EAN 2020
58th conference on experimental stress analysis

Identification of MTB Enduro Bicycle Frame Behaviour

KROPÍK B.[1,a], MALÁ A.[1,b], SCHMIDOVÁ N.[1,c], DOUBRAVA K.[1,d] , PONÍŽIL T.[2,e] , DVOŘÁK M.[1,f], MAREŠ T.[1,g]

[1] Department of Mechanics, Biomechanics and Mechatronics, Faculty of Mechanical Engineering, Czech Technical University in Prague. Technická 4, Praha 6, Czech Republic

[2]Compo Tech PLUS, spol. s r.o. Nová 1316, Sušice, Czech Republic

[a] Bohumil.Kropik@fs.cvut.cz, [b] Anna.Mala@fs.cvut.cz, [c] Nikola.Schmidova@fs.cvut.cz, [d] Karel.Doubrava@fs.cvut.cz, [e] tomas.ponizil@compotech.com, [f] Milan.Dvorak@fs.cvut.cz, [g] Tomas.Mares@fs.cvut.cz

Keywords: Bicycle frame, CFRP, Filament winding, MTB enduro, Integrated joint

Abstract. This paper deals with the design of a bicycle frame. The experimental part is focused on identification and evaluation of the front triangle down tube behaviour with a significant effect of the shock absorber. Evaluation of extreme values and assessing the frequency of their occurrence with focus on selecting important measuring places for future tests was done. Part dedicated to the finite element method is focused on new version of bicycle frame front triangle with focus on finding of equivalent horizontal force acting into front fork related to measured strain and detection of critical places of bicycle frame front triangle. Critical places together with equivalent force were identified. Also bending and tension/compression component of strain distribution along the front triangle down tube was evaluated. Important measured channels were selected, and all these data are valuable for future testing of new version of bicycle frame front triangle. Laboratory test and comparison with finite element (FE) analysis was done.

Introduction

Joining of composite tubes is big a design challenge. Current joining techniques are mostly based on bonding in of additional parts or in bicycle industry commonly used hand lamination over the joined tubes. Objective of project is to develop cost-efficient high-performance joint for frame structures demonstrated on mountain bicycle frame. This contribution deals with an experimental identification of behaviour of MTB enduro bicycle frame made fully from Carbon Fibre Reinforced Polymer (CFRP) filament wound tubes with Integrated Loop Technology (ILT) joints. Motivation is thus to identify applied loads to the frame tubes and joints during testing which is crucial and provide crucial information for design of the strong, stiff and durable joint.

Bicycle design. The main triangle of the bicycle frame is made of CFRP filament wound tubes with ILT joints as shown in Fig. 1. The ILT is described in detail in [1]. The single pivot full suspension mountain bike frame consists of two parts: the front triangle and the swing arm. These two parts are connected by the main pivot and a shock absorber. The front triangle tubes made including the integrated joints are bonded together to form the base of bicycle frame. The scheme of the bicycle frame is shown in Fig. 2.

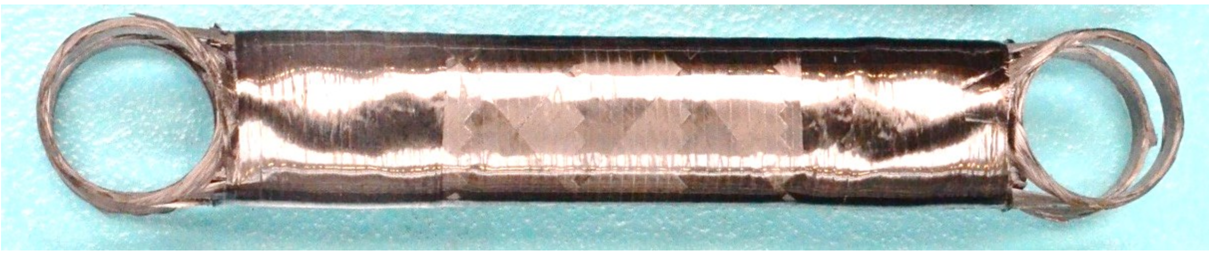

Fig. 1: CFRP filament wound tubes with ILT joint

Measurement. Most complex load state on the bicycle frame is on front triangle down tube due to shock absorber connection. Critical in terms of safety and performance of the bicycle is the front triangle Down Tube (DT) and Head Tube (HT) joint. Therefore, 1- axis linear strain gauges (SGs) were installed on top and bottom sides of DT (see Fig. 2. place a – d) and shear SGs were installed on both sides (place e). Combination of quarter, half and full bridge connection was used for identification of axial, bending and torque load. The set of HBM QuantumX measurement units carried in a backpack was used for measurement. Some basic load cases were recorded at first, followed by measuring of routine driving on tracks in terrain as shown in Fig. 3.

