

Zbigniew RACZYŃSKI

## STUDY OF THE MECHANICAL PROPERTIES OF THE MS-40 BRIDGE SPAN

**Abstract.** The paper presents selected results of strength tests of the MS-40 bridge span. The tests included static loading of the bridge as specified by the standard for MLC 70 (T) class - tracked vehicles - and MLC 110 (W) class - wheeled vehicles. Stresses in selected points of the main and auxiliary spans of the bridge were recorded during the tests.

**Keywords:** bridge span, tensometric tests, stresses, load, deflection

### 1. INTRODUCTION

The development project "Mobile MLC 70/110 folding bridge for negotiating medium-sized water and terrain obstacles" is a research and development project the purpose of which is to develop a bridge for negotiating gaps up to 40 metres.

Work on the project started in 2008. The construction of the final model was preceded by simulation tests aimed at developing a bridge span that meets the set tactical, technical and structural requirements.

The model of the span, developed and then fabricated (Fig. 1) in accordance with design documentation, had to be subjected to tests to confirm that the assumptions made were met.

The tested specimen of the bridge span was the third version of the model, which included structural changes and improvements based on the results of previous tests [2].

The paper presents selected results of strength tests of the supporting structure of the bridge span carried out during the testing of a model of the MS-40 DAGLEZJA S bridge.



**Fig. 1.** A schematic drawing of the main span of the MS-40 bridge with rolling supports

### 2. ARRANGEMENT OF SENSORS ON THE MODEL OF THE MS-40 BRIDGE SPAN

The representation of the bridge span in the form of a strength model and the obtained calculation results [1] helped select the points where the greatest stresses of the mechanical structure would be expected during the crossing of the bridge by tracked vehicles of the MLC 70 class and by wheeled vehicles of the MLC 110 class.

Six strain gauges of the TFs-10 type (Fig. 2) were affixed to the lower chord of the main span in the middle of the bridge length at points indicated by OBRUM design engineers [3]. These gauges are marked as: t1 – t3 and t9 – t11. Two strain gauges were affixed halfway of the length of the auxiliary span, which forms a support when segments of the main span are arranged (steel structure of rectangular shape): t6 (top) and t7 (bottom).

The gauges were arranged so that the datum direction was parallel to the longitudinal axis of the tested span.

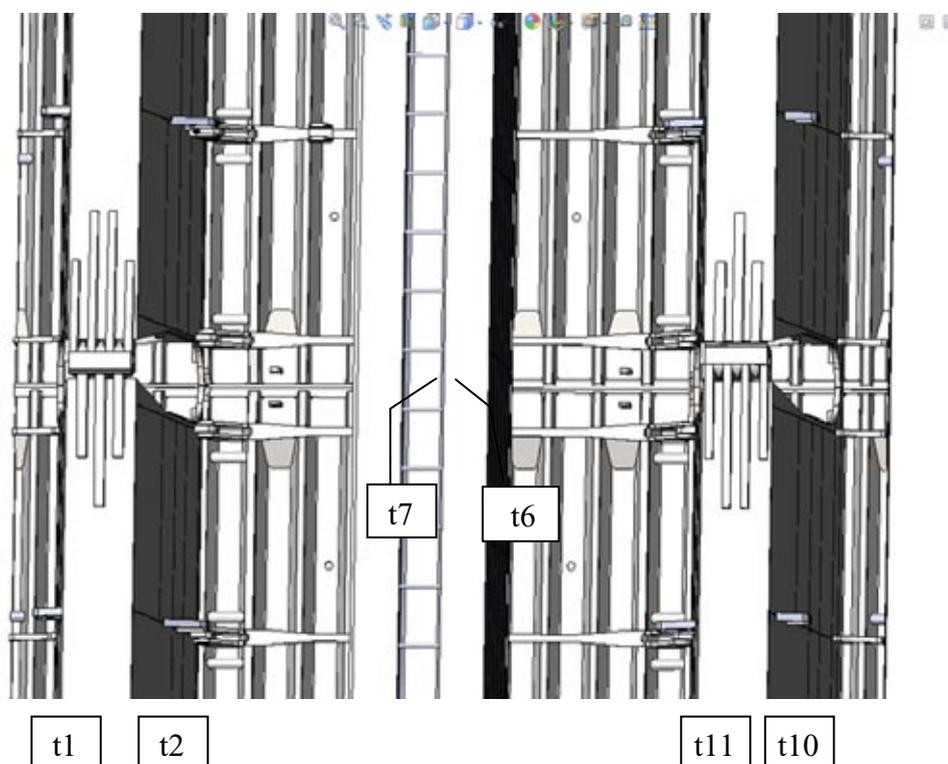
To be able to assess the strength of the entire span, rather than that of the lower chord only, four additional single strain gauges were affixed at selected points halfway of the length of the main span (datum direction parallel to the longitudinal axis of the span). These gauges are indicated in Fig. 3 as: t4, t5, t8 and t12.

Two more strain gauges were affixed to evaluate stresses in other points of the span: t13 and t14 (not shown in the drawings).

