Experimental verification of innovative shear connection of composite steel-concrete beams using push-out tests

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Abstract: - The paper presents an experimental verification of shear connection between steel and concrete part of a composite beam. 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 and to investigate the possibility of application of steel fiber reinforced concrete for such technology. 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

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 processed parametric study, mentioned for example in [2-4], the method of shear connection was chosen using pcb-W technology.

This technology , described also in [5], which development was initiated by Munich engineering office SSF Ingenieure GmbH, combines the benefits of method of rolled girders in concrete (W) and pcb technology. Pcb-W technology 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 the lower part of concrete deck or into a concrete beam which generates so called "composite dowels". The longitudinal shear force is then transformed by these composite dowels instead of headed studs. Major advantage of this method is an increased internal lever arm up to 20% compared to the pre-stressed cross-sections which leads to more efficient cross-sections with considerably increased stiffness and more economical use of materials [7].

The standard push-out test according to [1] is used to verify the bearing capacity of elements of shear connection and parameters of such shear connection. The purposes of this experiment are mostly 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 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 Figure 1. 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.

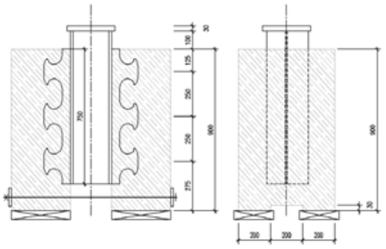


Figure 1: Push-out test scheme

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.

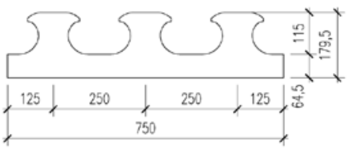


Figure 2: The diameters of the steel strip

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.

2.1 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.

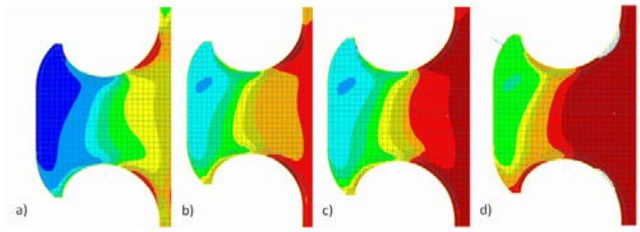


Figure 3: Stress distribution under the different load conditions

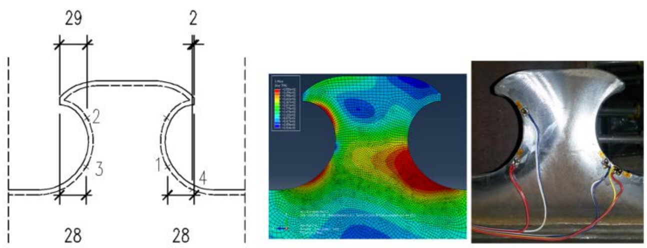


Figure 4: Identification of HOT SPOT, strain gauges

3 Preparatory work

3.1 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.

Figure 5: Concreting

4 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 6: 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 7: 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.

4.1 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.

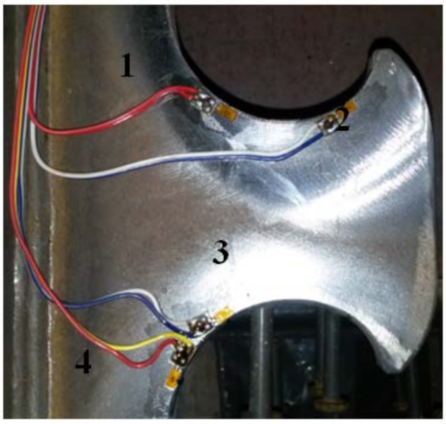


Figure 6: The positions of strain gauges

5 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.

References:

[1] ČSN EN 1994-1-1. *Eurokód 4: Navrhování spřažených ocelobetonových konstrukcí – Část 1-1: Obecná pravidla a pravidla pro pozemní stavby.* Praha: Český normalizační institute. 2006. 101 s.