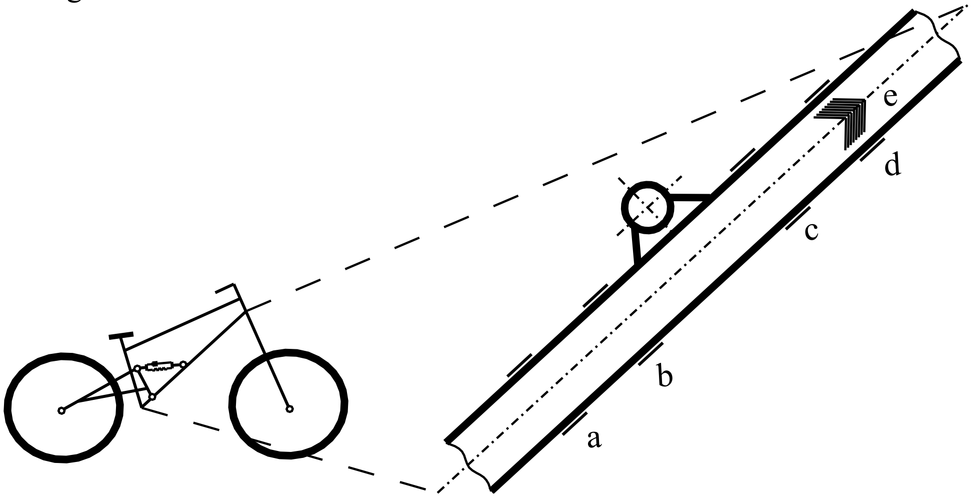

Fig. 2: Scheme of the frame and the positions of the strain gauges on the down tube

Fig. 3: One of the load cases

Evaluation. With distances of positions of SGs (see Fig. 4 a – e) and shock absorber (place f) related to the maximal length of down tube, bending and tension/compression component of strain from SGs connected as quarter bridges (places a and d) was evaluated. Together with bending strain from half bridges (places b and c), they were used for extrapolation to the position of shock absorber. From this, a distribution of bending and tension/compression component of strain behaviour was obtained in time during load cases. All strain values in this paper are related to the maximal measured strain value during experimental measurement. Example of distribution measured during simple load state – single jump – is shown in Fig. 5 for static state with sitting rider, in Fig. 6 during take-off, in Fig. 7 for flying part and in Fig. 8 during landing. Another example of distribution shown in Fig. 9 was observed during routine driving on tracks. This evaluation gives us an idea of load effects on the bicycle frame front triangle down tube and influence of shock absorber. Torsion SGs in position e connected as full bridges gives us an idea of torsion behaviour near DT and HT connection.

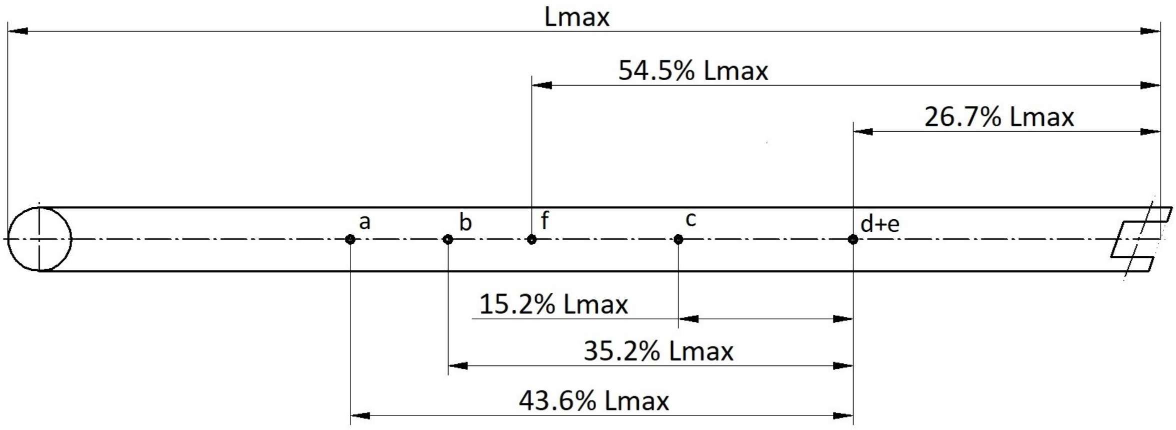

Fig. 4: Distances of positions of SGs and shock absorber on down tube

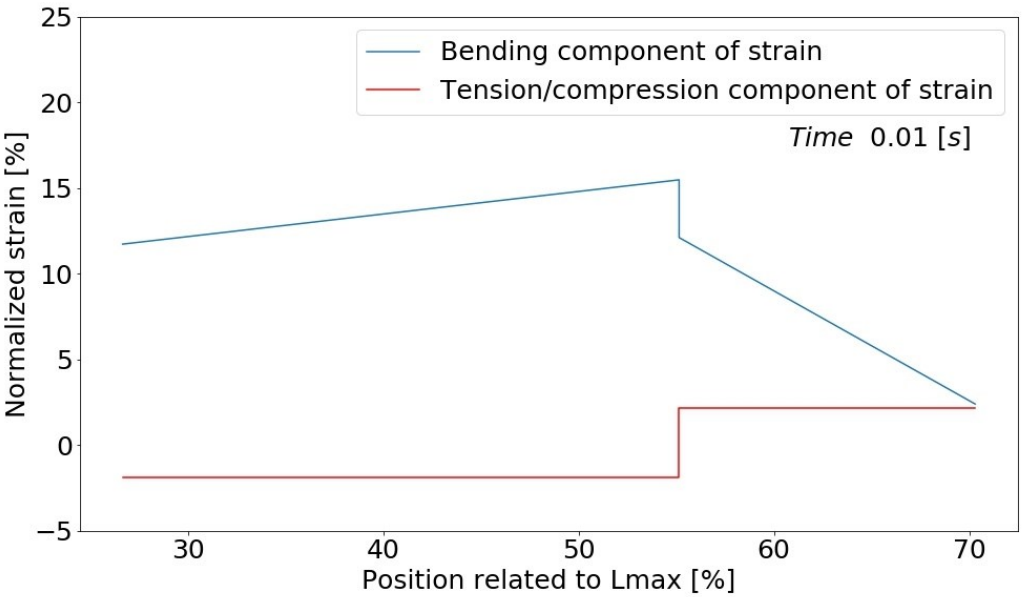

Fig. 5: Distribution of bending and tension/compression component of strain along DT in static state mode with sitting rider