All strain gauges were connected to multichannel logging device UPM60 from HBM (Fig. 4) to collect relative elongation measurement data from the strain gauges. Temperature compensation for the strain gauges is provided by the manner of connecting to UPM60 through a VT21 terminal block, with a compensating gauge of the same type connected (every strain gauge channel in a semi-bridge arrangement).

Measurement of the sag at half length of the span was done using a potentiometric displacement sensor from Buster (Fig. 4) with a measuring range of 600 mm and nonlinearity error  $\pm 0.05\%$ , connected to an LMS Scadas Mobile recorder, and Leica DISTO A5 laser distance meter.

Photographs at the end of the article show selected points on the main span with strain gauges attached.



**Fig. 2. Schematic of the arrangement of strain gauges on the lower chord of the middle segment of the main span and auxiliary span**

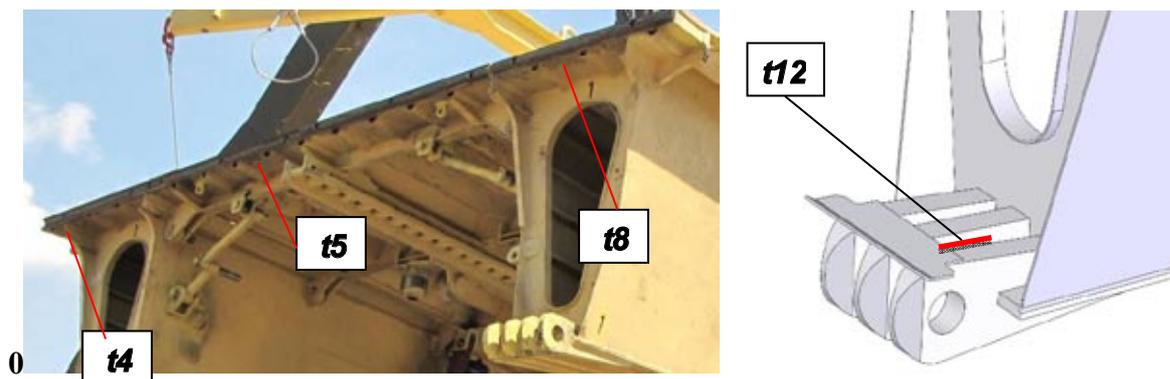


Fig. 3. Arrangement of other strain gauges on the middle segment of the main span

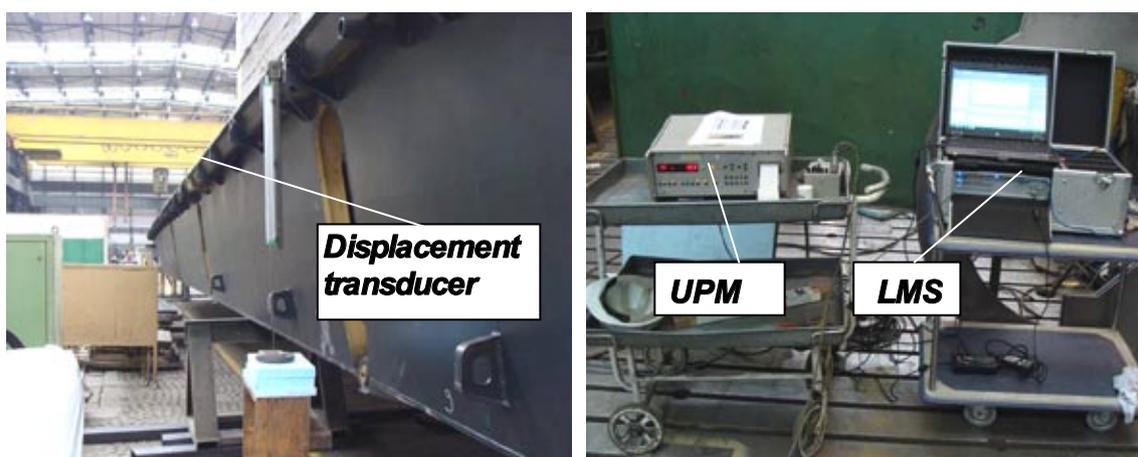


Fig. 4. Displacement transducer and measuring apparatus

### 3. STRENGTH TESTS OF THE SPAN FOR MLC 70 CLASS – TRACKED VEHICLES [5]

To apply loads onto the bridge span according to STANAG 2021 for tracked vehicles of the MLC 70(T) class, a special frame (contact area with span ca. 4.57 m long and ca. 0.7 m wide with pads of hard rubber 45 mm thick) was prepared to imitate tank tracks. The frame was set along the axis of the bridge span as shown in Fig. 5.