[2] PŘIVŘELOVÁ, V. *Optimization of composite steel and concrete beams in terms of the influence of material strength on carrying capacity - parametric study.* Published in JUNIORSTAV 2014, Brno. 2014.

[3] PŘIVŘELOVÁ, V. *Optimization of composite steel and concrete beams with lightweight concrete deck in terms of the influence of material strength on carrying capacity – parametric study.* Published in 6th Ph.D. Student Conference of Civil Engineering and Architecture Young Scientist, Herlany. 2014. ISBN-978-80-553-11668-0.

[4] PŘIVŘELOVÁ, V. *Modelling of Composite Steel and Concrete Beam with the Lightweight Concrete Slab. International Journal of Civil, Architectural, Structural and Construction Engineering, Volume 8, Number 11.* World Academy of Science. 2014. ISSN-1307-6892. P 1070-1074.

[5] PŘIVŘELOVÁ, V. *The use of pcb-w technology and concrete with added value in composite steel and concrete structures.* In: 17. odborná konference doktorského studia Juniorstav 2015, Brno. 2015. ISBN 978-80-214-5091-2.

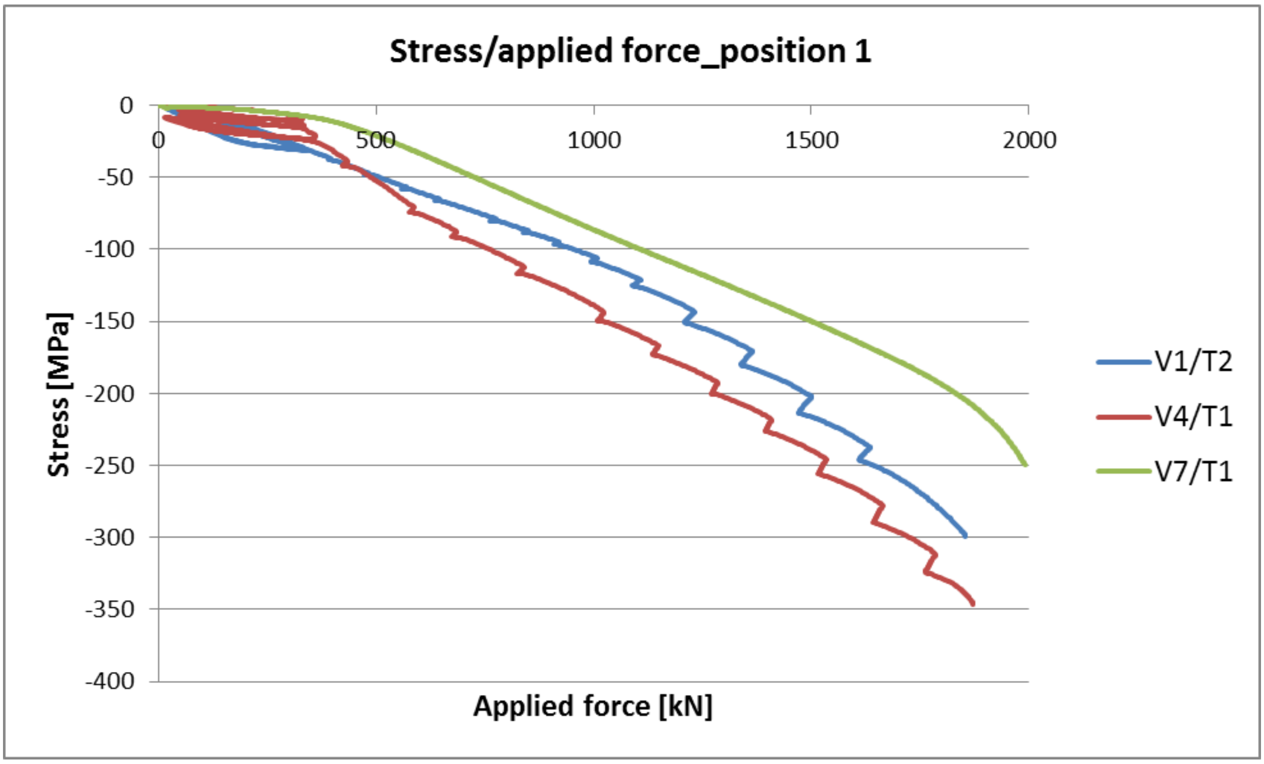
[6] BUBA, R. Mosty v technologii VFT®. Příručka pro projektanty a výrobu. München. 2010. 42 s.

