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TESTS OF SCISSORS-TYPE BRIDGE STABILITY

Abstract. The paper presents functional classification of military bridges with respect to different phases of combat operations. Individual phases of positioning the bridge span over a gap are described, with particular attention paid to maintaining longitudinal and transverse stability. A method of determining the longitudinal stability margin and the additional overturning moment for the MG-20 bridge span is described. This moment results from the systems' inertia in the case of bridge span emergency stop during bridge launching. A method of verifying the longitudinal and transverse stability of the MS-20 bridge span in vertical position under windy conditions is also described. The analyses have demonstrated proper stability of both the MS-20 and MG-20 bridge spans.

Keywords: scissors-type bridge, longitudinal stability, transverse stability, stability margin.

1. INTRODUCTION

Troop mobility is one of the most important factors that ensure the success of modern military operations at all levels. One of the principal tasks of engineer troops, as part of engineering support, is to ensure freedom of troop movement (mobility), in the shortest possible time and under all terrain and climatic conditions. This requires, among other things, providing the troops with the possibility to negotiate terrain obstacles (canals, rivers and anti-tank trenches) using bridge facilities. Many countries have recently instituted development work with the goal to replace existing bridgelaying equipment. New technologies and materials [1,2] are being sought to satisfy modern battlefield requirements [3].

Poland was lacking a bridge that would meet present-day requirements, and work was undertaken to develop new tactical bridges MG-20 [4] and support bridges MS-20 [5] and MS-40. The new bridge systems should take into account the advantages of the old designs [6] and make use of the experience gained in the course of testing and operating them, and supplement them in terms of load bearing capacity, functionality and viability of new solutions.

2. CLASSIFICATION OF MILITARY BRIDGES

Military bridges (Fig. 1), depending on their purpose and position in a combat formation, can be classified according to the NO-01-A001:2011 standard [7] as follows:

a) assault (tactical) bridges on tracked undercarriages;

b) support bridges on wheeled undercarriages;

c) line of communication (foldable) bridges.

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Of particular importance for the modern battlefield are the assault bridges ("battlefield bridges") [3]. These bridges are used to directly support the first fighting echelons in the area of firing distance from the enemy.
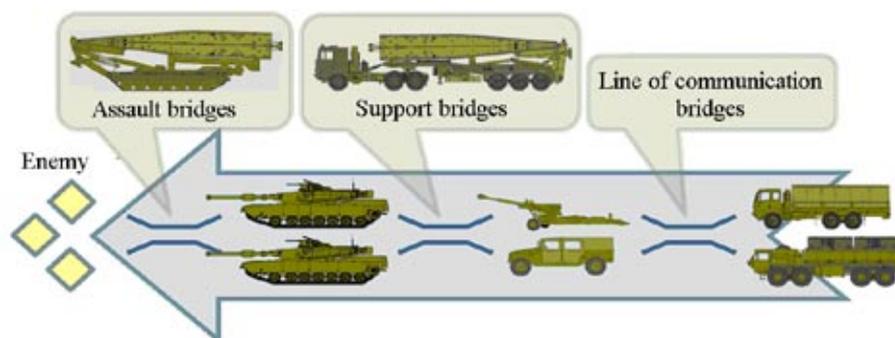
Fig. 1. Types of bridges used at the various phases of combat operations

To avoid the risk and effects of direct and indirect enemy fire, the bridge launching time should be as short as possible. The rate of launching the bridge has a direct effect on the time and safety of positioning the bridge over an obstacle after the bridge carrying vehicle is stopped. This is related to the occurrence of dynamic loads during the launching and retrieving of the bridge span resulting from its weight and other external loads caused by, for instance, weather conditions (gusts of wind, mud, etc.). For this reason, at the design stage, in addition to strength analyses, strong emphasis is placed on conducting comprehensive analyses of issues related to transverse and longitudinal stability margins in assault and support bridges. This applies to all phases of bridge operation. To conduct such analyses it is necessary to have extensive expertise in the field of operating principles of bridge mechanisms and knowledge of the phenomena associated with bridge launching. Particularly important is the information on the effect of inertia or failure of hydraulic systems on bridge stability, the risk of increasing the overturning moment due to incorrect handling of the bridge by the operator, etc. At the design stage, it is necessary to take into account all the factors that have an impact on bridge stability, and then at the testing stage to verify the correctness of the adopted design solutions. This enables achieving short bridge construction times (tactical requirements) and safe working conditions for the bridge operators (operational requirements). Proper knowledge of equipment capabilities allows the use of automated systems for controlling the process of bridge laying and retrieving in order to ensure the best equipment performance, while maintaining appropriate safety conditions for the operating personnel. These systems, at subsequent stages of bridge construction, can automatically adjust the output of the hydraulic system, which determines the rate of bridge span launching and retrieving, and may indicate possible deviation from the vertical of the bridge carrying vehicle, or automatically stop the launching process.