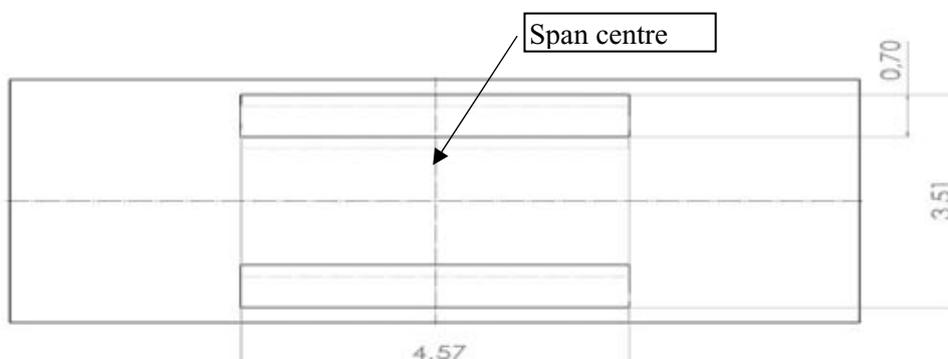


Fig. 5. Dimensions of the frame for simulating MLC 70(T) load and its position on the bridge span

### 3.1 Effect of span weight on bridge load

It was assumed that the dead weight of the span was distributed uniformly. In the given case the unit load resulting from the dead weight of the MS-40 bridge span under study was:

$$q_p \approx 9.8 \text{ kN/m}$$

Distance between axes of span supports:  $L = 43.7 \text{ m}$ .

The bending moment at the middle section is thus:

$$M_d = 1/8 \cdot q_p \cdot L^2 = 2340 \text{ kNm} \quad (1)$$

The same moment will be obtained under equivalent point load  $D$  calculated from the following formula:

$$D = M_d \cdot 4/L = 214.2 \text{ kN (21.8 t)} \quad (2)$$

For the proper assessment of the overall structure effort, stress resulting from span dead weight should be distinguished from that resulting from applied load. To this end the following was done.

The span was supported on one side on its own supports, and on the other side on a special frame (Fig. 6) and it was levelled. The structure of the frame on the right side of the drawing (with hydraulic cylinders) enables testing the span subjected to cyclic fatigue load (not the subject of this article).



**Fig. 6. Manner of supporting ends of the main span of the bridge**

In order to measure the stress resulting from the dead weight of the span, the load had to be relieved by a force applied at the centre of the span and equal to the equivalent point load  $D$  (214.2 kN), as calculated from formula (2). For this purpose the centre of the span was lifted by crane with a dynamometer in between until a reading of ca. 214.2 kN was obtained. At this stage the indications of the strain measuring apparatus were zeroed.

Then the span returned to its rest position and stresses  $\sigma_{do}$  resulting from the dead weight of the span were measured.

The results of these measurements are given in Table 1.

Table 1. Results of measurements of stresses resulting from the dead weight of the span

	Gauge no.													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
$\sigma_{do}$ (MPa)	94	91	102	-42	-25	-5	-1	-49	105	91	89	69	-13	22

The highest values of stress resulting from span dead weight occurred in lower chords of the span and were equal to ca. 100 MPa.

As during the testing the strain gauge apparatus were not reset to zero, the measured values of the stress resulting from span dead weight were automatically added to the stress measured during load testing of the bridge span.

### 3.2 Bridge span tests under ultimate load for MLC 70 class

For MLC 70 (tracked vehicles) class loads [4], the weight of the vehicle is:  $G = 63.5$  t. Thus the required loads on the bridge span (according to [4]) are as follows:

$$- \text{ working load} - P' = 1.075 \cdot (D+G) = 89.8 \text{ t} \quad (3)$$

$$- \text{ overload} - O' = 1.33 \cdot P' = 119.4 \text{ t} \quad (4)$$

$$- \text{ ultimate load} - U' = 1.5 \cdot P' = 134.6 \text{ t} \quad (5)$$

**Note:** When estimating the working load  $P'$ , the 1.075 factor is used to take into account all other loads applied to the span [4].

For low load classes the adopted value of this factor is 1.15 (up to MLC 30), for medium load classes (MLV 60 and higher) it is linearly reduced to 1.075. For MLC 100 and higher classes the factor is ignored.

As the load was assumed to act on existing span with an equivalent point load  $D$ , the additional applied load corresponding to MLC 70 class should be reduced by this value and will be as follows:

$$P = P' - D; \quad O = O' - D; \quad U = U' - D \quad (6)$$

In the case under consideration:

- working load -  **$P = 68$  t;**
- overload -  **$O = 97.6$  t;**
- ultimate load -  **$U = 112.8$  t.**

