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DEPENDENCE OF MILITARY BRIDGE LENGTH AND PARAMETERS DEFINING ITS MANUFACTURING COSTS

Peter MAKO

Abstract: Knowledge of dependence between the length of the bridge and parameters which are defining the costs for its production can be extraordinary valuable for making decisions during planning, procurement or any other inhouse processes of manufacturers of this equipment. This article is expressing graphical and functional dependence between the bridge length and the basic parameters which are defining manufacturing costs of the bridges. Presented functions allow to predict parameters defining manufacturing costs for bridges which are out of the scope of this article also.

Keywords: Bridge; STANAG 2021; Bridge length; Static analysis; AM-50; Dependence.

1 SLOVAK ARMED FORCES BRIDGE EQUIPMENT

At the moment Slovak Armed Forces are using several types of bridging equipment. Mostly they are equipped with assault bridging systems and support bridging systems. Assault bridging systems are represented by wheeled vehicles AM-50 and PM-55. Tracked assault bridging systems are represented by vehicle MT-55. As support bridging systems the Slovak Armed Forces are using PMS-60 floating bridge. All of mentioned bridge bays can be considered as Orthotropic bridges. [2]

Orthotropic bridges are described like bridge structure which consisted of relatively thin sheet plate components. Road of the bridge is made from thin sheet plate, based on bridge bay load capacity. Road is supported by a series of closely spaced longitudinal ribs with support by orthogonal transverse floorbeams. Construction is normally supported by two main longitudinal beams. [1]

Mentioned description is absolutely valid for all mentioned bridge bay types which are in use of Slovak Armed Forces.

Orthotropic bridge bays can be divided in to two groups based on the shape of longitudinal ribs. It is a bridge bay with open ribs and bridge bay with closed ribs. Both construction types can be seen on Fig. 1. [1]

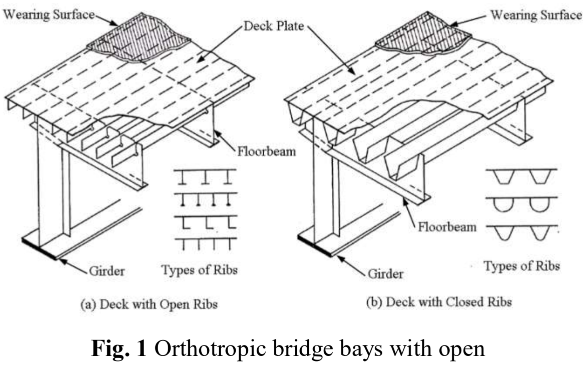

Fig. 1 Orthotropic bridge bays with open and closed ribs
Source: [1].

2 BRIDGE BAY OF AM-50 VEHICLE

One of the most used bridging equipment in Slovak Armed Forces is assault bridging vehicle AM-50. Construction of bridge bay is made from steel sheets which are connected by welding. Structure consists of two main beams which are stiffened in bottom part. These two beams are connected by several floorbeams and they are interconnected by series of closely spaced longitudinal ribs which are placed perpendicular to them. These longitudinal ribs have L shape. Roadway is made from thin steel sheet which is covering the whole construction from top side. Bottom side is not closed. Description of AM-50 bridge bay construction is exactly aligned to Orthotropic bridge bay with open ribs.[3]

AM-50 bridge bay has length of 13.5 m and as single bridge bay allow to overcome barrier with length of 12.5 m. It was designed for 50 tons load capacity for tracked vehicles and 70 tons for wheeled set. These two parameters are not specified anyhow closer. There are missing basic information and descriptions of contact area between the bridge and tracks or wheels. Spacing between axles of wheel set is missing too and the weight distribution for wheel set is missing as well. Nowadays this vehicle is facing two essential issues which are service age and insufficient tactical parameters. The result of second problem is disable interoperability of AM-50 bridging vehicle with heavy equipment in service of NATO member countries forces. [3]

Vehicle AM-50 went into service in 1977. At the moment the oldest pieces can have 45 years in service already. Because of that it is possible to predict their replacement in close time. [3]

3 REQUIREMENTS ON TACTICAL PARAMETERS OF BRIDGING SYSTEMS

At the moment most of the heavy equipment in service of NATO member states are classified into category MLC70 as per standard STANAG 2021. Based on that fact can be this category considered as minimal requirement for bridging equipment in service of NATO member states. In some cases, it is possible to find bridging equipment with even higher load capacity MLC80. The length of the obstacle which can be overcome by AM-50 by using of single span can be considered as one of the shortest. Comparable vehicles such as TMM-6 has bridge bay with length of 17 m. [2]

Possible change of bridge bay construction and increasing of the load capacity or length of the bridge will have essential effect on parameters which are defining costs for production of that bridge. Knowledge of dependence of load capacity and the length of the bridge and parameters which are defining the costs for its production can be extraordinary valuable for making decisions during procurement processes of these equipment or any other inhouse processes of their manufacturers.