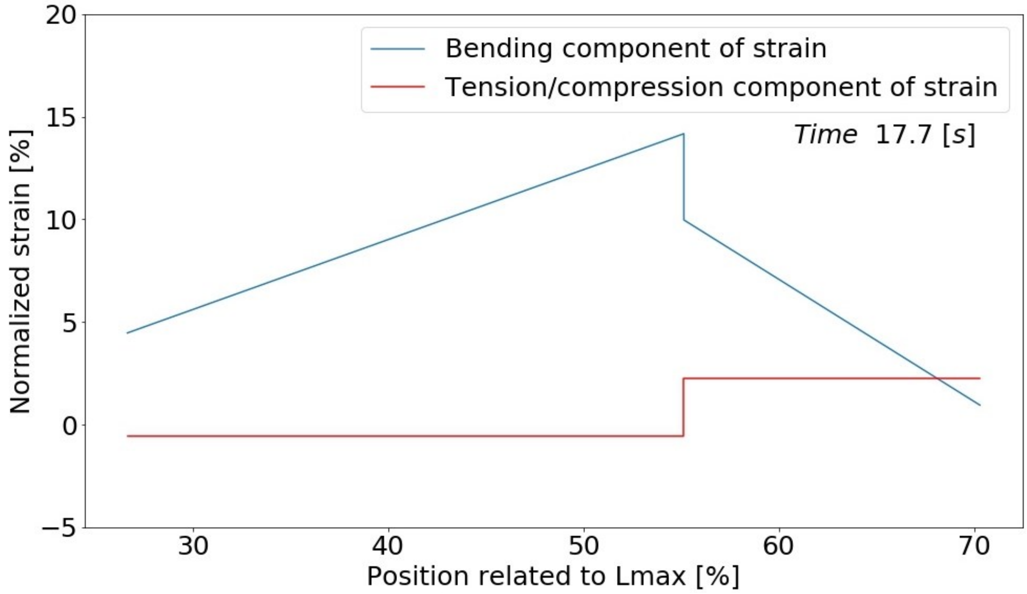

Fig. 6: Distribution of bending and tension/compression component of strain along DT during take-off

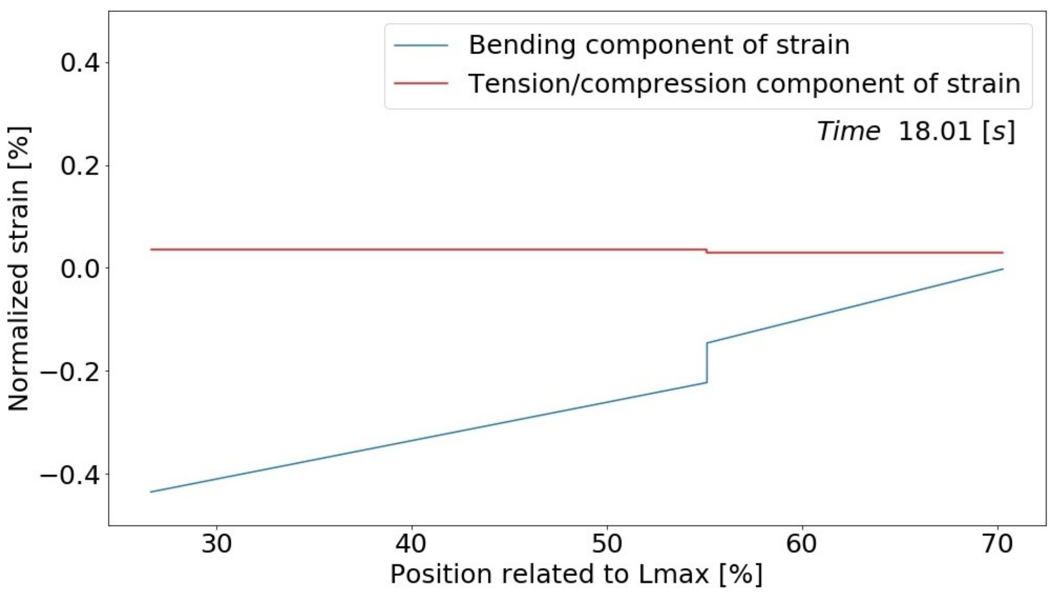

Fig. 7: Distribution of bending and tension/compression component of strain along DT during fly

