Proposals for the Military Load Capacity Assessment of Existing Road Bridges

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Abstract The STANAG 2021 agreement, which is used by NATO member states, defines the standards for the military capacity assessment of road bridges. The standard allows bridges to be classified into 16 classes. The standard does not give a fixed value for the factors for the load capacity classification, but each member country can determine these in the light of their national bridge design codes. The present study summarises the proposals for the inclusion of certain factors (safety factor, dynamic factor) for the classification of existing bridges in Hungary. This summary also includes a proposal for modifications to the magnitude of civil loads travelling parallel to military loads.
With these factors, many trial calculations were made for each group of existing Hungarian road bridges. Out of the hundreds of sample calculations, some examples (for eight types of bridges) have been presented, including some with good load capacity and some with low load capacity.
Based on the sample calculations, it can be determined for which types of bridges it is recommended to carry out further calculations to verify higher military capacity. For this, STANAG 2021 provides options assuming cautious and risk crossing conditions. The sample calculations also show where in the Hungarian bridge stock structures can be found that may be inadequate for military mobility.
Our research is also an example of civilian and military cooperation, which is essential for the load classification of existing road bridges.

1 Introduction

Most civil and military transport uses the same road network. Bridges on public roads are designed and built for civilian loads. Civil and military road traffic has several different characteristics. It is necessary to validate the load capacity of civil road bridges for military traffic (Fig. 1.).
NATO has developed a uniform system for classifying the military load capacity of bridges. This is the STANAG 2021 [1] and the underlying standard [2], which has been adopted and is used by many countries (hereafter referred to as STANAG 2021.) Hungary has also adopted the STANAG 2021. Both vehicles and bridges should be assessed against this standard. Countries that use STANAG

2021 are responsible for classifying their own bridges for their own military transports and also for the military transports of NATO members passing through their countries [3].

Figure 1: Typical military heavy transport [4].

2 System of the STANAG 2021

STANAG 2021 consists of two main parts: it lays down procedures for classifying military vehicles according to their load and geometry, both wheeled and tracked. The second part of the standard provides for the classification of the load capacity of bridges, ferries and rafts. The purpose of the standard is to ensure that if the classification number of a bridge, a ferry or a raft is greater than that of the military vehicle, there is no load limitation for the crossing.

The standard has a total of 32 types of vehicles, 16 tracked and 16 wheeled. They are designated from MLC4 to MLC150. For the 16 types of tracked vehicles, the number is equal to the mass of the ideal tracked vehicle expressed in short tonnes (short ton) of the unit of measurement of the English century. For the ideal wheeled vehicles, the total mass is greater than the classification number [5].

The first striking difference between the STANAG 2021 classes and the civil bridge design standards is the number of vehicle classes. For the classification of vehicles, any integer from MLC4 to MLC 150 can be used iteratively. For the classification of bridges, there is no iteration, only the 16 values

given can be used. The military classification is particularly important in two cases. One is for loads over 80 tonnes, which significantly exceeds civil loads. The other is for bridges with weight restrictions (e.g. max 12 tonnes gross weight). In this study, we have looked at the conditions under which heavy vehicles (over 80 tonnes) can be driven.
STANAG 2021 includes moment and shear force data calculated for a simply supported beam for light duty in both tabular and graphical form. These can be used to quickly classify vehicles and simply supported beam bridges. All bridges are assessed for both wheel and t-track loads. The two load capacities are not the same: this is illustrated in Figure 2, where the specific moment curves for the three largest wheel and track loads are plotted in a common coordinate system. As expected, the largest differences are for the smaller openings. For example, at an opening of 12 m span, the curves MLC100/T and MLC150/W intersect. So, the load capacity of a 12 m span bridge opening for a wheeled vehicle can be up to two categories higher than for a tracked vehicle.
Figure 2 also shows that between 5 and 40 m, the load capacity of the bridge for a wheeled vehicle is greater than that for a tracked vehicle, but between 40 and 80 m, the reverse is true: the load capacity for a tracked vehicle is greater than that for a wheeled vehicle. Knowing these relationships, it is possible to partially derive the load capacities of the two types from each other, if they are not known. (The change in trend seen around the 70 m opening is due to the fact that military vehicles follow each other in convoys and from then on, several vehicles load the bridge together.
The above example of classification includes simplifications, for example, in addition to the moment, the shear force should be checked in all cases. The classification of bridges should also consider the structural system of the bridge (e.g. multi-span, arch bridge, width, etc.).
The critical point in the static calculation is the magnitude of the safety factors and dynamic factors. STANAG 2021 does not give values for these, only recommendations. These factors should be determined at a national level. The magnitude of the safety factors and dynamic factors depends on the standard used for the design of the bridge, the simultaneity considered and the calculation procedure used.