4 ARTICLE TARGET AND BOUNDARY CONDITIONS OF ITS REACHING

The main target of this article is to present a solution of dependence between the length of the bridge bay of bridging equipment as its tactical parameter and parameters which are defining its manufacturing costs.

Standard STANAG 2021 is not giving details such as basis of design or details regarding structural analysis of bridge components. These can be find in standards used in civil sector. It is for example standard EN 1993-1-1 Design of steel structures and its second part EN 1993-2 Steel bridges. In case of designing of bridge structure it is necessary to make all structural analysis based on these standards. STANAG 2021 is giving different details regarding hypothetical vehicles which will be crossing of bridges or details regarding safety factors, wind conditions etc. In case of designing of military bridge is essential to use both standards.

Study presented in article is showing different possibility of structural analysis made by FEM simulation in limited situations. This analysis can be used for designing of first bridge concepts before their structural analysis as per official standards.

The base for realization of analysis was 3D model of AM-50 bridge bay which was created based on existing design documentation of this vehicle. This 3D model was subjected by static analysis of load capacity as per standard STANAG 2021. Like default category was selected category MLC60. This category was selected due to missing detailed specification of loads and prediction that existing structure could be falling in to mentioned category. STANAG 2021 is defining in total 16 categories of load capacity and for each of them describing hypothetical tracked vehicle and wheeled set. For these hypothetical vehicles determines specific size of contact surface between tracks or wheels and surface of bridge road deck. On the same time defining the load applied on contact surfaces and in case of wheeled set the spacing between each axle. By using of these data was possible to establish the conditions of static analysis of each assessed bridge structure. Load conditions for category MLC60 is possible to see on Fig. 2. [4]

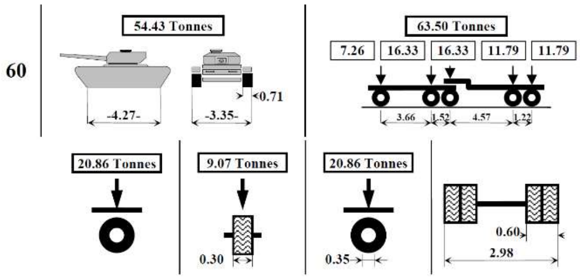

Fig. 2 Definition of hypothetical vehicles of category ML60 as per STANAG 2021
Source: [4].

Presented structural analysis is focusing on stress results in bridge structure from unfavorable situations which are creating the biggest bending moment on the bridge. The biggest bending moment will be applied on the bridge in situation where the vehicle center of the gravity will be on the same plane as geometrical center of the bridge. From logical reasons this should be a most unfavorable situation of placing of load on the bridge for static analysis. That is valid mainly for tracked vehicles. In case of wheeled set, it was impossible to reach different situation of load positioning because complete length of hypothetical vehicle was almost same as the bridge bay length. Because of that fact the geometrical center of the wheeled set was placed in to the same plane as geometrical center of the bridge. In both cases only centric movement will be taking in consideration. [4]

Except the contact surfaces of hypothetical vehicles standard STANAG 2021 defines other condition which must be met also. One of the most important boundary conditions for solving of bridge static analysis is required safety coefficient. Standard defines basic safety coefficient for Bending and/or Tension on level k=1.33. In case of Bearing safety coefficient it is necessary to multiple this value by constant 1.33. Final safety coefficient will looks as follows: k=1.33x1.33=1.7689. It is necessary to take in to consideration inaccuracy of simulation so final safety coefficient can be rounded to k=1.8. [4]

Next boundary condition of FEM static structural analysis is selection of material which will be considered as built material of the bridge. Original bridge bay of AM-50 vehicle was mainly made from steel CSN 15 222. This material under this standard is not possible to find on the market anymore. That was also the reason why company ZTS VVU Kosice a.s., like one of the original manufacturers of bridging equipment AM-50, replaced original steel with a steel S700 for its new products. That is the reason why this steel S700 was selected as built material for static structural analysis purpose. One of the most important material properties for planned type of static structural analysis is yield strength. In case of steel S700 is maximum yield strength 700 MPa. After applying of safety coefficient as per STANAG 2021 is allowable stress in bridge construction $\sigma_{allowed}$=389 MPa.[5]

All other effects defined by STANAG 2021 such as wind, additional loads like mud, snow and ice load, longitudinal horizontal forces and etc., were not included in this study.