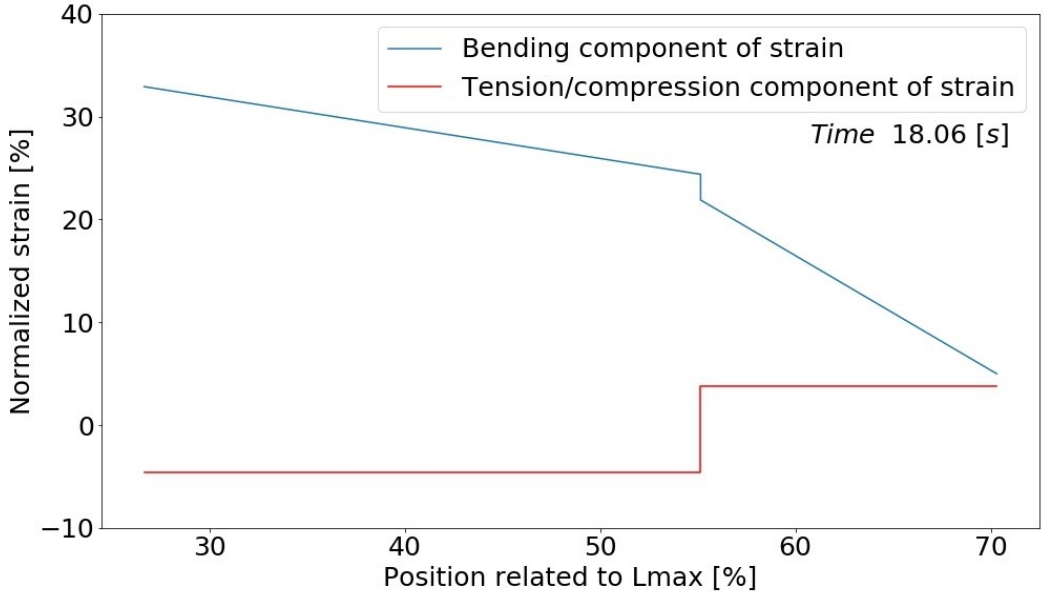

Fig. 8: Distribution of bending and tension/compression component of strain along DT during landing part

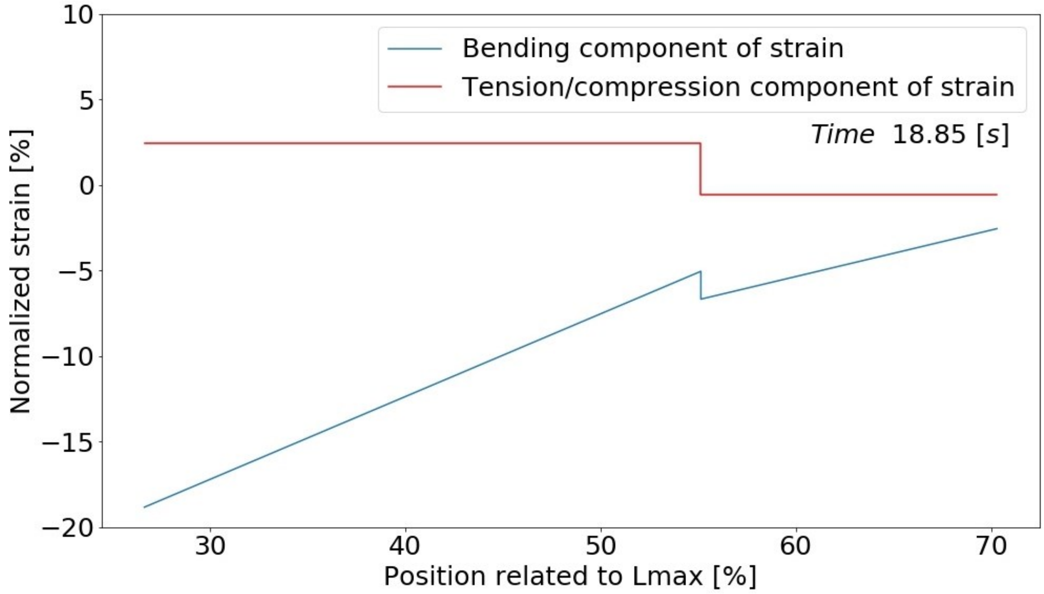

Fig. 9: Distribution of bending and tension/compression component of strain along DT during routine driving

Minimal and maximal values of measured normalized strain were evaluated as shown in Tab. 1. These values were used for the finite element (FE) model to find equivalent force which is described below in FE analysis chapter. Sorting of measured strain values into predefined levels was also done in order to find how often these and close values are achieved. This evaluation shown that most of these values are corresponding to extreme cases, such as bad landing. Extreme values from SGs, torsion behaviour and distribution of bending and tension/compression component of strain along DT were also used for selection of important positions for future tests. Linear SGs in position c and d in a quarter bridge configuration were chosen for future testing. Based on the evaluation can be said that the measured data were valid and may be used for further analysis as inputs for cases of fatigue load or identification of specific behaviour of the frame according to individual load cases such as jump, etc.

Tab. 1: Evaluated strain extremes in % of maximal strain

Position	Minimum [%]	Maximum [%]
a_top	-15.3	10.7
a_bottom	-5.6	25.7
b	-8.4	44.9
c	-19.8	82.8
d_top	-100	39.8
d_bottom	-30.7	75.9
e	-14.9	14.4

Laboratory test stand based on ČSN EN ISO 4210-6 [2] was built in order to compare different versions of bicycle frame and with regard to future fatigue tests necessary for approval of the bicycle frame. Test stand is shown in Fig. 10 and corresponds to the FE analysis simulation. Test arrangement with corresponding FE model was designed for the first comparison of bicycle frames in quasi-static load cases and to validate FEM simulations within the beginning of the project. Both should give us basic idea of bicycle frame durability during the future fatigue test. First quasi-static test with tension force acting on front fork of newer version of bicycle frame was done and comparison of measured values and FE analysis is given in the end of FE section.