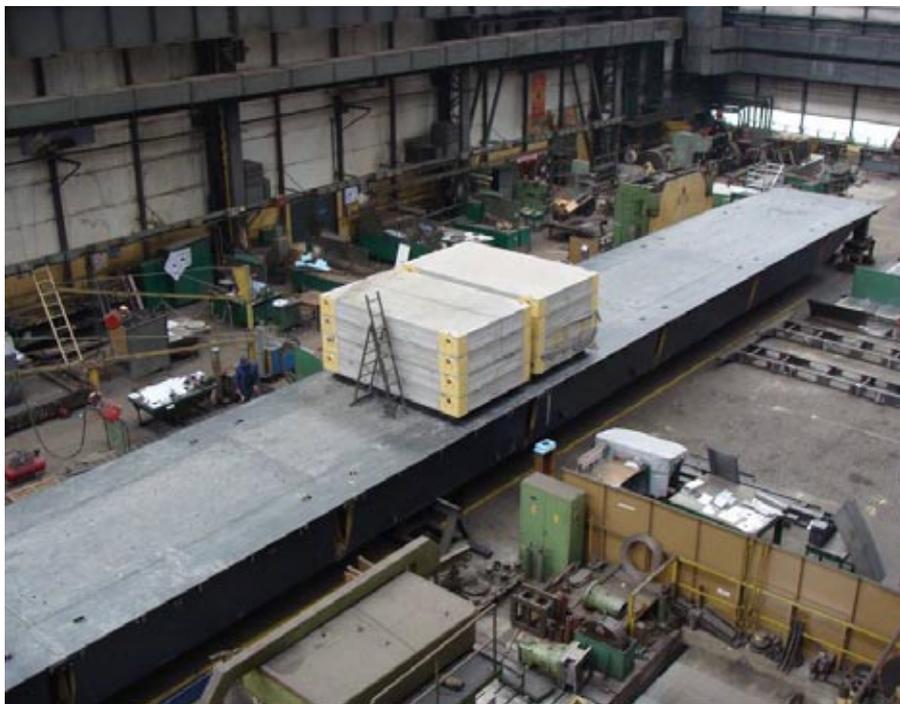
The equivalent load  $D$  constitutes ca. 32% of the working load and ca. 19% of the ultimate load (MLC 70 – tracked vehicles).

Loads were applied to the span (positioned on supports) in the following manner.

Concrete blocks, two in each layer, were set on the frame in succession. The loading step was ca. 16 t. The blocks were weighed when positioned on the span. The weight of the frame (1.64 t) was taken into account when loads were applied to the span.

The load was increased gradually (Fig. 7) and stresses and deflections on both sides of the span were recorded. Every subsequent load was maintained for 2 minutes.

Design values of loads: "P" – 68 t; "O" – 97.6 t; "U" – 112.8 t.  
 Actual values of loads: "P<sub>r</sub>" – 70.5 t; "O<sub>r</sub>" – 96.5 t; "U<sub>r</sub>" – 113.7 t.



**Fig. 7. Span during the "P" test – load from vehicle tracks**

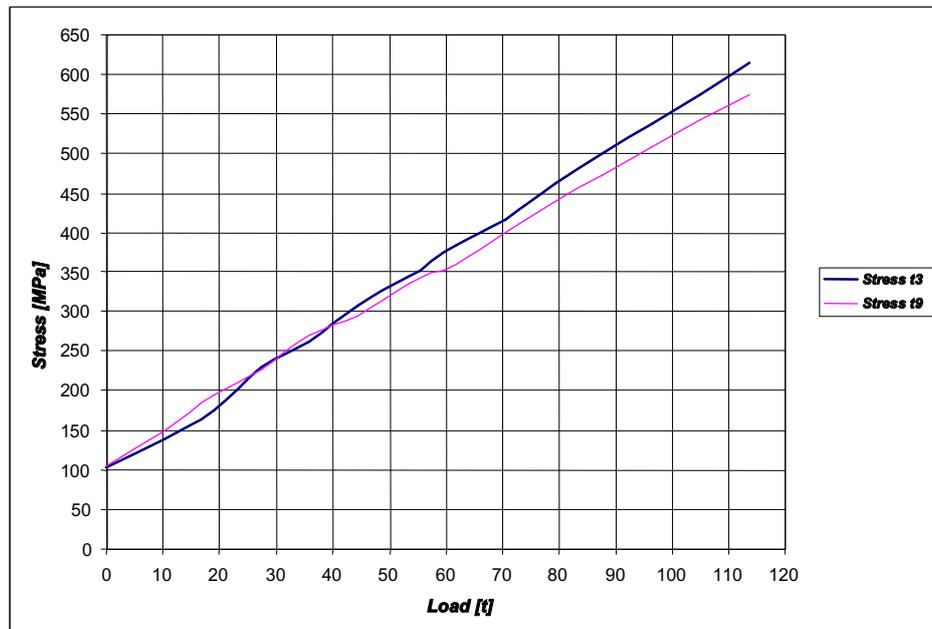
The overload test was run three times, with the set "O<sub>r</sub>" load maintained for 30 minutes each time.

The ultimate load test was run only once, with the set "U<sub>r</sub>" load maintained for 30 minutes.

Table 2 lists the results of stress measurements at gauge points under the actual loads "P<sub>r</sub>", "O<sub>r</sub>" and "U<sub>r</sub>".

Table 2. Stress values at gauge points under the loads "P<sub>r</sub>", "O<sub>r</sub>" and "U<sub>r</sub>".

