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Strength Testing of a Composite Mounting Frame for a Multi-Sensor Detection System

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Abstract. The work concerns the design and implementation of a support frame for a multi-sensor detection system and conducting strength tests on it. The system consists of GPR, a metal detector and a non-linear junction detector, so it is vital that the support structure be made of a dielectric material. A commercial frame made of glass fiber reinforced polyester (GFRP) profiles was used to construct the frame. After the system was completed, strength tests were carried out under field conditions for the most adverse load conditions.

Introduction

At present, fibre-reinforced composites are gaining more and more popularity among constructors, mainly due to the advantages of these particular materials. What gives them this high position in the ranking of construction materials is mainly their high strength and very low weight when compared to other construction materials, including steel. The absence of electrical conduction is also an important parameter determining the use of composites in constructions. This is especially important if, for example, induction detectors are attached to the designed structure [1-3].

Frame design

The frame design was made on the basis of input data on geometrical parameters and mass of individual system components. The design also takes into account the load and operating conditions of the system in operational conditions, including field conditions and travel off-road. The design of the structure was made using the currently available tools for graphical modelling (Autodesk Inventor) and for strength calculations (Ansys LS-Dyna).

At the beginning, a geometric model of the device was made, taking into account the possibility of attaching it to the base vehicle. Afterwards, strength calculations were conducted within the static range for the position when the frame works without the support of its wheels. In addition, dynamic simulation was performed for the full range of the frame positions and up to 20km/h of operating speed. Based on strength analyses and the available composite profiles, rectangular profiles (stringers and crossbars) made of polyester-glass composites with the dimensions of 100x100x5 mm were used for the designed structure. The properties of the composite used are given in Table 1. Fig. 1 presents the designed frame with elements of the detection system.

Table 1. Parameters regarding physical- and mechanical properties of composite profiles [5]. Matrix: isophthalic polyester resin; glass content: 50%-60%.

Parameter	Standard	Lengthwise MPa	Crosswise MPa	MPa	[--]
Flexural Strength	EN ISO 14125	250	30-80		
Tensile strength	EN ISO 527-4	250	30-80		
Compressive strength	EN ISO 14126	240	30-80		
ShearStrength	EN ISO 14130			25	
E-modulus	EN 13706	25 000	9 000		
Compressive modulus	EN ISO 14126	10 000	4 000		
Shear modulus	EN ISO 14130			3 000	
Poisson ratio lengthwise/crosswise	EN ISO 527-4				0.23
Poisson ratio lengthwise/crosswise	EN ISO 527-4				0.09
IZOD impact strength [kJm^2]	ASTM D-256				300
Density [kg/dm^3]	ISO 1183				1.9
Barcol hardness	EN 59				>30

Application limits	Short-term behaviour		Long-term behaviour	
	Lengthwise [MPa]	Crosswise [MPa]	Lengthwise [MPa]	Crosswise [MPa]
Bending strength	135	25	70	20
Tensile strength	135	20	70	15
Compression strength	135	25	70	20
Shear strength	17	17	8	8

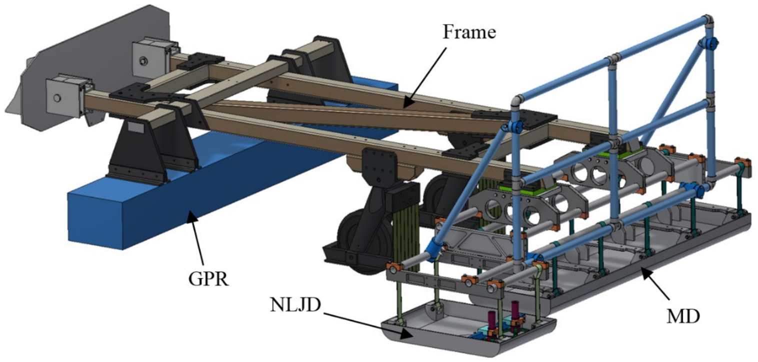

Fig. 1. Frame model with elements of the detection system

Stress tests of a multi-sensor detection system supporting frame under field conditions

In the next stage, having completed the system, strength tests were carried out using strain gauges (base: 3 mm, resistance: 120 Ω). The strain gauges were glued on the outer surface of the beams, in accordance with the diagram shown in Fig. 2 [4].