5 STATIC ANALYSIS OF AM-50 BRIDGE BAY AS PER SELECTED BOUNDARY CONDITIONS

All static structural analysis, which were done within this article and as per mentioned boundary conditions, were realized in software ANSYS 2021 R1.

Static analysis of original AM-50 bridge bay was done as per conditions mentioned in capture 4 of this article and for category MLC60 as per STANAG 2021. Like default position for tracked hypothetical vehicle was its place in the middle of the bridge which means that the tracked vehicle´s center of gravity was in the same plane, perpendicular to road way, as geometrical center of the bridge bay. In this situation is prediction of biggest effect of bending moment on bridge bay and prediction of biggest stress in bridge material as well.

Study is focused mainly on maximum stress due to biggest effect of bending moment on bridge bay and therefore no other location of hypothetical vehicle was checked.

Static analysis was done by standard procedure in module “Static Structural”. For starting of simulation was necessary to set default material, defining contacts between each construction parts of bridge structure, mesh creation and defining of boundary conditions and application of the loads on the bridge structure.

Like result of the simulation was taken Maximum Principal Stress. The Maximum Principal Stress which was found in bridge bay was σ_{max1}=778.11 MPa. This value is higher than allowed stress but this maximum value was found only on several small areas. Stress in the rest of the structure was smaller than allowed stress. Visualization of the result is possible to see on Fig. 3.

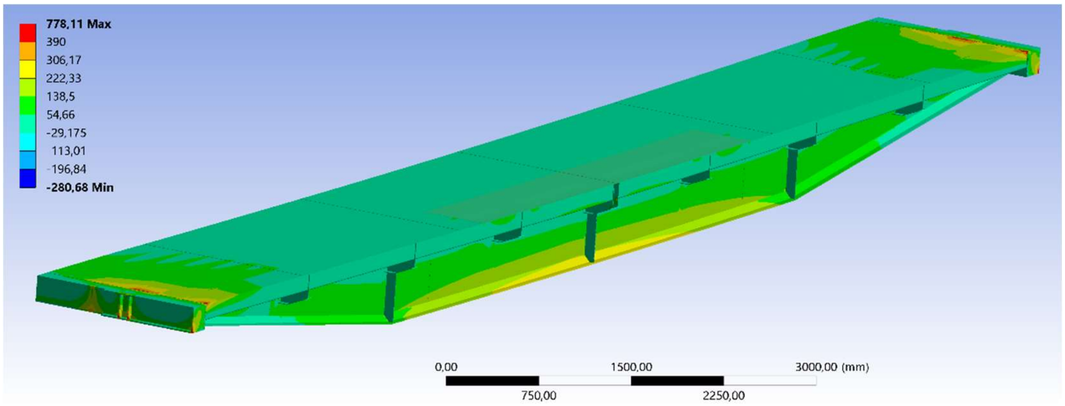

Fig. 3 Graphical result of static analysis of AM-50 bridge bay loaded by hypothetical tracked vehicle as per MLC60
Source: author.

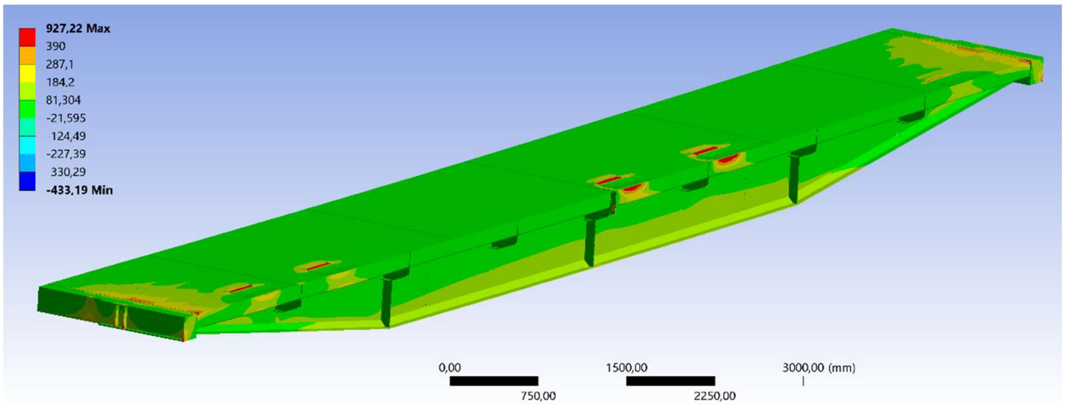

Fig. 4 Graphical result of static analysis of AM-50 bridge bay loaded by hypothetical wheeled vehicle as per MLC60
Source: author.