Load	Stress	Gauge no.													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
"P <sub>r</sub> " 70.5 t	$\sigma_P$ (MPa)	372	367	417	-183	-79	-100	90	-169	402	320	336	239	-79	103
"O <sub>r</sub> " 96.5 t	$\sigma_O$ (MPa)	481	476	538	-217	-94	-133	145	-199	508	399	423	296	-71	115
"U <sub>r</sub> " 113.7 t	$\sigma_U$ (MPa)	551	546	610	-240	-109	-163	178	-219	575	451	476	328	-53	130

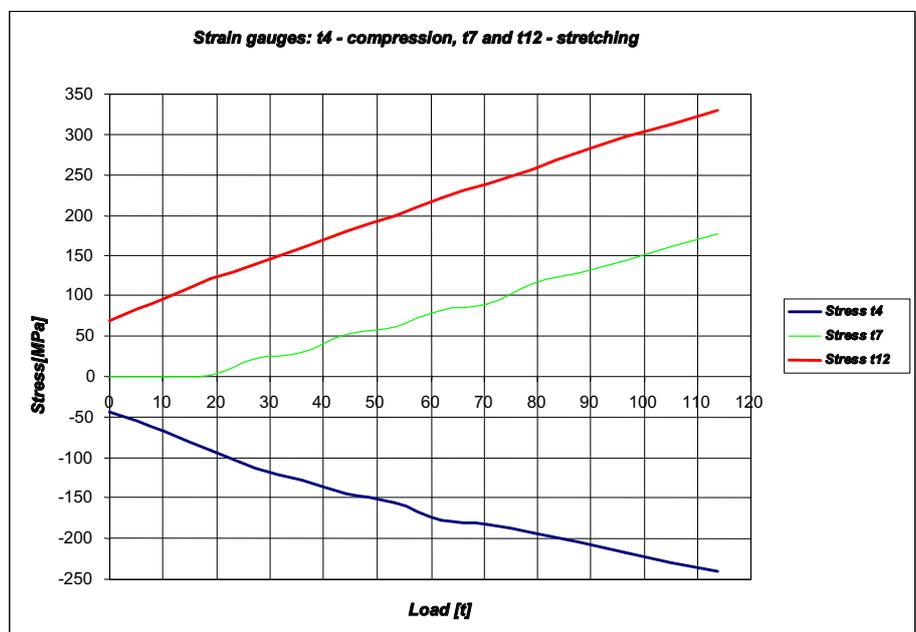


**Fig. 8. Stresses measured on gauges t3 and t9 - vehicle track load**

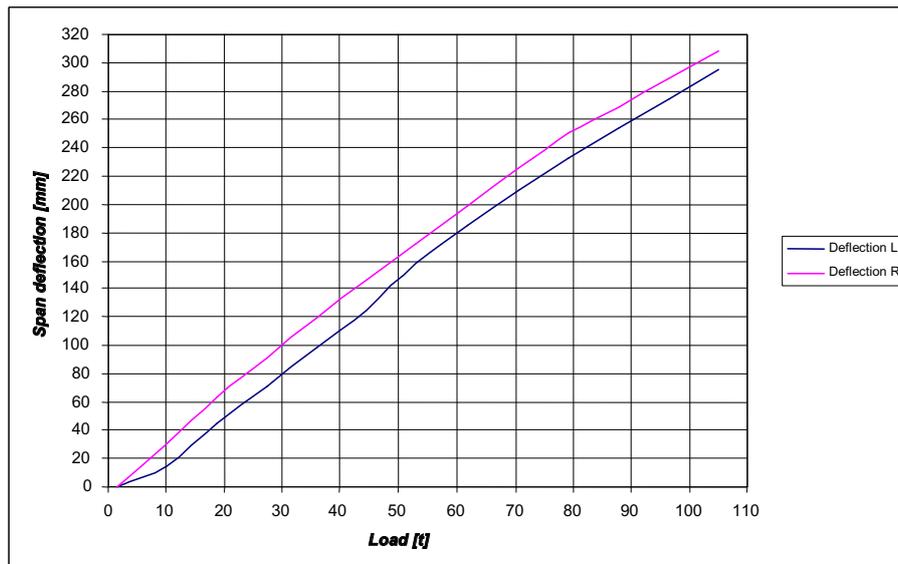
The highest stresses were recorded in the axes of lower chords of the main span.

Figs. 8 and 9 show graphs of stresses measured on selected gauges, and Fig. 9 shows a graph of deflection of the bridge span under load.

Stresses resulting from main span dead weight for the lower chords under consideration are equal to ca. 100 MPa, therefore the graph (Fig. 8) is shifted up by this value.



**Fig. 9. Stresses measured on gauges t4, t7 and t12 - vehicle track load**



**Fig. 10. Deflection measured in the middle of the MS-40 bridge span - vehicle track load**

The characteristics of span deflection (Fig. 10) indicate that the left side of the span differs only slightly from the right side. This results from the loose support of the bridge on one side. After the play is taken in, the characteristics of deflection are identical within error limits.

The deflections indicate the increasing role of the auxiliary span in the taking over of the loads (stiffness of the span increases – lower deflection increment under load).

No buckling and no joint cracks were observed on the main and auxiliary spans.

The plastic strain in the maximum deflection plane after all three tests ("P", "O", "U") was 2 mm.

The formula for computing the static safety coefficient related to the yield point is as follows:

$$X_k = R_e / \sigma_{Px} \quad (7)$$

where:

$X_k$  - k-th value of the static safety coefficient,

$\sigma_{Px}$  - stress measured on the strain gauge  $t_x$  under working load (MPa),

$R_e$  - yield strength of the material of the span (MPa).