3. STABILITY OF SCISSORS-TYPE BRIDGES

Bridges deployed over an obstacle in the scissors manner require greater stability margin as compared to horizontally launched bridges. This is due to the change in the position of the centre of gravity of the span during launching, which increases the impact of atmospheric phenomena on the stability of the bridge laying process. During the process of launching and retrieving scissors-type bridges, the bridge span has to go through various phases of span position, as shown in Figure 2. When the span is positioned vertically relative to the undercarriage, then there is the greatest risk of loss of stability due to the wind acting

on a large front and side surfaces of the span. In addition, during the last stage of bridge launching, the process must be slowed down to prevent the span from hitting the ground. At that time, due to the inertia of the span, an additional overturning moment occurs. This paper presents the results of tests and studies performed during the development work on the MG-20 tracked bridge [4,8] and MS-20 wheeled bridge [5,9], both bridges comprising 15-tonne scissors-type spans.
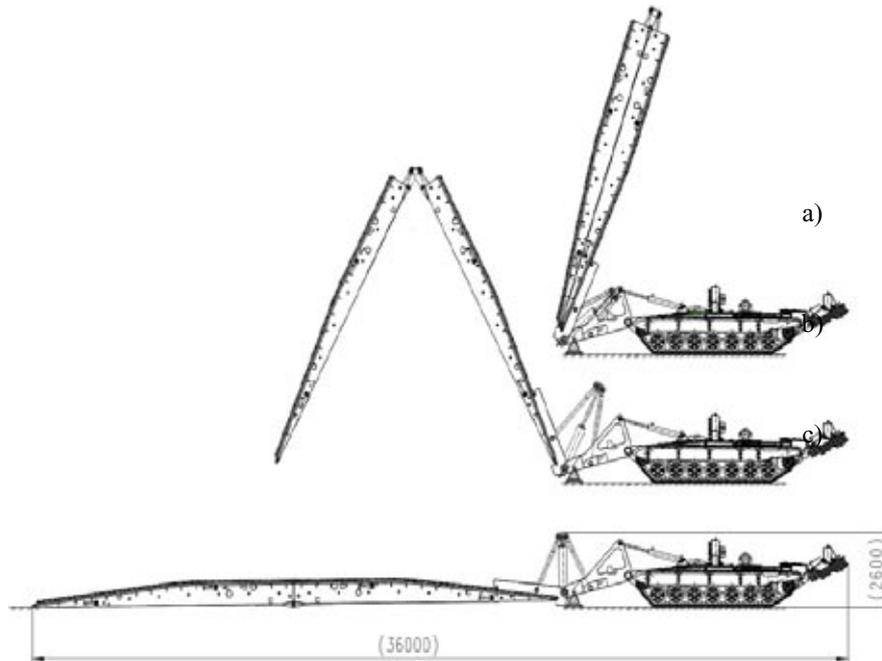

Fig. 2. Phases of launching the MG-20 bridge over an obstacle [4]

3.1. Determination of longitudinal stability margin of the MG-20 bridge during launching of span

The analysis of the longitudinal stability margin of the MG-20 bridge was carried out for the worst case occurring during the laying of the span. This is the case of the span positioned directly over the ground – opening angle of the span is 180° (Fig. 2.c).

Table 1. Stabilizing and overturning moments from bridge components and the determined longitudinal stability margin for bridge in position as in Fig. 2c.