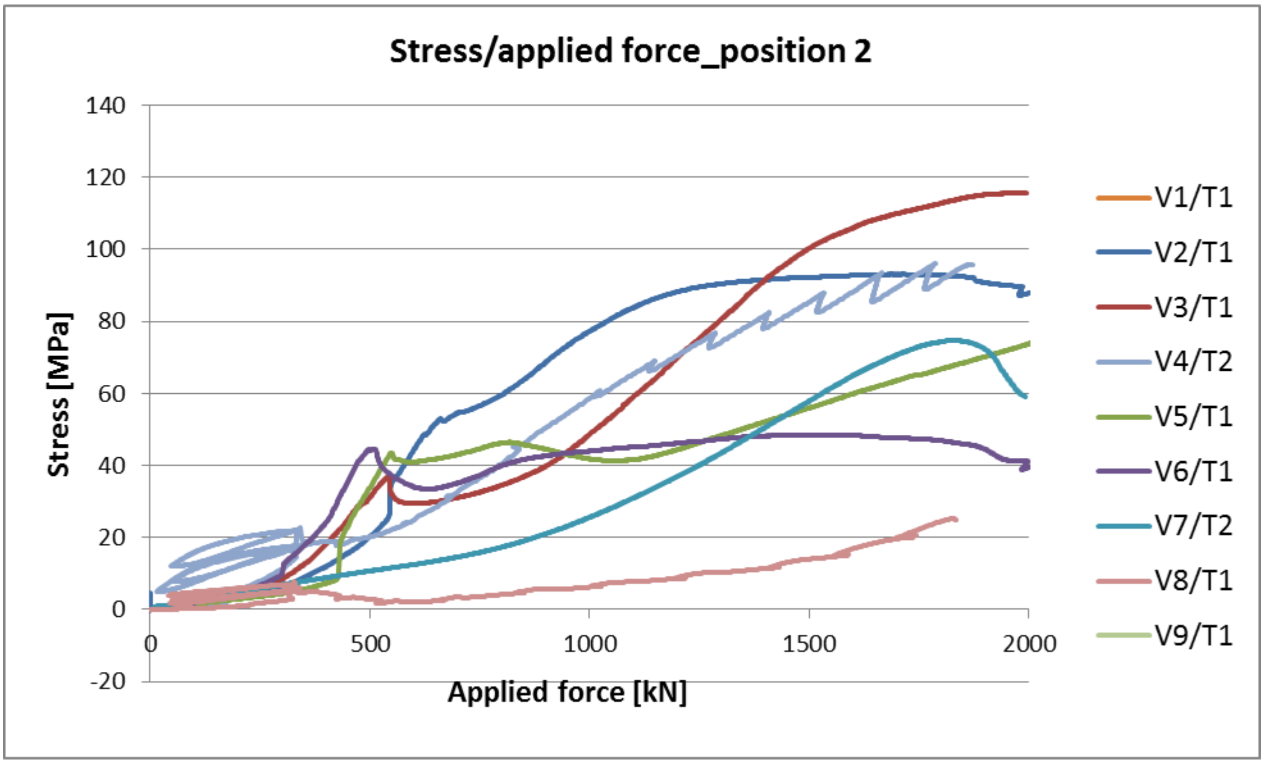
[7] SEIDL, G. - HOYER, O. *WFT - WIB Technology. Design, Construction and Applications.* Berlin. 2012. 103 s.