3 Expected value of the military load

The road bridges should be designed for civil traffic loads. The live loads are given in the standards, specifying the characteristic value. The characteristic value in many standards is associated with a 5% probability of failure. The distribution of civil road traffic loads can be calculated using a normal distribution. The normal distribution is confirmed by measured data of actual road traffic in Germany (see Figure 3a) [6].
The normal distribution can be significantly deformed by the influence of external regulators. A good example is the effect of truck weigh stations at the Schengen border in Hungary. In Hungary, at all border stations along the eastern border (to Ukraine, Romania and Serbia), the load of road trucks in both directions of traffic is monitored by weighing (axle weight and total weight). This has the effect of significantly increasing the compliance of road users. The distribution of vehicle loads is lognormal as a result (see Figure 3b).
The stronger the regulation, the more asymmetric this lognormal distribution. In the case of military transport, the load distribution is extremely asymmetric due to the standard and strict

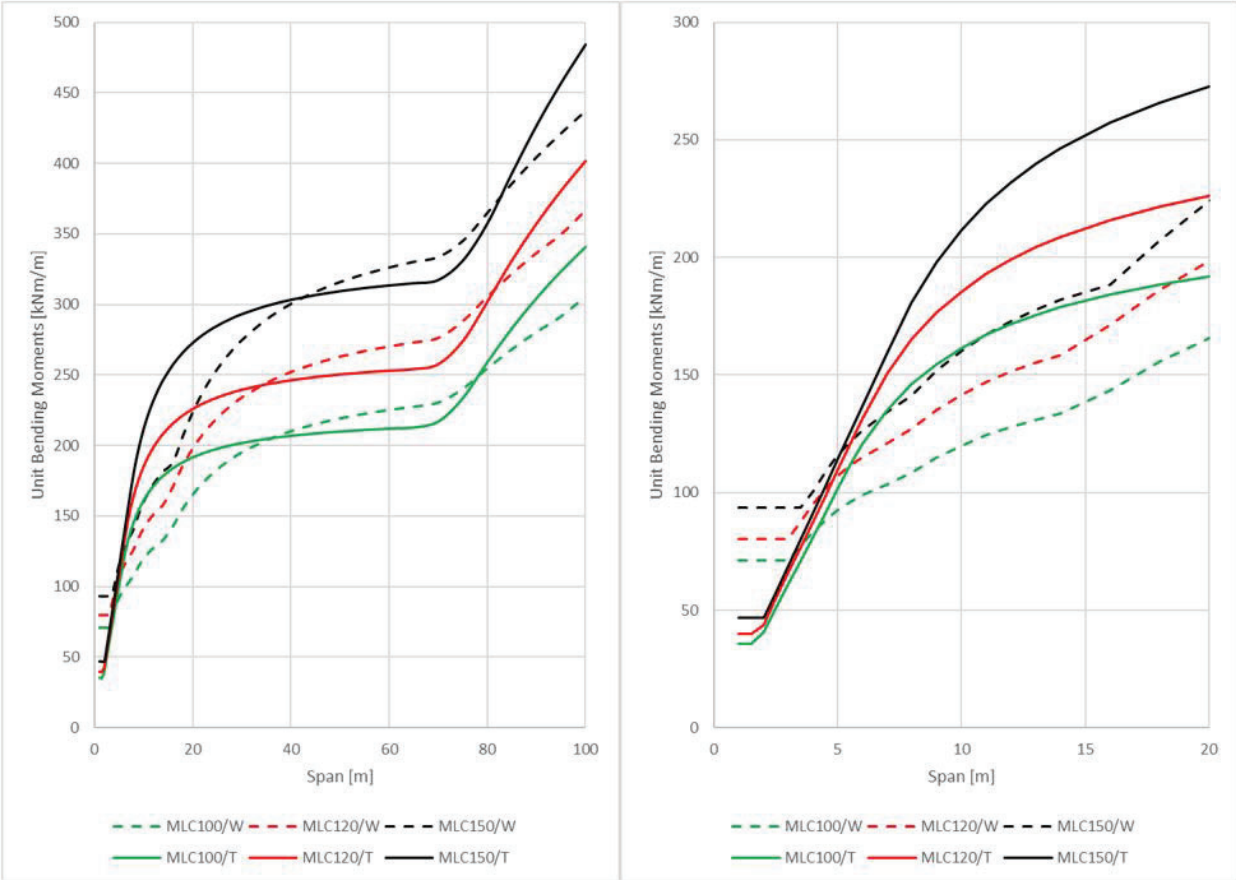

Figure 2: Unit bending moments graph of MLC100 – MLC 150 for tracked and wheeled live loads Source: author.

classification of military vehicles (see Figure 3c). This distribution allows a higher utilisation of the effective load capacity of the bridges (even with modification of the safety factors) or results in a higher safety factor.