Bridge component	Distance of centre of gravity to pivoting point (m)	Component weight (t)	Moment (Tm)
Undercarriage	6.48	31.50	204.12
Span	-12.35	15.0	-185.25
Saddle	9.03	1.50	13.55
Main arm	0.85	1.40	1.19
Catch arm	-1.78	1.40	-2.49
Support	0.00	0.40	0.00
2 cylinders	4.13	1.20	4.96
2 cylinders	-0.45	1.20	-0.54
Stabilizing moment			223.82
Overturning moment			-188.28
Stability margin			15.87 %

Table 1 lists the values of stabilizing and overturning moments from individual bridge structural components and the determined longitudinal stability margin for the bridge.

Tactical and technical requirements for the support bridge on tracked undercarriage [10] specify minimum longitudinal stability margin at not less than 15%. Analysis of the results listed in the table allows to state that the longitudinal stability margin of 15.87% during the bridge launching operation is sufficient.

3.2. Verification of transverse and longitudinal stability of the MS-20 bridge during span launching exposed to wind blowing at a velocity of 30 m/s

Resistance of the bridge to wind was assessed using the simplified method according to PN-ISO 4302:1998 [11] by determining boundary force resulting from wind pressure. The verification was carried out for the case of span displacement in the least advantageous position at wind velocity of 30 m/s. The least advantageous case of load occurs when the span is positioned vertically, and stability tests were performed with the span in this position (Figs. 3 and 4).

For the purpose of the study, the area of span surfaces exposed to wind was calculated: side (16.8 m^2), face (48 m^2), the value of the experimental dimensionless resistance coefficient K of *1.7* was adopted (due to the solid-wall design of the span), and then the aerodynamic forces of wind pressure were calculated using formula (1):

$$W = w \times A_{cal} = A_{cal} \times K \times v^2 / 16. \tag{1}$$

The design maximum forces of aerodynamic pressure of the wind were as follows: for the side surface of the span: 1512 kG, for the face surface of the span: 4320 kG.
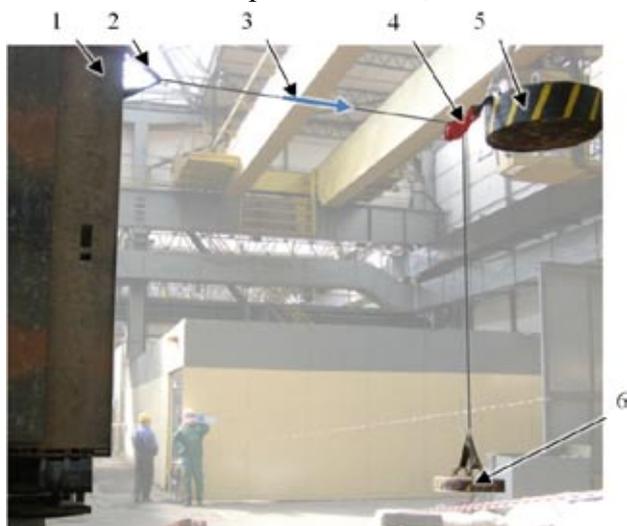
Fig. 3. Verification of the resistance of the bridge span in vertical position to wind blowing from the side using the simplified method
1 – front view of the span, 2 – suspension belt,
3 – steel cable, 4 – pulley block, 5 – ballast, 6 – steel block

Fig. 4. Verification of the resistance of the bridge span in vertical position to wind blowing from the front using the simplified method
1 – side view of the span,
2 – suspension belt, 3 – steel cable,
4 – pulley block, 5 – ballast, 6 – steel block

Transverse and longitudinal stabilities of the bridge were verified on a test stand at OBRUM [5]. Transverse stability was tested by affixing a cable to the span at the level of the

geometric centre of the side surface of the span, i.e. 6.5 m, and by applying to the cable a load of 1512 kG to simulate the effect of wind. Longitudinal stability was tested by affixing a cable to the bridge span at the level of the geometric centre of the face surface of the span, i.e. 6.25 m, and by applying to the cable a load of 4320 kG. During the side (Fig. 3) and front (Fig. 4) wind effect simulation tests, no stability loss, in the form of bridge supports being detached from the ground, has been observed. The verification has indicated that for the case of the least advantageous position of the span, the bridge is resistant to the action of wind blowing at a velocity of 30 m/s.