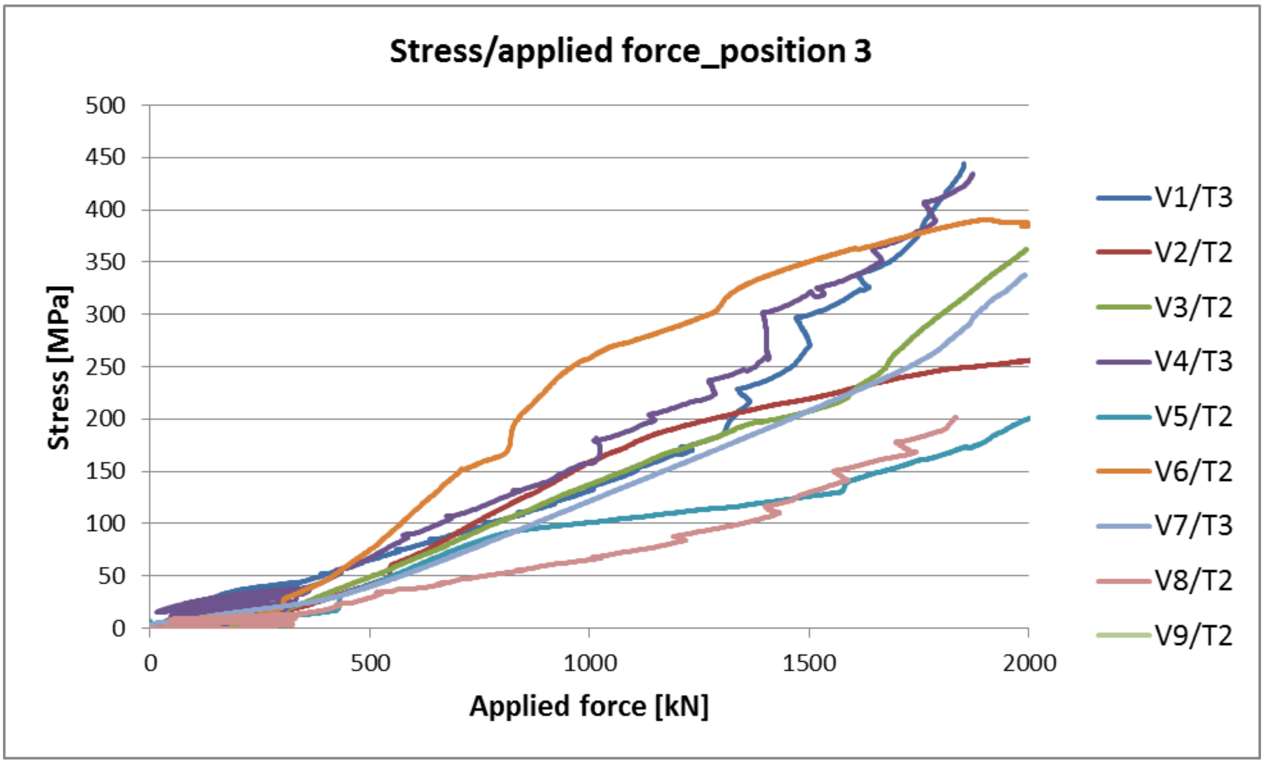
[8] SCHMITT, V. - BUBA, R. *Innovative Building Methods for Bridges with Small and Medium Spans - VFT and VFT-WIB.* Sborník konference Steel Bridges. Praha. 2006. Str. 66 - 74.