Second static analysis of original AM-50 bridge bay was done with wheeled set as per STANAG 2021 MLC60 category. Geometrical center of the wheeled vehicle was placed in the plane which is perpendicular to road way and in which is also located the geometrical center of the bridge.

The Maximum Principal Stress which was found in bridge bay due to application of wheeled set load was σ_{max2}=927.22 MPa. In contact area between the wheels and road way of bridge was found higher stress than allowable stress in material. This finding was more serious and more critical in comparison of the results with tracked vehicle. Visualization of the result is possible to see on Fig. 4.

The biggest disadvantage of presented FEM simulation is impossibility of efficient implementation of nonlinear buckling effects on complete model. Nonlinear buckling analysis can be done in mentioned software but efficient it will be only in case of single components analysis which correspond to structural analysis procedure as per mentioned standards EN 1993-1-1 and its second part EN 1993-2.

Based on the gained results is possible to evaluate that original AM-50 bridge bay is not capable to carry loads defined in STANAG 2021 category MLC60. The gained maximal stresses are higher than yield stress which will cause in yielding and plastic deformation in the end. With implementation of nonlinear buckling are expected even worse results. At the same time there is prediction of not positive results for bridge carrying capacity in regards to EN 1993-1-1 and EN 1993-2 as well, but this has to be checked.

6 DESIGN CHANGE OF ORIGINAL AM-50 BRIDGE BAY AND STATIC ANALYSIS AS PER GIVEN BOUNDARY CONDITIONS

Because of unfavorable results of static analysis of original bridge bay structure, it was necessary to accede of its design change. After a series of design changes and they verification by static analysis was created a final version of concept bridge structure for further investigation.

The biggest change was done in bottom part of the main beam. The thickness of this beam remains same but the thickness of bottom support flange which is perpendicular to that beam was changed from original 12 mm to 15 mm. Reinforcement which connected the main beam and support flange, and which was bended, and its thickness was 6 mm was changed also. This original reinforcement was replaced by four longitudinal reinforcements with thickness of 3 mm and placed perpendicular to the to bottom support flange. Advantage of this solution is that it is not increasing weight of original structure, it is easier for manufacturing and welding and improving the stiffness of the structure. Another radical change was done in front area of the bridge bay. In this area have been added four longitudinal reinforcements which are connecting the bottom support flange and roadway of the bridge bay. Their thickness is 3 mm as well. Longitudinal ribs were also changed. Their original thickness was 2.7 mm and for a new bridge design were used ribs with 3 mm thickness. Their spacing were reduced and three on each side of the bridge were added. Final optimized construction has weight of 6 461 kg, width is 4 000 mm and complete length is 13 500 mm. In comparison with original bridge structure is around 510 kg heavier. Components which were changed are marked on Fig. 5 and Fig. 6. [3]

The results of static analysis of redesigned bridge as per conditions mentioned in chapter 4 are in Tab. 1.

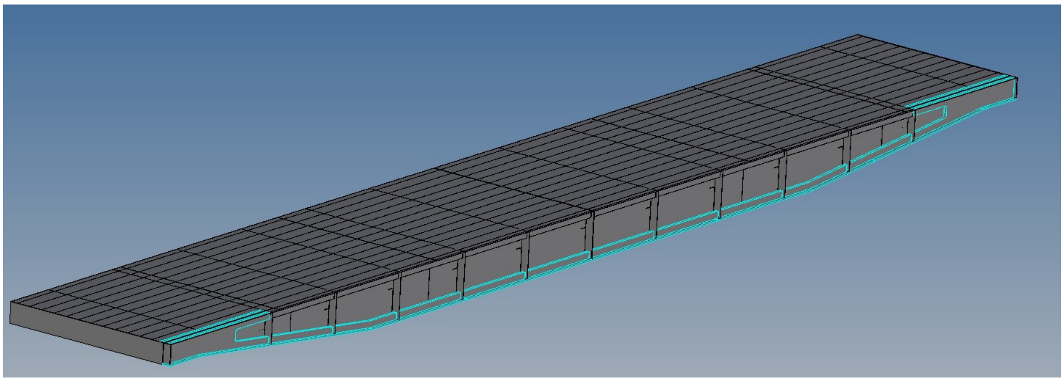

Fig. 5 Visualization of main changes done on original AM-50 bridge bay construction, upper view
Source: author.