The tests were conducted using a complete set of sensors being mounted onto the frame. These sensors included the following: ground-penetrating vehicle, metal detector and non-linear junction detector.

Six (6) tests in total were performed in order to test the system's operation under varying operating conditions.

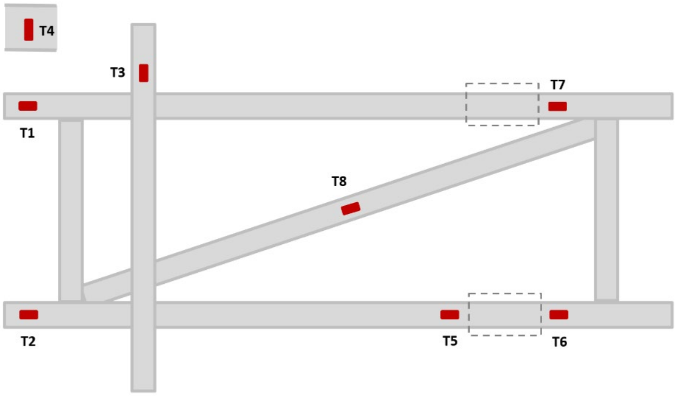

Fig. 2. Stress pattern as registered by sensors 1÷ 8 for Test No. 1÷6

Fig. 3. presents a frame with strain gauges and wiring prepared for the tests, as well as the system during testing. The test results are presented in the charts in Figs. 4-9.

Fig. 3. Loaded frame with strain gauges (on the left) and the frame during tests (on the right)

During test No. 1, the road was traversed in operational (working) position (the system is wheel-supported). The system was moving forward, down a gentle hill at a speed of 2km/h. During the travel, first a 15 cm-deep and 50 cm-wide hole was encountered, followed by a 15 cm-high and 100 cm-long bump (front right wheel from the UGV perspective).

As part of test No.2, the system was being turned back in operational position (the system was wheel-supported).

Test No. 3 involved the road being traversed in operational (working) position (the system is wheel-supported). The system was moving forward, up a gentle hill at a speed of 2km/h. During the travel, first a 15 cm-deep and 50 cm-wide hole was encountered, followed by a 15 cm-high and 100 cm-long bump (front right wheel from the UGV perspective).

Test No. 4 consisted in the system being turned back with the frame being lifted to a height of ca. 0.5 m above the ground.

Test No. 5 comprised static lifting and of the frame to a height of ca. 0.5 m above the ground followed by lowering of the frame.

As part of test No. 6, static lifting and of the frame to a height of ca. 0.5 m above the ground was followed by impact of a side force equal ca. 300N at the end of the frame on the left, and the identical impact on the right side, followed by lowering of the frame.