[9] HECHLER, O., LORENC, W., SEIDL, G., VIEFHUES, E. *Continuous shear connectors in bridge construction.*

Appendix:


Stress/applied force_position 1
0
-50
-100
-150
-200
-250
-300
-350
-400
0
500
1000
1500
2000
Stress [MPa]
Applied force [kN]
V1/T2
V4/T1
V7/T1


Stress/applied force_position 2
140
120
100
80
60
40
20
0
-20
0
500
1000
1500
2000
Stress [MPa]
Applied force [kN]
V1/T1
V2/T1
V3/T1
V4/T2
V5/T1
V6/T1
V7/T2
V8/T1
V9/T1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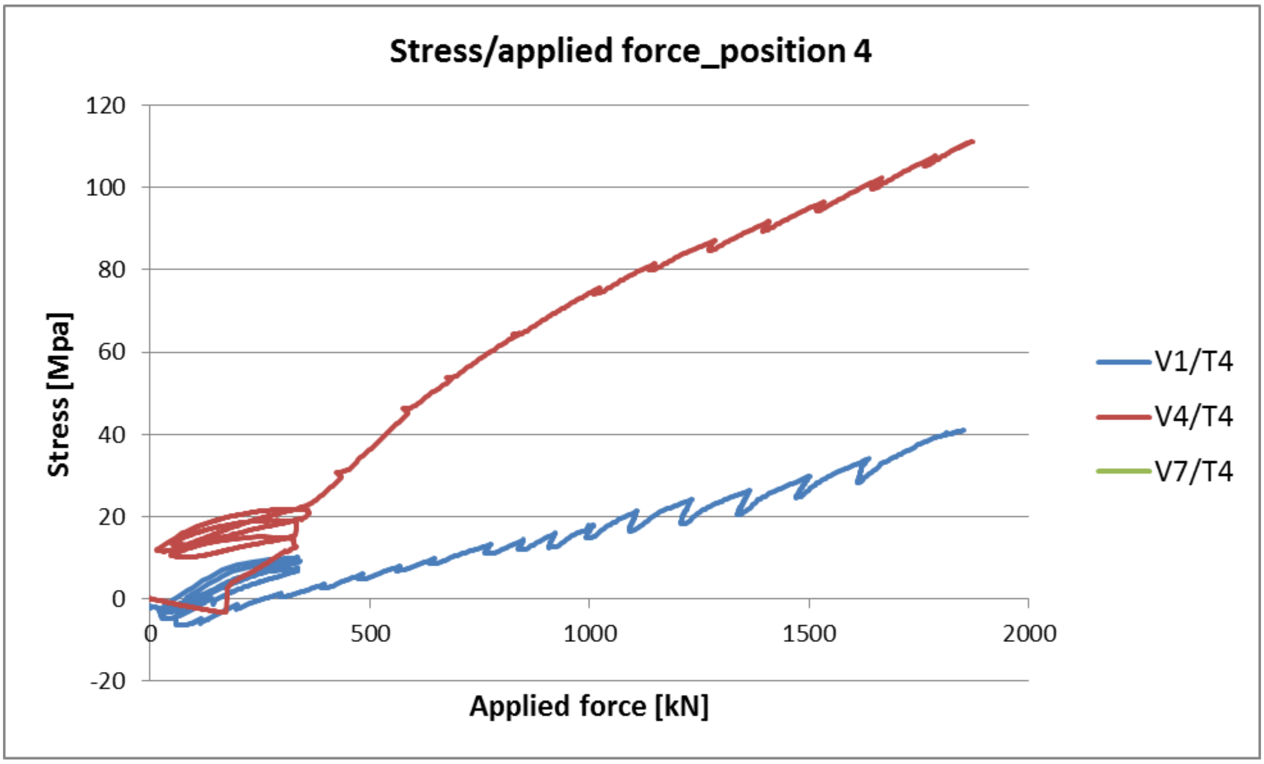
Stress [MPa]
500
450
400
350
300
250
200
150
100
50
0
0
500
1000
1500
2000
Applied force [kN]
V1/T3
V2/T2
V3/T2
V4/T3
V5/T2
V6/T2
V7/T3
V8/T2
V9/T2


Stress/applied force_position 4
Stress [Mpa]
120
100
80
60
40
20
0
-20
0
500
1000
1500
2000
Applied force [kN]
V1/T4
V4/T4
V7/T4