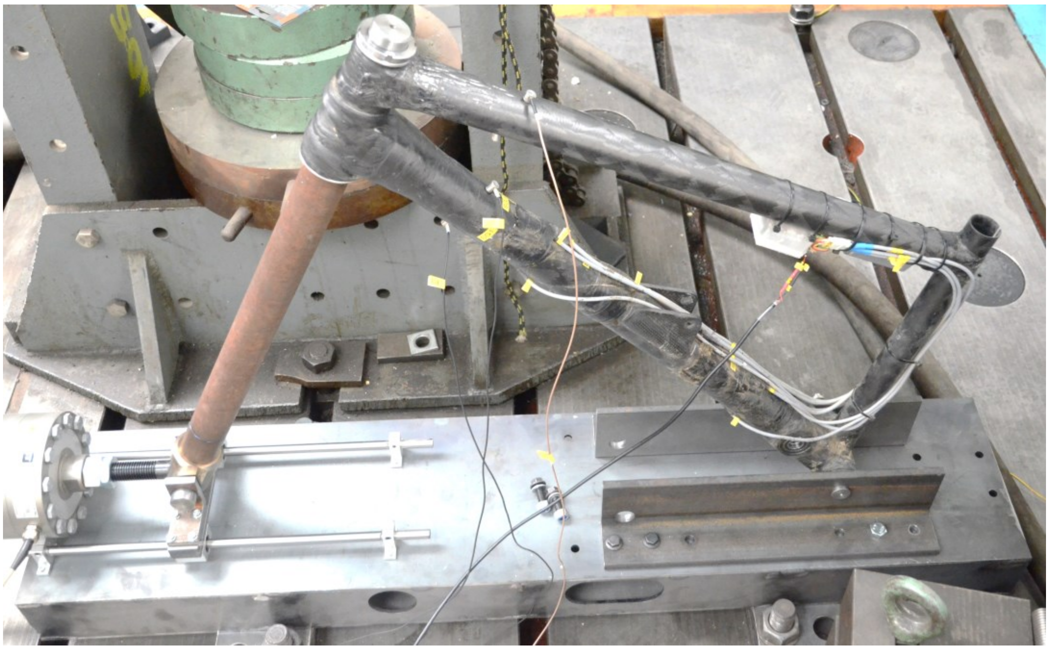

Fig. 10: Laboratory test stand for quasi-static and fatigue load cases

FE model. As mentioned before, the FE model was used to find equivalent force in tension and compression in quasi-static load case and for comparison between quasi-static laboratory test and simulation. Development of the ILT [1] and the bicycle frame is parallel. Improved design of the ILT to the one used for the frame analysed in the field was developed based on the analyses in [1]. It was decided to focus on gradual development of more complex FE model of the frame made with the last version of the ILT due to good correspondence of FE model results and test coupons results in [1]. First simple FE model was made within the beginning of the project with focus on basic design and comparison and it is described here. FE model is being continuously modified to simulate load cases more realistically and to simulate more complex load cases closer to real riding behaviour. Test configuration with rotary binding was used for bottom bracket and sliding binding for front fork which was also horizontally pushed or pulled (see red arrow) is shown in Fig. 11. Model was equipped with selected SGs sensors modelled and bonded to appropriate positions.

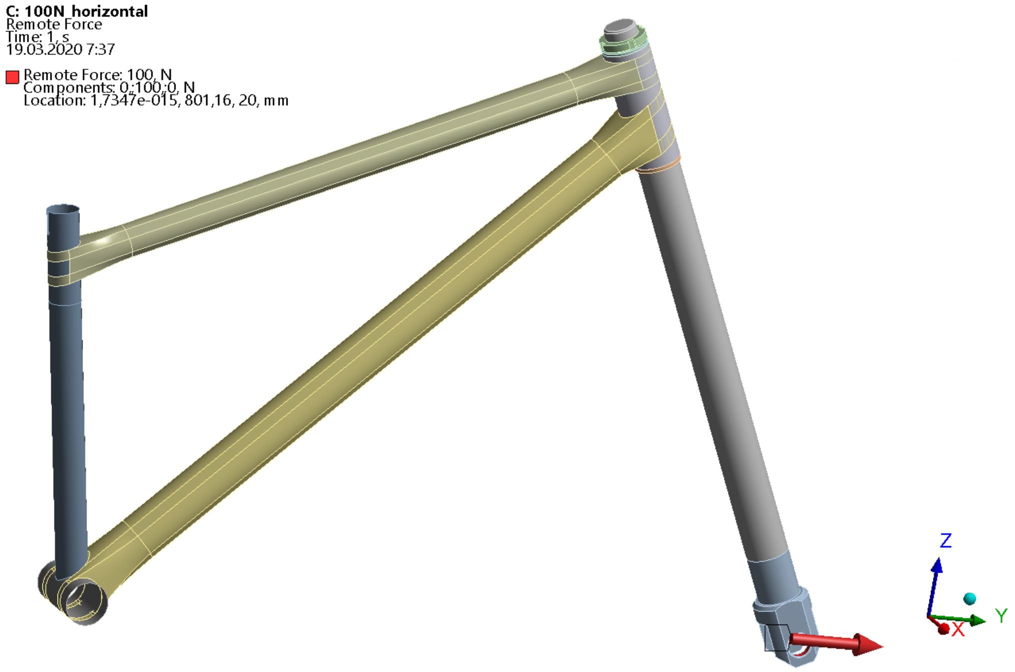

Fig. 11: FE model of bicycle frame according to ČSN EN ISO 4210-6 [2] with force oriented in tension

This analysis gave us tension and compression forces acting on the front fork in the horizontal plane corresponding to the measured strain extremes. The list of values is shown in Tab. 2. A discussion of used model is essential for interpretation of these values. Bicycle frame was made from shell elements with oriented layers of CFRP according to new version of bicycle frame. Analysis was performed as strictly linear, which means that damaged places still retains the same mechanical properties, model is geometrically linear and do not consider plasticity in the first step. Since the progressive damage model was not used, it is expected that these values are bigger than in a real quasi-static test. Even so, this model serves well to detect the first points of failure and to detect weak places of the front triangle design. It should be mentioned that since the model does not fully correspond to the measured bicycle frame these values are only informative.