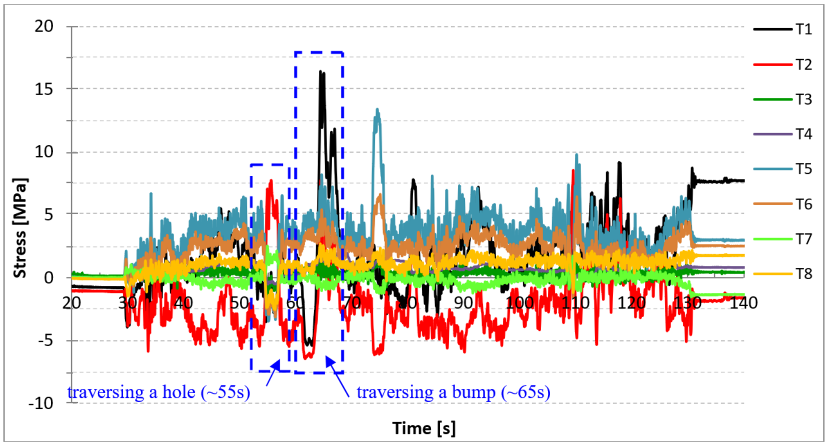

Fig. 4. Stress pattern as registered by sensors 1÷ 8 for Test No. 1

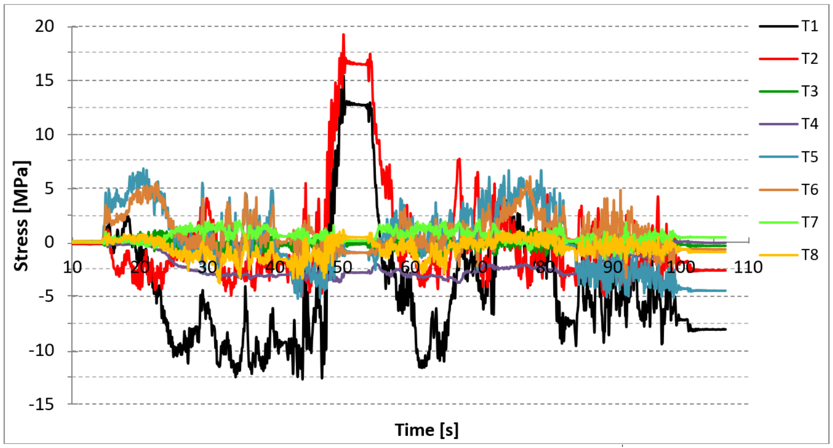

Fig. 5. Stress pattern as registered by sensors 1÷8 for Test No. 2

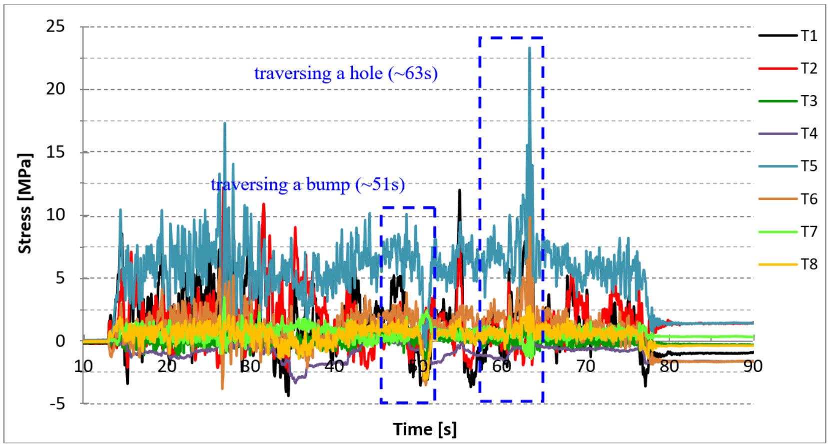

Fig. 6. Stress pattern as registered by sensors 1÷8 for Test No 3.