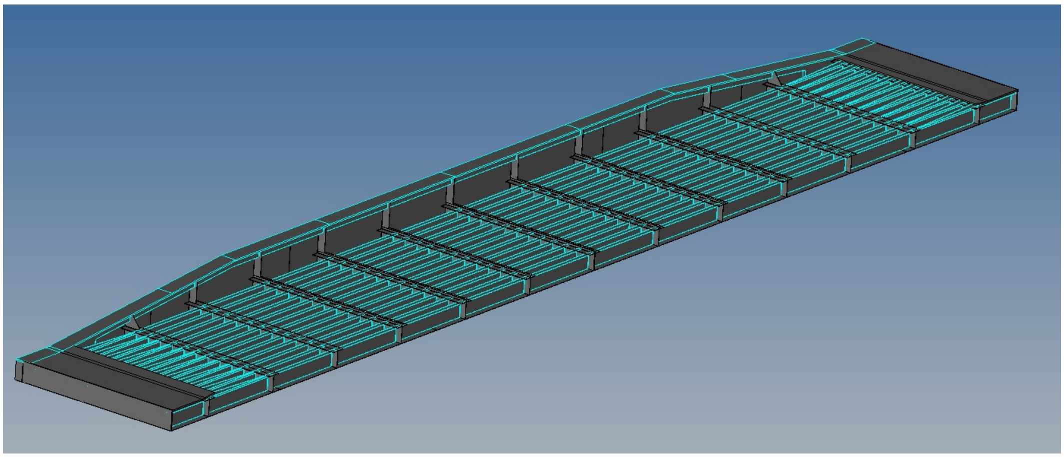

Fig. 6 Visualization of main changes done on original AM-50 bridge bay construction, bottom view
Source: author.

Tab. 1 Results of static analysis of redesigned AM-50 bridge

Principle stress	Tracked vehicle	Wheeled set
Average stress in main beam, bottom support flange and longitudinal reinforcements (MPa)	88.16	61.52
Average stress in floorbeams (MPa)	43.33	30.04
Average stress in longitudinal ribs (MPa)	25.58	15.70

Source: author.

7 STATIC ANALYSIS AND OPTIMALIZATION OF BRIDGE STRUCTURES OF DIFFERENT LENGTHS BASED ON ORIGINAL AM-50 BRIDGE

Successful result of redesigned original AM-50 bridge with length of 13 500 mm and width of 4 000 mm represent starting point for next analysis. Construction of this bridge is marked as variant A in rest of this article.

In next phase of article´s target solving were step by step created four bridge variants which were designed as per construction of variant A. In first phase the thickness of all main components were same. Width of all bridge variant structures was same as variant A. Width of the bridge 4 000 mm was considered as not changeable parameter.

Single length and marking of each bridge structure which were analyzed in this article is possible to find in Tab. 2.

Tab. 2 Marking of each bridge length variant

Length of the bridge (mm)	Bridge variant marking
13 500	A
14 500	B
15 500	C
16 500	D
17 500	E

Source: author.

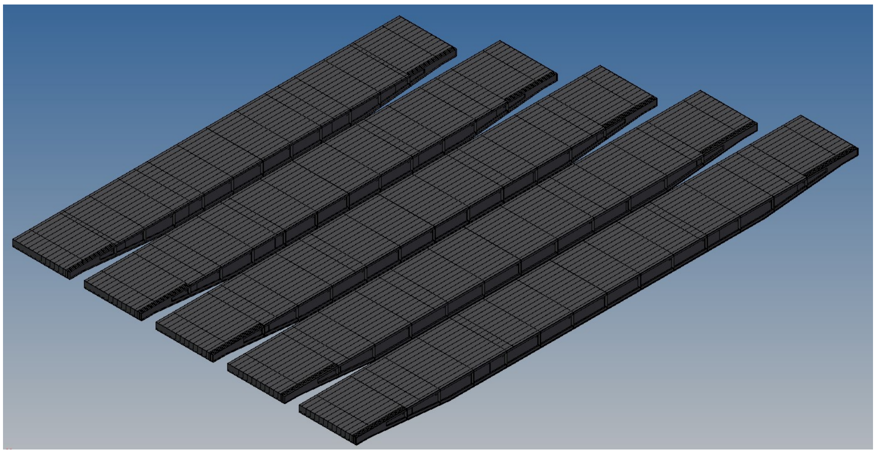

Fig. 7 Graphical presentation of all bridge variants
Source: author.