Tab. 2: FE analysis data

Position	Force in tension [kN]	Force in compression [kN]
c	6.9	-1.6
d	5.4	-2.2
d_top	6.4	-2.5
d_bottom	4.5	-1.8

As a representation of damage failure in this FE model a failure index Inverse Reverse Factor (IRF) is used. Value of IRF equal to 1 or over means that the element is damaged. IRF with tension force of 2 kN is shown in Fig. 12. Maximal IRF value is in this case lower than 1 so there is no visible damage yet. In Fig. 13 is shown the same with 4 kN force and similarly in Fig. 14 with 6 kN tension force. In these figures IRF is equal or over 1 so and damage on areas near head tube was observed.

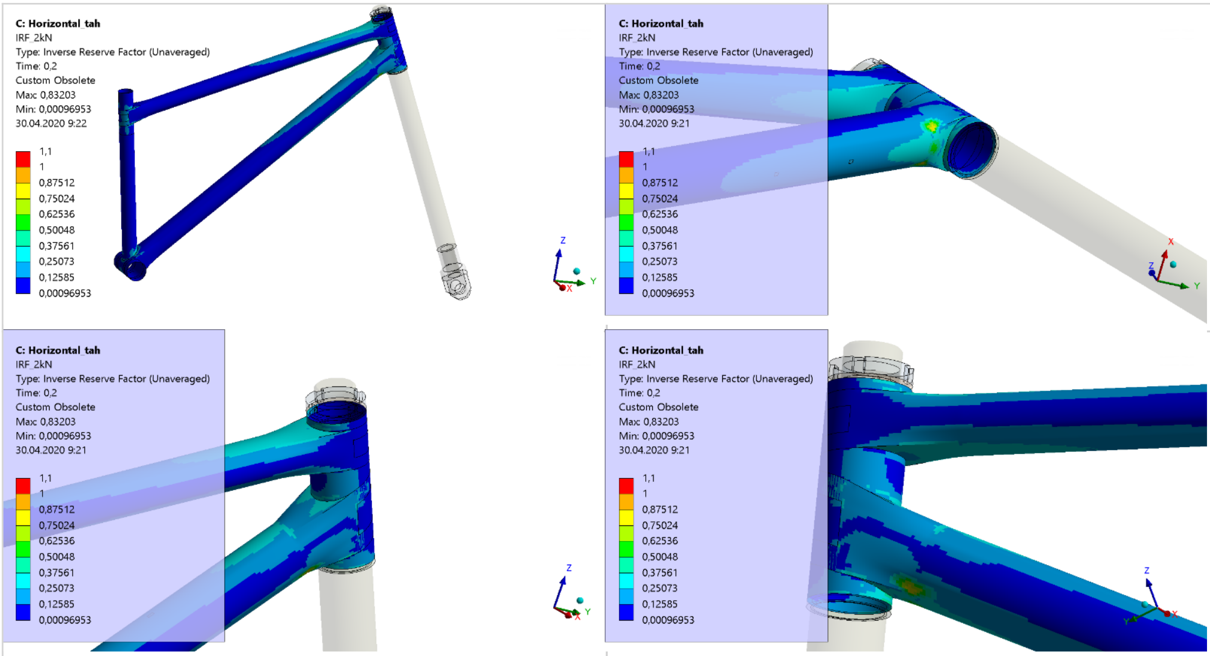

Fig. 12: IRF factor from Ansys analysis for 2 kN tension force

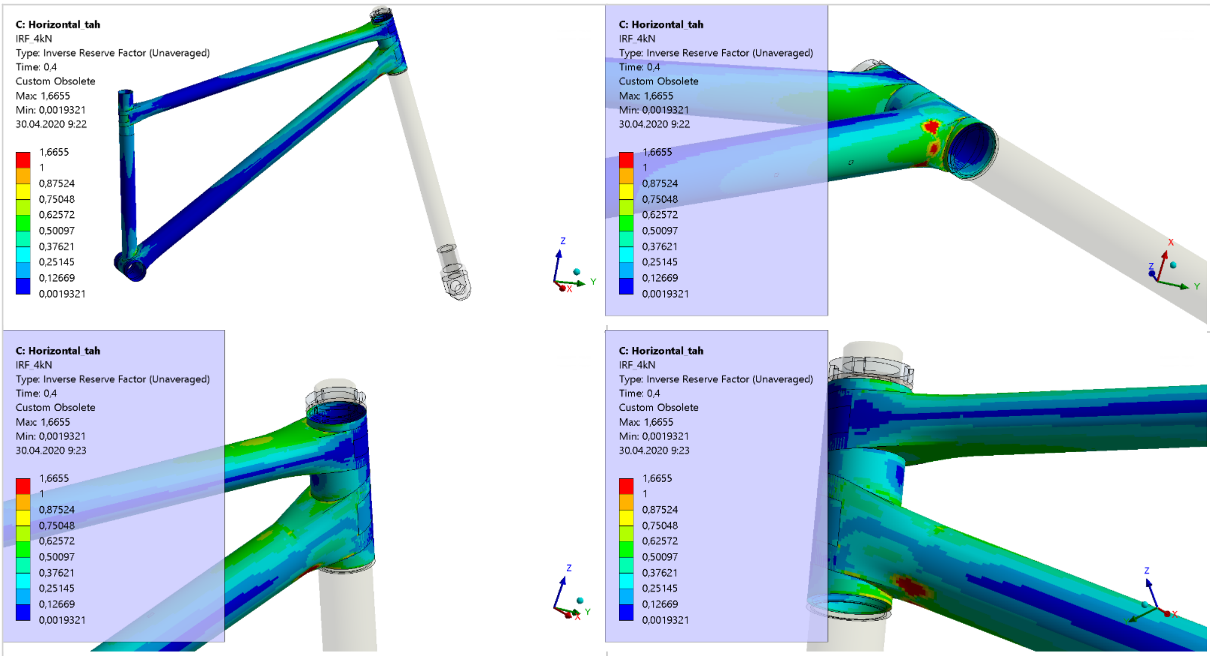

Fig. 13: IRF factor from Ansys analysis for 4 kN tension force

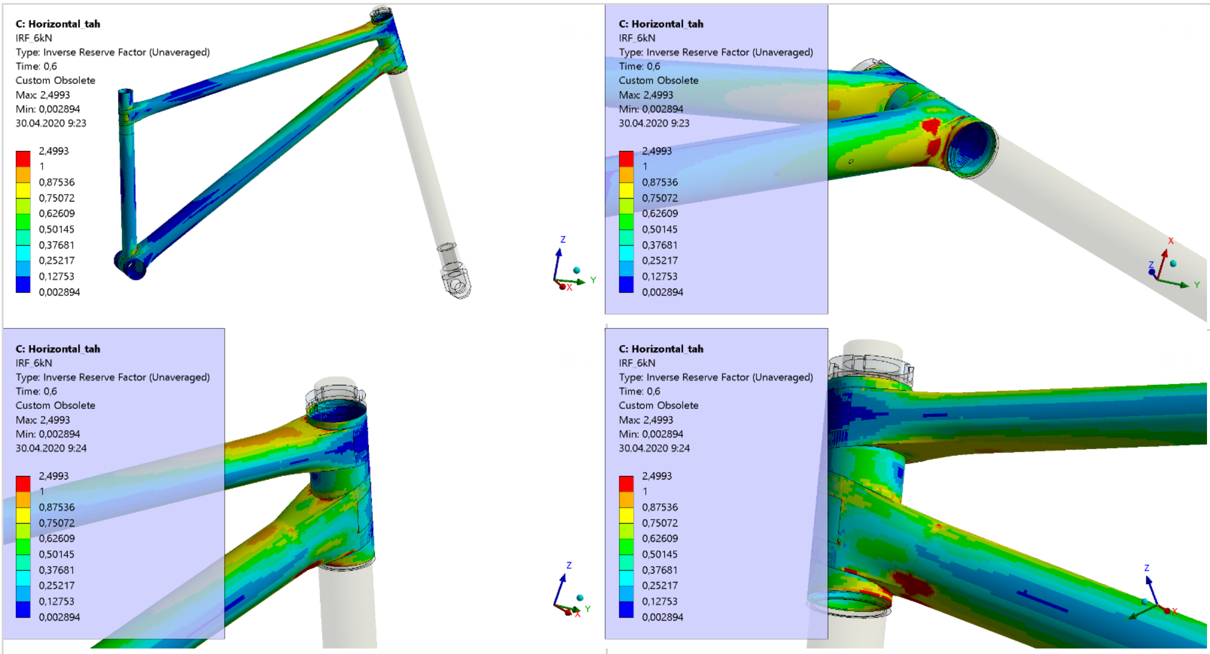

Fig. 14: IRF factor from Ansys analysis for 6 kN tension force

FE analysis also shown damage close to the rest of integrated joints of bicycle frame front triangle with rising load force, but these areas were not that large as joint of head tube to down and top tube. This analysis gives us horizontally oriented equivalent force related to measured strain and information about potentially weaker places of bicycle frame which is useful for future improvement and prediction of maximal load during laboratory test. Progressive damage model will be used in future for improvement of force prediction.

As mentioned before, FE model was also used for comparison between analysis and experimentally measured data in laboratory test stand of newer version of bicycle frame. All forces in next figures are related to maximal measured value. Since the measured frame and analysis had SGs in the same positions there is comparison between force and displacement (taken from hydraulic actuator) dependence in Fig. 15 and comparison between force and strain dependence of d_top SG. Due to the visible damage of bicycle frame joints from previous rides it is expected that FE simulation is more rigid and comparison look sufficiently for simple analysis.