3.3. Verification of longitudinal stability of the MG-20 bridge during emergency stopping of the span launching operation

The purpose of verification was the determination of the value of additional overturning moment resulting from the span inertia after emergency stopping of the span during bridge launching operation [8]. Comparison of the determined value with requirement specifications, that stipulate that the dynamic surplus generated during span launching and retrieving should not exceed 10% of the maximum overturning moment [10], enable verification whether the design of the span and of the hydraulic system meets the requirements for safe operation of the bridge.

In order to determine the value of the increase in the overturning moment resulting from the dynamics and inertia of the system, an emergency stop in the bridge launching operation was effected with the span stopped in its most critical position (at a height of 1 m above ground - Fig. 7). Stresses at selected points of the bridge layer frame were measured during the test using strain gauges. The measuring system comprised [8]:

– LMS measuring device with VB8E module, connected to strain gauges for stress measurement;

– HP Elitebook 8740w laptop computer with LMS Test.Xpress 4B software for measurement data management and comprehensive analysis;

– resistance strain gauges from TENMEX – TFr-10(k).

A diagram of strain gauges arrangement on the bridge layer is shown in Fig. 5, Fig. 6 shows positions of gauges nos. 2 and 5, Fig. 7 presents the moment corresponding to emergency stopping of the span. Resultant stress graph obtained during the test is shown in Fig. 8.
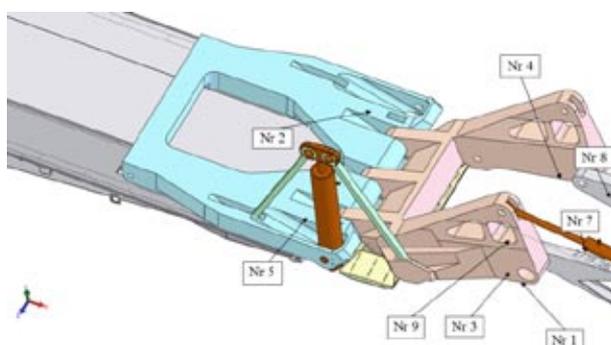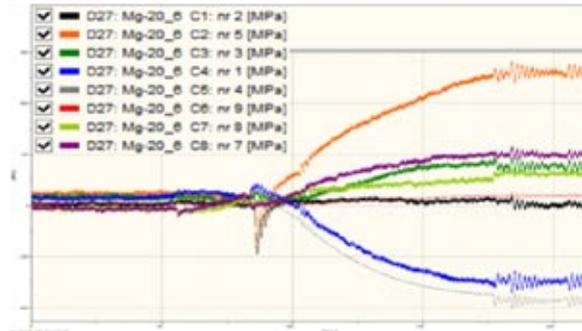

Fig. 5. Diagram of strain gauges arrangement on the bridge layer

Fig. 6. View of strain gauges arrangement on the bridge layer

Fig. 7. Moment corresponding to emergency stopping of the span 1 m above the ground

Fig. 8. Recorded stress graph

The increase in the overturning moment of the MG-20 bridge was calculated based on the analysis of stress changes in the components of the MG-20 bridge layer during emergency stop of the span. Video recording of the test enabled assigning the measured values of stress in the bridge layer structure to the individual stages of the span launching operation. Afterwards overturning moments of the span were determined for these positions of the span in relation to the pivoting point (layer foot). Results are listed in Table 2. These enabled determination of the relationship between the overturning moment and stresses in the bridge layer (Fig. 9). The stress graph shown in Figure 8 indicates that the emergency stopping of the span is accompanied by additional dynamic loads which are manifested by the occurrence of span vibrations and increased stress in the bridge layer frame.

Table 2. Stress in bridge layer structure vs. overturning moment

Span launching stage	Time, t	Stress, MPa	Overturning moment, Tm[*]	Distance of centre of gravity to pivoting point, m
Span at 45° to supporting vehicle	20.00	18.00	+60.00	4.00
Span in vertical position	47.00	74.00	-10.88	-0.73
Span opening angle 90°	87.00	195.00	-145.50	-9.70
Span 1 m above ground	121.00	255.00	-185.25	-12.35
Emergency stop 1 m above ground	121.00	283.00	**-203.32**[**]	-12.35

[*] "+" indicates stabilising moment, "–" indicates overturning moment.
[**] Value calculated from the graph representing the overturning moment vs. stress in bridge layer relationship (Fig. 9)