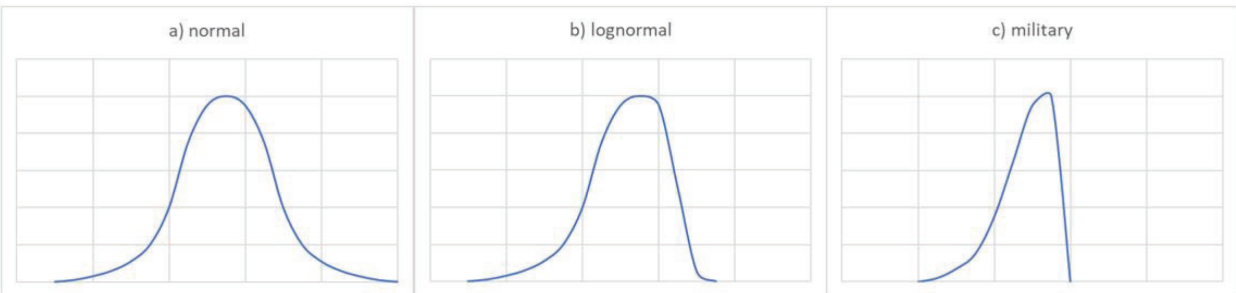

Figure 3: Possible theoretical shape of the distribution. Source: author.

3.1 Dynamic factor

According to STANAG 2021, if the speed is low (< 5 km/h), there is no dynamic effect. This is confirmed by the study of Oliva [7], who states that below 15 km/h the dynamic factor can be

neglected.
Thus, for caution and risk-crossing conditions, there is no dynamic surplus. In normal and axis-crossing conditions, different dynamic factors can be applied [8] [9].
The literature suggests that the dynamic factor of tracked vehicles should be maximised at 1.1. For wheeled vehicles above 800 kN, the dynamic factor can be maximized at 1.1 and can be omitted above 1200 kN [10].

3.2 Safety factor

The safety factors (their modification) should only be considered for procedures based on detailed calculations (Assessment levels 5-6-7 according to STANAG 2021) and only for qualified personnel (Level of Expertise C, D, HN). It is recommended that no modification of the safety factors is required for the demand comparison method. No safety factor reduction has therefore been applied in this article.
However, it is pointed out here that knowledge of the original design standard of the bridge is very important. An example of this is the 1956 Hungarian bridge code: the ideal vehicle was 60 tonnes, but, with modifying factors, this corresponded to a load of 80 tonnes [11]. Thus, for example, in this standard, under certain conditions, an increase factor of up to 1.33 (80/60) can be used.