The highest stresses occurred in the lower chord of the span and reached  $\sigma_{P3} = 417$  MPa. For the XABO steel used,  $R_e = 1100$  MPa. Therefore the static safety coefficient for the studied model of the bridge span of MLC 70 class (tracked vehicles) estimated from measurement results using the formula (7) is:

$$X_1 = 1100/417 = 2.63$$

The  $X_1$  value is much higher than the required static safety coefficient of the bridge span in relation to the yield strength  $X_B \geq 1.5$  (requirement imposed on the MS-40 bridge, item 5.13.1) [6].

#### 4. STRENGTH TESTS OF THE SPAN FOR MLC 110 CLASS – WHEELED VEHICLES [5]

Preparations to bridge span loading tests with an MLC 110 class vehicle were similar to those described in section 3 of the article. In order to reproduce the pressure of wheels applied to the treadway of the span, 10 soft pads (1.0 m x 0.4 m each) that correspond to the contact surfaces between the vehicle wheels and the span were used (STANAG 2021).

The pads were arranged on the span as shown in Fig. 11, so that the centre of gravity of the entire arrangement closely corresponded to the geometric centre along the longitudinal axis of the span. Distance between the pads (wheel base) is defined by the MLC 110 (W) class standard vehicle model.

Prior to tests, the measuring system was zeroed, in such manner as to take into account the dead weight of the span (as was the case with tests in section 3.1).

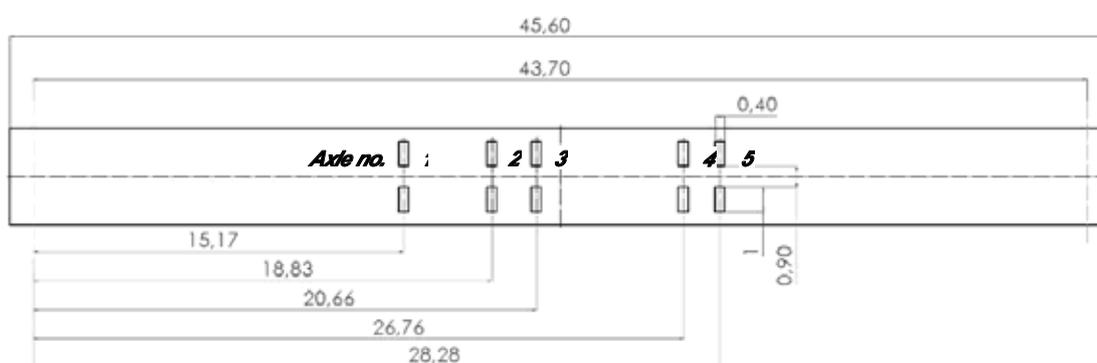


Fig. 11. Arrangement of rubber pads on the span

##### 4.1. Bridge span tests under ultimate load for MLC 110 class

For MLC 110 (wheeled vehicles) class loads [4], the weight of the set is:  $G = 114.8$  t.

The working load of the span, according to formula (3), is (see **Note** – section 3.2):  $P' = G + D = 136.6$  t, and overload  $O'$  and ultimate load  $U'$ , according to formulas (4) and (5), is 181.7 t and 204.9 t, respectively.

Thus, after subtracting the equivalent point load  $D$  in accordance with formula (6), the span load values will be as follows:

$$P = 114.8 \text{ t}; \quad O = 159.9 \text{ t}; \quad U = 183.1 \text{ t}.$$

The equivalent load  $D$  constitutes ca. 19% of the working load and ca. 12% of the ultimate load (MLC 110 – wheeled vehicles).

The theoretical wheeled vehicle axle load on the span (wheel base as shown in Fig. 11) should be as follows (Table 3):

Table 3. Theoretical wheeled vehicle axle load on the span

<b>Axle 1</b>	<b>Axle 2</b>	<b>Axle 3</b>	<b>Axle 4</b>	<b>Axle 5</b>	<b>Total</b>
(t)	(t)	(t)	(t)	(t)	(t)
15	30	30	19.9	19.9	P (114.8)
21	42	42	27.45	27.45	O (159.9)
23.9	47.8	47.8	31.8	31.8	U (183.1)

Design values of loads: "P" – 114.8 t; "O" – 159.9 t; "U" – 183.1 t.

Actual values of loads: "P<sub>r</sub>" – 111.2 t; "O<sub>r</sub>" – 163.2 t; "U<sub>r</sub>" – 184.2 t.

Loads were applied to the levelled span positioned on supports in the following manner.

Concrete blocks were set in succession on the span with the rubber pads arranged on it (Fig. 11). The load was increased gradually with an average increment of ca. 8.5 t and stresses and deflections on both sides of the span were recorded.

Every subsequent load was maintained for 2 minutes.

The overload test was run three times, with the set "O<sub>r</sub>" load maintained for 30 minutes each time.

The ultimate load test was run only once, with the set "U<sub>r</sub>" load maintained for 30 minutes. Due to the shortage of concrete blocks, additional steel weights were used for the last applied load (Fig. 11).



**Fig. 11. Span loaded with weights during the "U" test - wheeled vehicle load**

The actual individual axle loads on the span were not checked because of the absence of technical capacity to make such measurements.