Assigning the overturning moment to the measured stresses given in Table 2 enabled the plotting of the overturning moment (dependent on span position) as a function of stresses occurring in the bridge layer structure (Fig. 9). A trend line was determined and described with equation (2), which allowed for the calculation of the overturning moment occurring during an emergency stop of the span at the height of 1 m above the ground, for which the measured stress value was equal to 283 MPa.

$$y = 0.00172 \times x^2 - 1.51826 \times x + 88.59044 \tag{2}$$

The calculated value of the overturning moment was 203.32 Tm.
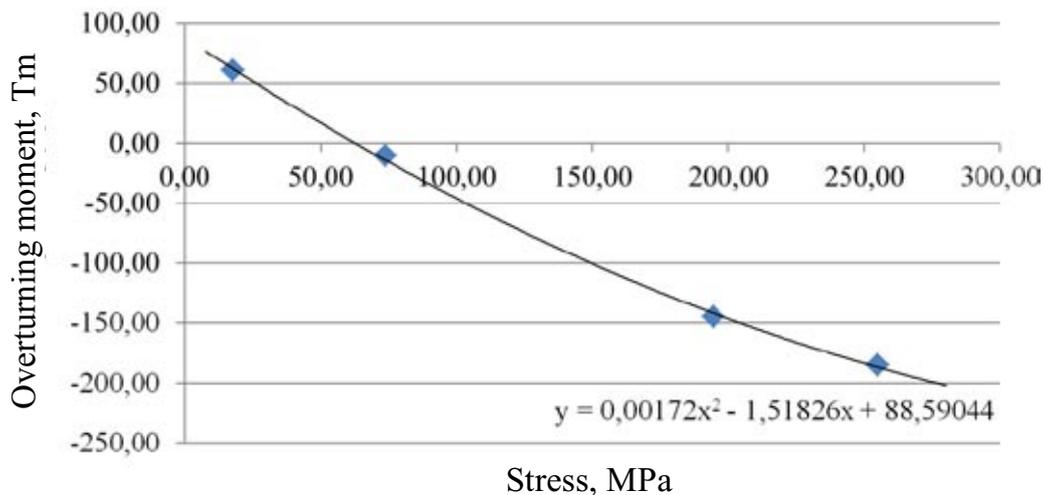
Fig. 9. Graph of the relationship between the overturning moment and stresses in the bridge layer

Analysis of the data in Table 2 leads to the conclusion that the difference between the maximum overturning moment of the span positioned at a height of 1 m above the ground, and the moment occurring during an emergency stop, resulting from the inertia of the span, is 18.07 Tm. This is equal to 9.75% of the maximum overturning moment. This means that the specifications of the Tactical and Technical Requirements, which stipulate that the "design of the hydraulic system should be such as to ensure that the dynamic surplus generated during span launching and retrieving or in the case of a sudden stop (caused, for instance, by hydraulic line failure) is not more than 10% of the maximum overturning moment", are satisfied. Meeting that requirement indicates that the stability margin of the MG-20 bridge is sufficient for the safe operation of the bridge. It is appropriate to state that the proper weight distribution of the span and of the layer and the hydraulic system design provide the required stability of the system, both static as well as dynamic.

4. CONCLUSIONS

Mobile military bridges, both assault bridges and support bridges, constitute an important component of the system that provides troop mobility on the battlefield, during peace keeping missions and operations eliminating the effects of catastrophes and natural disasters. To be able to safely carry out their tasks, they should be properly designed and tested with regard to the fulfilment of the conditions listed below

1. During launching operation, the scissors-type bridges should have adequate transverse and longitudinal stability, which allows the erection of the bridge in a variety of field conditions, taking into account all factors that affect their stability.
2. The hydraulic system, directly responsible for effecting span launching and retrieving operations, should be designed so as not to pose any hazard for the operators' health as an effect of the loss of bridge stability.
3. Automated systems for controlling the process of bridge laying and retrieving should be used in the design of scissors-type bridges to enable fast and safe erection of the bridge.
4. The operator's knowledge of the stability characteristics of the scissors-type bridge and of the span dynamics during bridge erection enables the operator to respond promptly to failures and to ensure safe operation of the bridge.

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