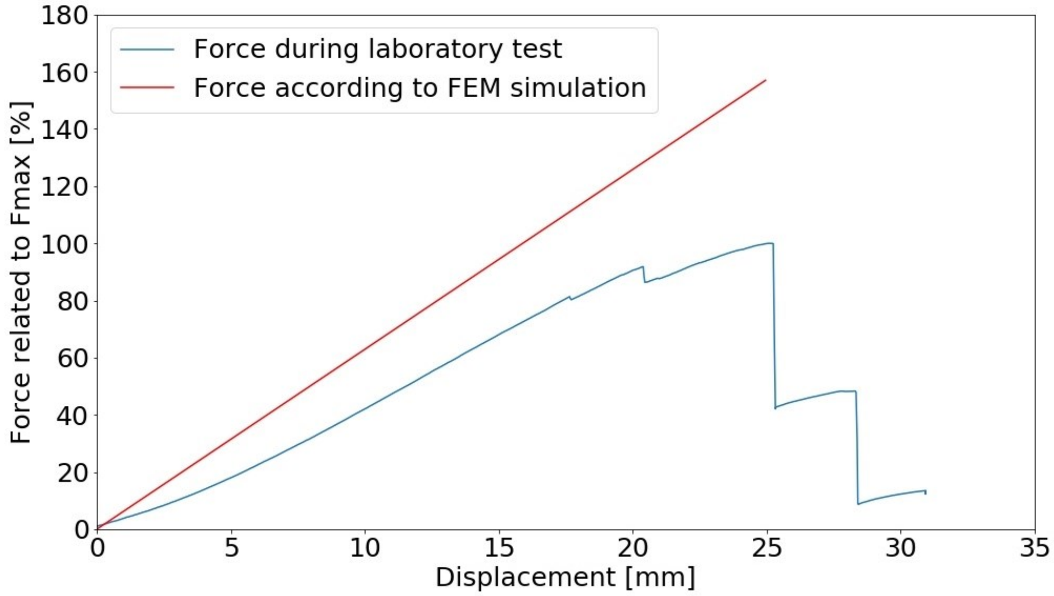

Fig. 15: Comparison of FEM analysis and experimentally measured dependence between force and displacement

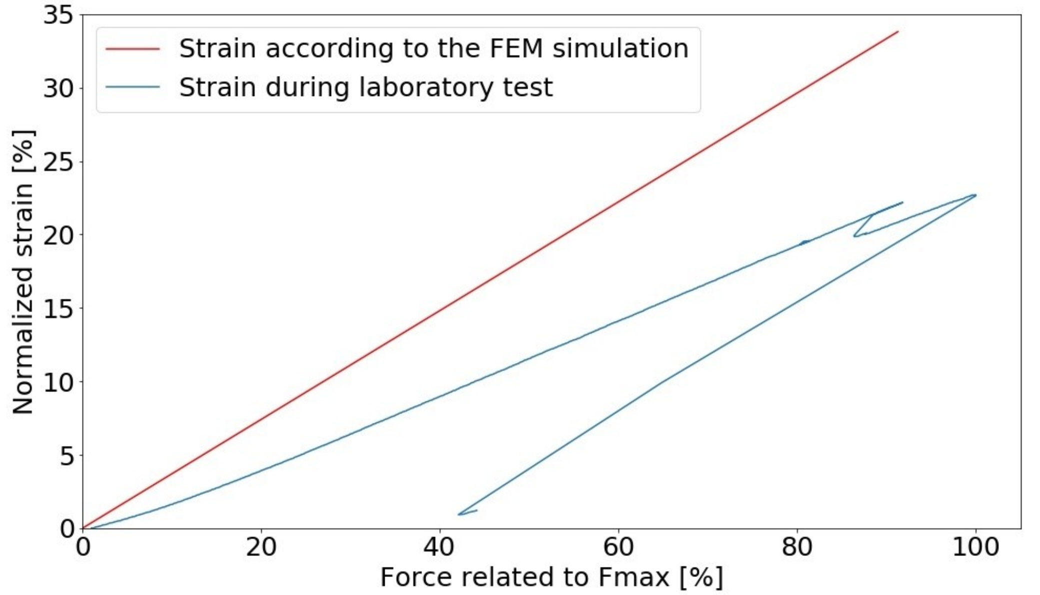

Fig. 16: Comparison of FEM analysis and experimentally measured dependence between force and strain

Conclusions

Complex strain behaviour of the down tube was identified. Significant impact of the shock absorber on its behaviour was confirmed. The measured data were used in FE analysis for finding the equivalent force and identification of potentially critical places. Also, reduction of measured channels to 4 quarter bridges in positions of c and d was done, which allowed usage of miniature measurement unit for new version of bicycle frame front triangle which will not restrict the rider so the full load range during a regular enduro race could be measured. Also, quasi-static laboratory test was done with comparison with FEM simulation. First generation of FE model provides expected results and will be improved according to laboratory and field measurements.

Acknowledgments

This work has been supported by project No. SGS18/175/OHK2/3T/12 of the Grant Agency of the Czech Technical University in Prague and by project No. TJ02000252 of the Technological agency of the Czech Republic.

References

[1] A. Malá, V. Kulíšek, N. Schmidová, T. Zámečníková, T. Ponížil, T. Mareš. Finite element analysis of composite tubes with integrated loop connections. In: PROCEEDINGS OF COMPUTATIONAL MECHANICS 2019. Plzeň: University of West Bohemia, 2019. ISBN 978-80-261-0889-4.

[2] ČSN EN ISO 4210-6. Jízdní kola - Bezpečnostní požadavky na jízdní kola - Část 6: Zkušební metody pro rám a vidlici. 2. vydání. 2016.

[3] Ansys® Academic Research Mechanical, Release 19.2, Help System, ANSYS, Inc.