3.3 Intensity of the parallel civilian traffic

The STANAG 2021 defines two types of normal crossing cases: when a military convoy is crossing in one lane and when a military convoy is crossing in two lanes. In both cases, simultaneous civilian traffic is possible on the remaining part of the bridge. This requires the determination of the intensity of the parallel civilian load.
If the majority of the civilian vehicles are heavy trucks and there is congestion (or stopping vehicles) then the maximum load on the bridge will be. The baseline value for congested truck loads, with an upper estimate, was considered to be 23.125 kN/m per lane, 2.86 kN/m for passenger cars [12]. On an empirical basis, the ratio of trucks to cars was set at 1/3 to 2/3 (see Table 1). We therefore estimate that the parallel civil traffic can be modelled with a load of 9.6 kN/m per lane.
The level of civilian traffic is sensitive to the military load rating while its definition is very uncertain.

Table 1: Estimating the intensity of parallel civilian traffic. Source: author.

heading level	traffic jam [kN/m]	rate	rate [kN/m]	sum [kN/m]
trucks	23.125	0.333	7.7	9.6
cars	2.86	0.667	1.9	

3.4 Crossing conditions: axis, caution and risk

In the Hungarian bridge design codes, the payload typically consists of an ideal vehicle and a simultaneous uniformly distributed load. In the first Hungarian standards (1910, 1950) there was no uniformly distributed load for only one vehicle (except for some special cases).
If there is no civilian traffic next to the military vehicle, the military column can travel on the axis of the bridge. This is more favourable from a static point of view because the ideal vehicle according to the standard should always be placed where its impact is most unfavourable (typically at the edge of the bridge and not in the axis). For this crossing case, the designation axis was introduced [13].
In the axis, caution and risk crossing conditions, the military vehicle can only travel on the axis of the bridge, and we can therefore derive the resulting excess load capacity. The available surplus depends on the width of the bridge. The wider the bridge, the higher the value of the surplus can be.
The surplus only comes from the ideal vehicle, the simultaneous distributed load can be considered symmetric. Conservatively estimated for an ideal vehicle of 800 kN and a simultaneous 10 m wide load of 3 kN/m2 in our calculation, the calculated load capacity surplus decreases with the span size as the ratio of distributed load increases.
Using a conservative cross-distribution ratio of 0.4-0.6, the resultant surplus for a bridge wider than 10 m is 1.2 for a load in the bridge axis (0.6/0.5). Proportionalizing this to the distributed load, we obtain the theoretical curve shown in Figure 4. The curve is simplified with four different constant values in the range 0-100 m.

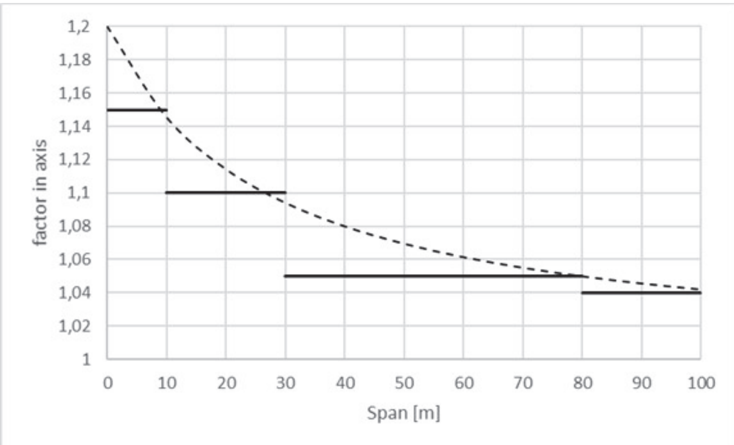

Figure 4: Theoretical and simplified modifying factor for Hungarian bridge codes from 1956. Source: author.

For narrow bridges, this surplus will be smaller, because the external accuracy associated with the design condition is lower. As a first approximation, it is proposed to neglect the available surplus below 8 m width and to calculate the surplus by half a value between 8 and 10 m width.
In the older Hungarian bridge design standards there are no simultaneous distributed loads, so the usable factor will be independent of the support structure (see Table 2).

