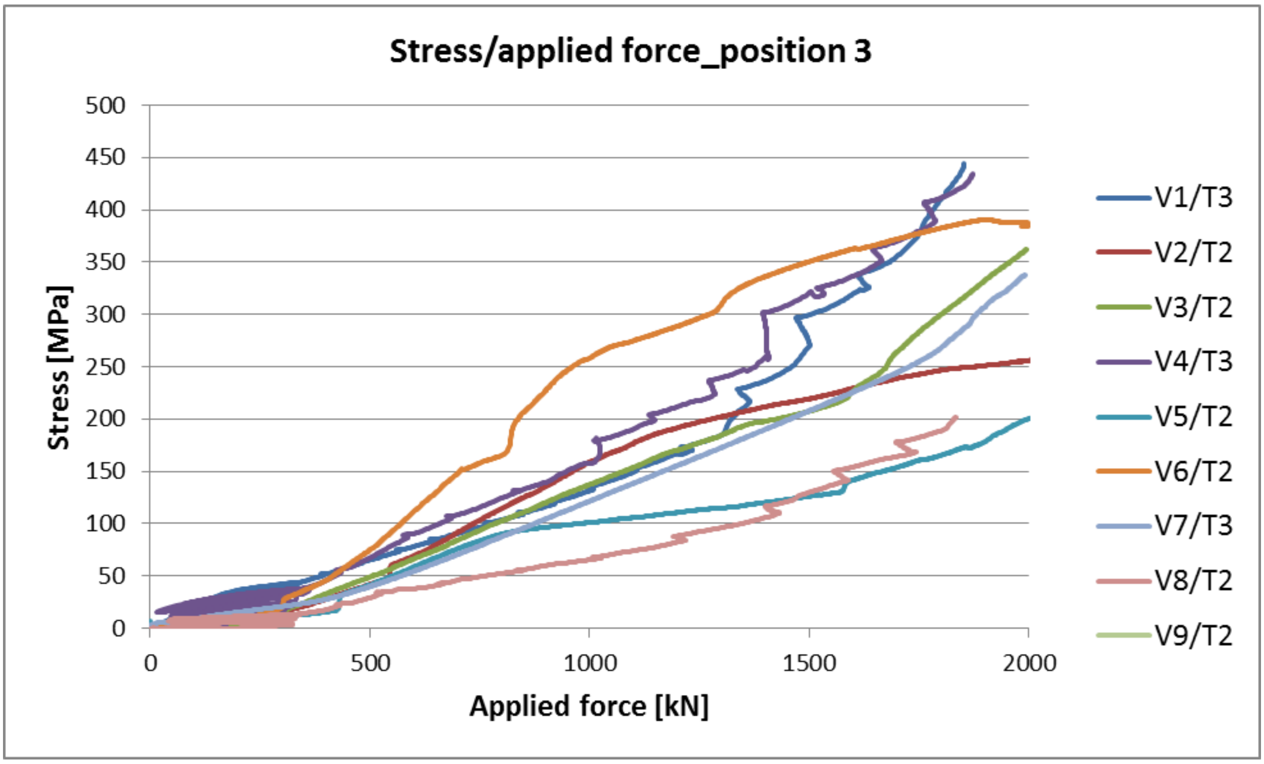
V7/T2
V8/T1
V9/T1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Applied force [kN]
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150
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1000
1500
2000
V1/T3
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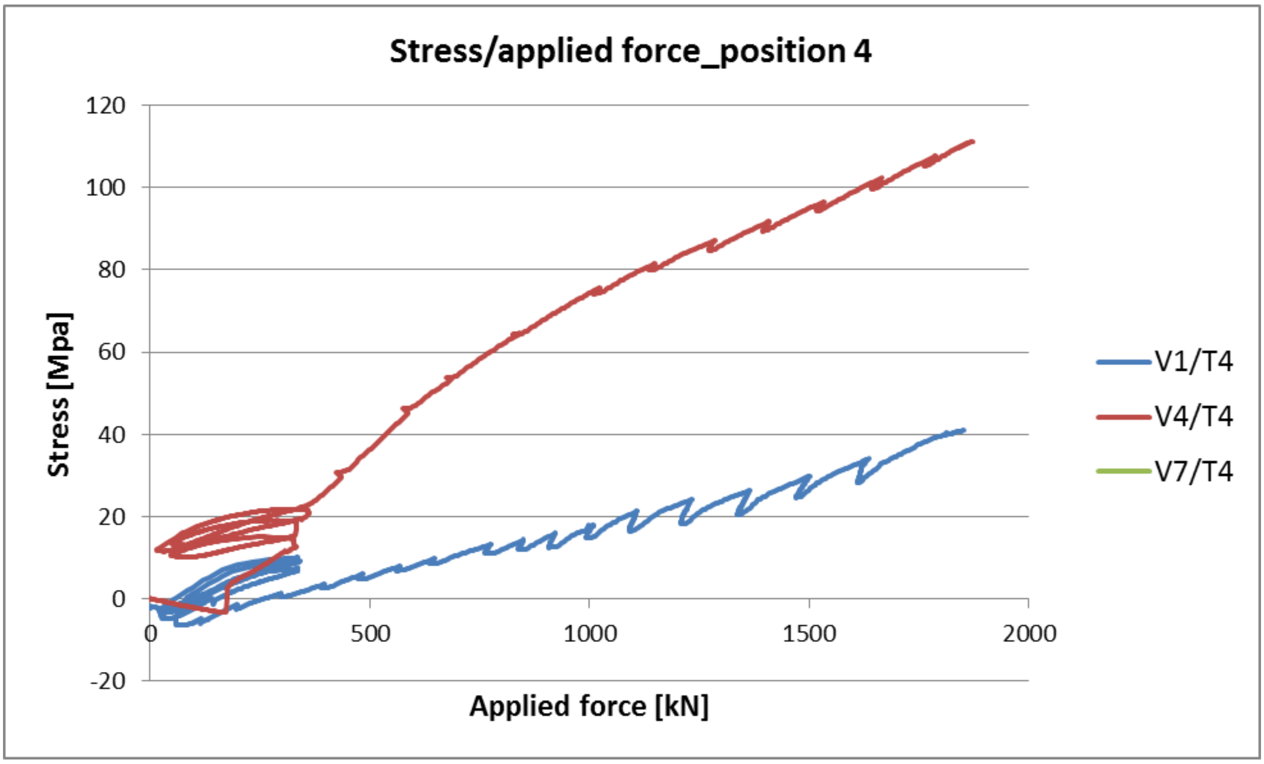
V3/T2
V4/T3
V5/T2
V6/T2
V7/T3
V8/T2
V9/T2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