Table 4 lists the results of stress measurements at gauge points under the actual loads "P<sub>r</sub>", "O<sub>r</sub>" and "U<sub>r</sub>".

The highest stresses were recorded in the axes of lower chords of the main span.

Table 4. Stress values at gauge points under the loads "P<sub>r</sub>", "O<sub>r</sub>" and "U<sub>r</sub>".

Load	Stress	Gauge no.													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
"P <sub>r</sub> " 111.2 t	$\sigma_P$ (MPa)	467	469	514	-188	-106	-160	173	-178	489	396	415	287	-1	116
"O <sub>r</sub> " 163.2 t	$\sigma_O$ (MPa)	650	653	713	-248	-147	-235	238	-237	662	543	569	383	17	167
"U <sub>r</sub> " 184.2 t	$\sigma_U$ (MPa)	731	737	807	-274	-160	-267	279	-257	747	610	630	428	8	190

Figs. 13 and 14 show graphs of stresses measured on selected gauges, and Fig. 15 shows a graph of deflection of the bridge span under load.

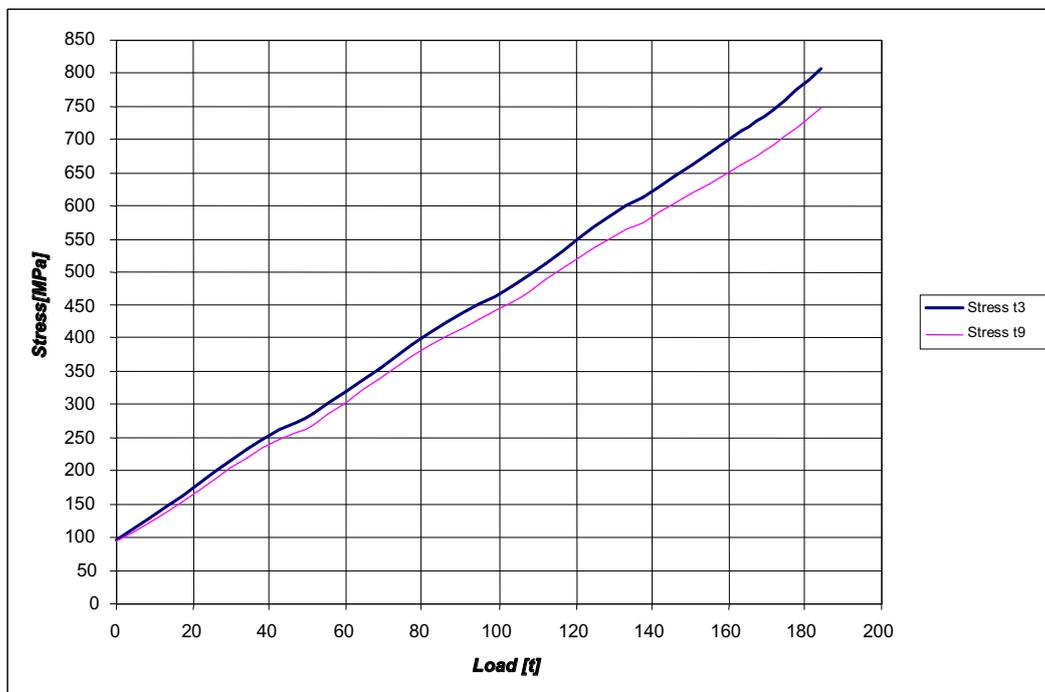


Fig. 13. Stresses measured on gauges t3 and t9 - vehicle wheels load

The strains are virtually linear in nature. It is only when the 140 t load is exceeded that slight nonlinearity occurs (faster stress increase on graph in Fig. 13).

The characteristics of deflections (Fig. 15) indicate that the left and right sides do not differ. Any possible play remaining after previous application of loads has been eliminated.

No buckling and no joint cracks were observed on the main and auxiliary spans.