Each bridge variant mentioned in Tab. 2 was subjected by static analysis in software ANSYS 2021 R1. Based on this analysis each bridge structure was optimized to meet same requirements as bridge variant A. For elimination of possibility of changes which will lead to too high stiffness or opposite to lower stiffness than other bridge structure it was set a parameter of average stress for tracked vehicle load situation in main bearing elements. This value was set as per results from variant A static simulation. 88.00 – 88.50. During optimalization process was emphasized on keeping the same construction scheme as variant A. Main design improvements were done by changing of thickness of components or by addition of components to increase stiffness of the structure. Mostly were changed thickness of longitudinal enforcements on support flange. Design of these components had biggest impact on monitored average stress. Most of the rest of the components were changed only because of the change of the bridge structure length.

Results of static structural analysis of each bridge variant is possible to see in Tab. 3.

Tab. 3 Results of static analysis of each bridge variant

Principle stress	**Tracked vehicle**	**Wheeled set**
Variant B		
Average stress in main beam, bottom support flange and longitudinal reinforcements (MPa)	88.02	64.37
Average stress in floorbeams (MPa)	47.26	35.00
Average stress in longitudinal ribs (MPa)	23.19	14.81
Variant C		
Average stress in main beam, bottom support flange and longitudinal reinforcements (MPa)	88.50	68.34
Average stress in floorbeams (MPa)	49.94	39.39
Average stress in longitudinal ribs (MPa)	21.73	14.65
Variant D		
Average stress in main beam, bottom support flange and longitudinal reinforcements (MPa)	88.47	71.30
Average stress in floorbeams (MPa)	52.40	43.71
Average stress in longitudinal ribs (MPa)	19.97	14.08
Variant E		
Average stress in main beam, bottom support flange and longitudinal reinforcements (MPa)	88.15	73.76
Average stress in floorbeams (MPa)	54.72	47.69
Average stress in longitudinal ribs (MPa)	19.51	14.17

Source: author.

8 DEPENDENCE EXPRESION OF BRIDGE LENGTH OF BRIDGING EQUIPMENT AND PARAMETERS WHICH ARE DEFINING COSTS FOR ITS MANUFACTURING

After successful finish of all static analysis and optimalization of each bridge construction was necessary to define basic parameters which are defining costs for bridge manufacturing. Based on practical experiences were set two basic parameters which were:

a) Weight of construction – based on information about weight of the structure is possible to evaluate some costs for bridge manufacturing. It is for example calculation of costs for construction material, costs linked with assembly and manipulation with structure. This parameter was divided in to two groups:
   - Weight of the main beam, longitudinal enforcement, and bottom support flange.
   - Weight of longitudinal ribs and floorbeams.

b) Size of surface content – based on information about the content of all bridge surfaces is possible to evaluate costs which are needed for application of paints or coatings. This parameter was divided in to two groups also:
   - Surface content of the main beam, longitudinal enforcement and bottom support flange.
   - Surface content of longitudinal ribs and floorbeams.

On the graphs below is possible to see dependence expression between bridge length and each parameter which is describing manufacturing costs of the bridge structure. All cost parameters were gained from 3D files of each bridge variants, A up to E, in the software Inventor 2019.

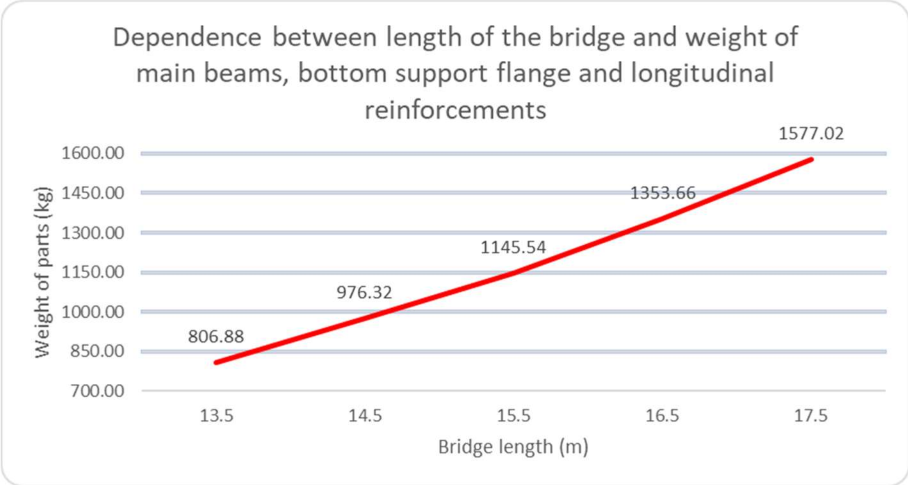

Fig. 8 Graph of dependence between bridge length and weight of main beams, bottom support flange and longitudinal reinforcements
Source: author.