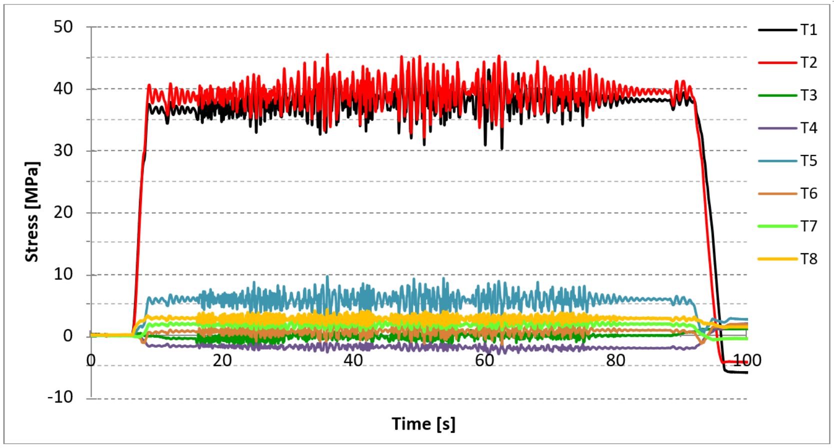

Fig. 7. Stress pattern as registered by sensors 1÷8 for Test No. 4

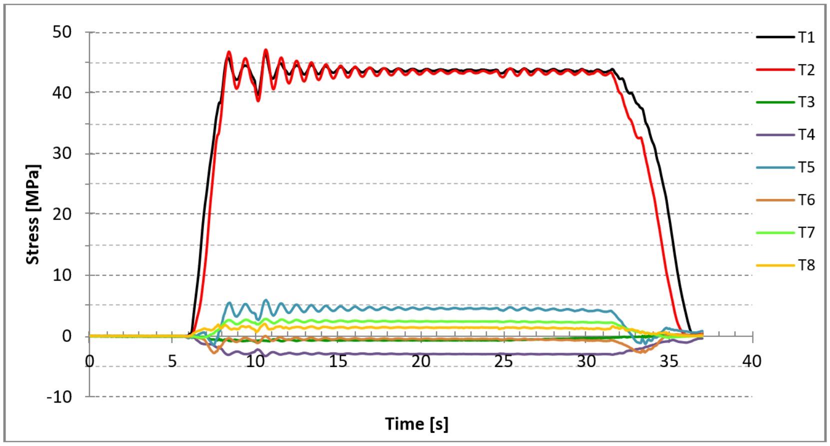

Fig. 8. Stress pattern as registered by sensors 1÷8 for Test No. 5

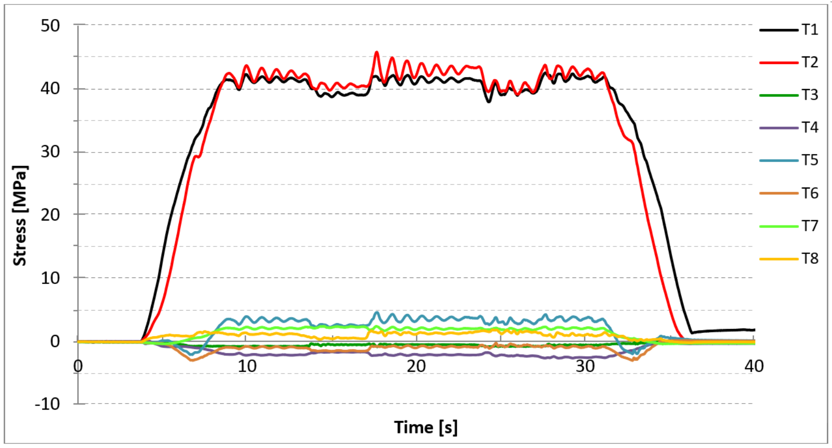

Fig. 9. Stress pattern as registered by sensors 1÷8 for Test No. 6

Summary

Based on the conducted analyses, the following have been found:

1) The highest normal stress within the main beams occurred during the process of lifting the entire assembly up. In addition, an increase in stress within the beam near the wheel was observed when the system was passing through a hole in the ground, while the passage over a bump did not reveal increased stress.
2) The greatest stress was noted for the support beams near the connection to the attachment area. The maximal values noted equaled 46.5 MPa. What results from the information contained in Table 1 is that the bending stress equals 70 MPa for a prolonged use, which means that the constructed frame operates safely with the coefficient of 1.5. For the short-term stress, the safety coefficient equals 2.9.
3) When the fully-loaded frame operated under field conditions (traversing uneven ground, including, holes and bumps) maximum stress equaled ca. 23 MPa.
4) When the fully-loaded frame operated under field conditions (lifting and lowering of the frame, travel in operating positions, turning), the system was tested multiple times during an 80-hour period. No mechanical damage to the structural elements was detected.

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