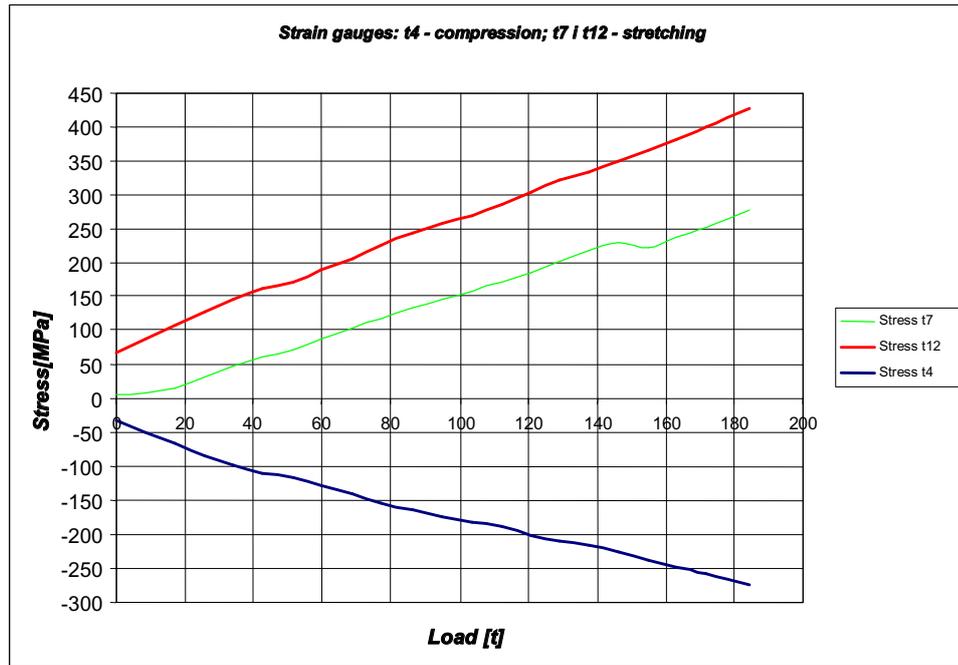


Fig. 14. Stresses measured on gauges t4, t7 and t12 - vehicle wheels load

The total plastic strain in the maximum deflection plane after overload ("O") and ultimate load ("U") tests was 12 mm.

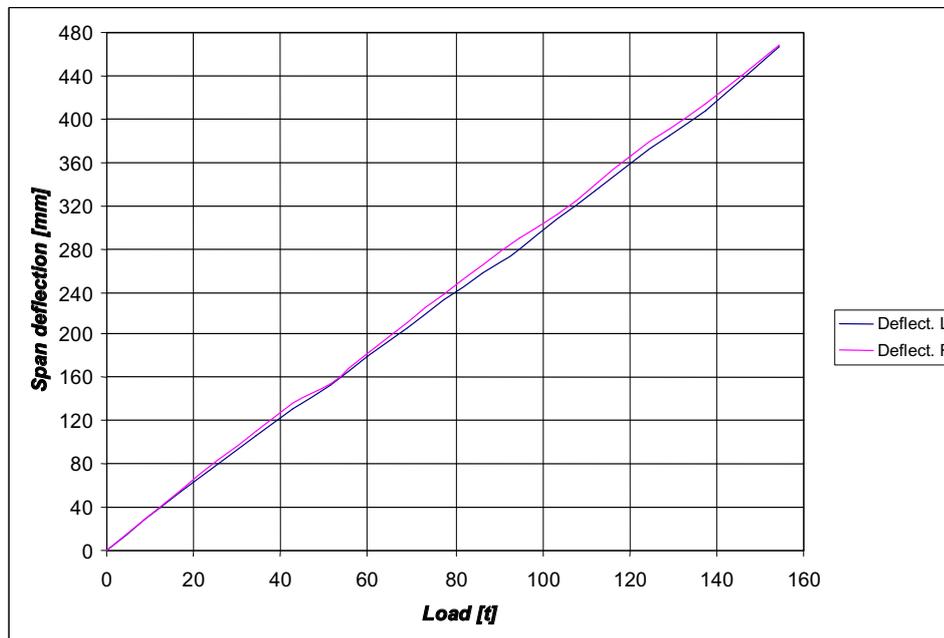


Fig. 15. Deflection measured in the middle of the MS-40 bridge span - vehicle wheels load

The stresses in the lower chord of the span reached  $\sigma_{P3} = 514$  MPa (for the XABO steel used,  $R_e = 1100$  MPa). The static safety coefficient for the model of the bridge span with MLC 110 class (wheeled vehicles) load, estimated from measurement results (for the tension chord) using the formula (4) is:

$$X_2 = 1100/514 = 2.14$$

The  $X_2$  value is higher than the required static safety coefficient of the bridge span in relation to the yield strength  $X_B \geq 1.5$  (requirement imposed on the MS-40 bridge, item 5.13.1) [6].

Maximum compressive stress in the upper chord (where buckling could occur) was  $\sigma_{p4} = 188$  MPa (gauge t4).

The estimated permissible limit for compressive stress may be half the value of  $R_e$  (for the steel used in upper chord,  $R_e = 980$  MPa). Therefore the limit value is 490 MPa.

## 5. SUMMARY

The span test results presented in the article cover only a selected, limited range of strength tests of the MS-40 bridge model.

The tests included static loading of the span as specified by the standard for MLC 70 class (tracked vehicles) and MLC 110 class (wheeled vehicles).

The obtained strain measurement results showed that during the "U" ultimate load tests the highest stresses (which occurred in the lower chord of the main span) did not exceed 810 MPa. The material used for the lower chord had the strength of  $R_e = 1100$  MPa. The span did not fail.

Analysis of the results of plastic strain measurements showed that the total plastic strain in the maximum deflection plane after "O" overload and "U" ultimate load tests (for the MLC 110 class) was equal to 12 mm only.

## 6. REFERENCES

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## 7. ANNEXES

### Annex 1. Points of affixing selected strain gauges.



Gauges t1 and t2 – lower right chord of the middle segment of the main span



Gauge t9 – lower left chord of the middle segment of the main span



Gauge t7 – lower chord of the middle segment of the auxiliary span



Gauges t4 and t13 – deck underside and vertical wall of the middle segment of the main span



Gauge t12 – lug beside the bolt of main span



Gauge t14 – lower right chord of the approach segment of the main span