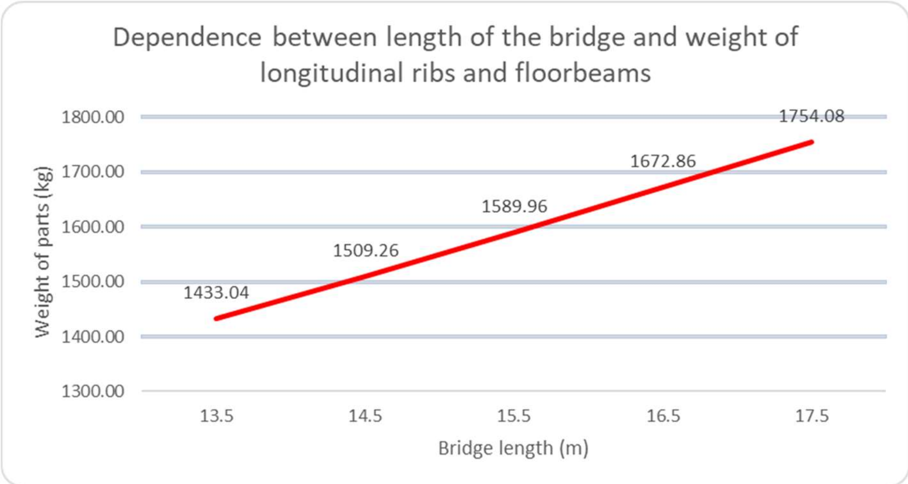

Fig. 9 Graph of dependence between bridge length and weight of longitudinal ribs and floorbeams
Source: author.

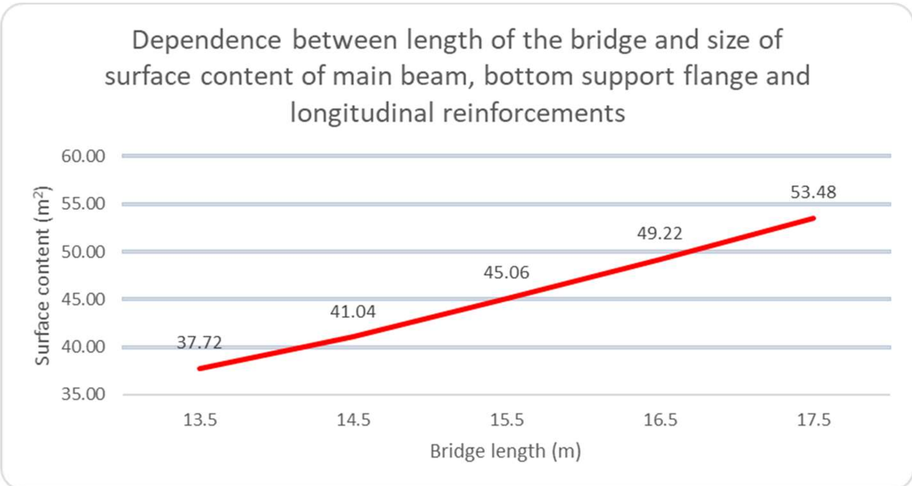

Fig. 10 Graph of dependence between bridge length and surface content of main beams, bottom support flange and longitudinal reinforcements
Source: author.

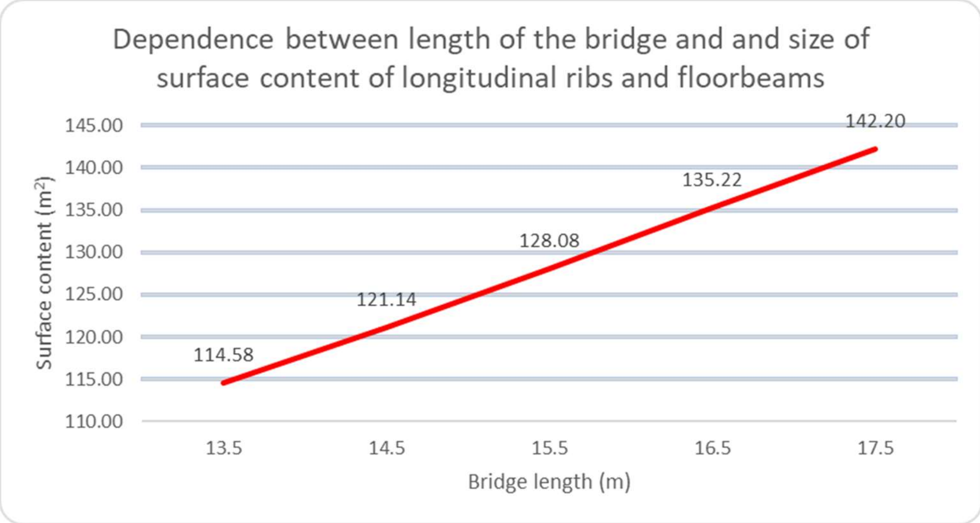

Fig. 11 Graph of dependence between bridge length and surface content of longitudinal ribs and floorbeams
Source: author.

From graphical dependence expression of each cost´s parameter on the length of the bridge is possible to evaluate, that for both parameters for main beams, bottom support flange and longitudinal reinforcement dependence have slightly exponential look. For Longitudinal ribs and floorbeams are dependence for both parameters linear. These results are logical because during increasing of the bridge length the stress in material of main beams, bottom support flange and longitudinal reinforcement was raising and here was necessity of material addition. In the rest of the structure the impact of length change was not significant to the stress cumulated in material. Therefor only addition of material due to length change was needed and this was on linear basis. Based on that it is possible to create an exponential or linear function for prediction of each parameter in case of different bridge length to the variants which were checked in this article. Functions which are describing each parameter were gained from software Excel by using of trendline.

Growth curves of these parameters is possible to define also by polynomic function. They will be valid only for bordered curves by exact length of the bridge from 13 500 mm up to 17 500 mm and it will be not possible to use them for predictions out of these limits.

Functions which are expressing each dependence are looking as follows:

a) Function for dependence expression between length of the bridge bay and cost parameter weight of main beam, bottom support flange and longitudinal reinforcements is:

$$y = 86.058e^{0.1667x} \quad (1)$$

$$y = -2.6158x^4+163.47x^3-3808.6x^2+39396x-152241 \quad (2)$$

b) Function for dependence expression between length of the bridge bay and cost parameter weight of longitudinal ribs and floorbeams:

$$y=80.568x+343.04 \quad (3)$$

$$y=-0.5133x3+24.741x2-314.69x+2435.2 \quad (4)$$

c) Function for dependence expression between length of the bridge bay and cost parameter size of surface content of main beam, bottom support flange and longitudinal reinforcements is:

$$y=11.492e^{0.088x} \quad (5)$$

$$y=-0.05x^3+2.4693x^2-36.37x+201.7 \quad (6)$$

d) Function for dependence expression between length of the bridge bay and cost parameter size of surface content of longitudinal ribs and floorbeams:

$$y=6.932x+20.798 \quad (7)$$

$$y=-0.045x^3+2.1668x^2-27.652x+203.7 \quad (8)$$

9 CONCLUSION

The basic target of this article was to find a dependence between length of the bridge bay which was coming out from original bridge of AM-50 vehicle and cost parameters which are defining manufacturing costs for these structures. This basic target has been achieved.

Like two mains cost parameters were set weight and surface content of the bridge structure. Both of these parameters were divided in to two groups defined by exact components. First group was made by main beam, bottom support flange and longitudinal reinforcement. The second group consisted of longitudinal ribs and floorbeams of the bridge. Dependence expression of bridge length and costs parameters for each group is possible to find in chapter 8 of this article. Except the graphical expression of mentioned dependences is also possible to find functions for each curve of these dependences in chapter 8. These functions can be used for calculation of cost parameters for the bridges out of the scope of this article.

In addition to the basic target was found that the bridge of the bridging vehicle AM-50, which is now in equipment of Slovak Armed Forces, does not meet the requirements of MLC60 category of standard STANAG 2021. This finding was done by FEM simulations in specified conditions, see chapters 4 and 5. To confirm this conclusion is necessary to subject the bridge to the complex structural analysis according to EN 1993-1-1, part 2 in combination with STANAG 2021.

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Dipl. Eng. Peter **MAKO**
Armed Forces Academy of General M. R. Štefánik
Department of Mechanical engineering
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: p.mako.peter@gmail.com

Peter Mako was born in Kosice, Slovakia in 1989. He received his Engineer degree in 2013 in field of Automotive production at Faculty of Mechanical engineering of Technical University in Kosice. He is PhD candidate of Department of Mechanical engineering of Armed Forces Academy of General M. R. Stefanik. His research is aimed to military bridging systems of engineery units.