Table 2: Modifying factor for Hungarian Bridge Codes in axis, caution and risk crossing conditions. Source: author.

Span [m]	Bridge codes until 1950			Bridge codes from 1956		
	Wide < 8 m	Wide 8-10 m	Wide > 10 m	Wide < 8 m	Wide 8-10 m	Wide > 10 m
0 – 10	1	1.1	1.2	1	1.075	1.15
10 – 30	1	1.1	1.2	1	1.05	1.1
30 – 80	1	1.1	1.2	1	1.025	1.05
80 – 100	1	1.1	1.2	1	1.02	1.04

3.5 Destruction, damage

In the case risk crossing condition of STANAG 2021, damage to the bridge is allowed. Determining the post-critical load capacity reserve of existing road bridges is a complex task [14].

There are only a few cases where a road bridge has to be demolished and there is room for a postcritical load capacity test. There are several known cases where even three times the bridge's nominal load capacity did not cause the bridge to fail and technical constraints prevented the bridge from carrying more load to cause it to fail.

During the Hungarian Revolution of 1956, a Soviet T-54 tank convoy is known to have crossed the Tisza Bridge at Vásárosnamény. From memories, we know that the deformation of the steel girder bridge was so great that the convoy was stopped and tanks were only allowed to cross the bridge one by one (i.e. in accordance with the STANAG 2021 caution crossing condition). For this example, we can calculate (estimate), assuming that the tracking distance of the tanks was 30.5 m (as per STANAG 2021), then the overload caused by the convoy was 3.4 multiplied (!) compared to the original load capacity of the bridge, and in case of passing one by one, the overload was "only" 1.7 multiplied. The bridge was not damaged.

For reinforced concrete prestressed structures, it is easy to see that if a small failure (cracking) is allowed, the load capacity of the bridge can be increased by at least 20-40%. The calculation can be done with a modifying factor for the bridge type. The modification factor can be determined by further tests.

3.6 Sample calculations

Over 100 sample calculations were made with the factors we collected. These calculations help to refine the classification procedure, which is the aim of this research. Among the calculations, the classifications prepared for eight types of bridges are presented. In all cases, the superstructure is a simply supported beam.

The calculations are made for spans between 3 and 100 m. The military traffic (crossing case) was considered in each case as a convoy and one lane. Where there is no parallel civilian traffic, we have assumed movement along the bridge axis (axis crossing condition). The results of the sample calculations are summarised in Table 3.

From a military point of view, it is certainly desirable that the wheeled load capacity reaches MLC120/W (tractor + trailer + heavy tank) and the tracked load capacity reaches MLC70/T (heavy tank). Therefore, in Table 3, the ranges where the calculated military load capacity does not reach these values are marked in grey.

Sample calculation No.1. Typical motorway and main road bridge, width 12 m, load capacity A-marked. Then, for wheeled vehicle classification, with the above factors, a simply supported beam up to 100 m span corresponds to MLC150/W-One (normal crossing case one lane military traffic + one lane civil traffic). For tracked classification, only MLC120/T-One is equivalent in the range 14 to 22 m, and MLC150/T-One for smaller and larger spans. As the maximum tracked vehicle currently in use does not exceed MLC80/T-One, these bridges are perfectly suitable for military traffic.

Sample calculation No.2. The classification of the bridge in the previous example was also made under the assumption that there are two lanes of civil traffic at the same time. This is practically possible on a freeway, assuming that the military traffic is on the extreme, technical safety lane. In this case, Table 2 shows that only up to 20 m MLC150/W-One can be justified and above 85 m only MLC100/W-One is the classification value. At this point, the tracked value exceeds MLC100/T-One everywhere, thus satisfying the military requirements.

Sample calculation No.3. In the next example, we investigated how the classification is obtained when the bridge width is only 8 m. The calculation still reaches MLC120/W-One and MLC100/T-One everywhere, thus meeting military requirements. It can be observed that the partial results show proportionally lower load-carrying capacity (in this case the width is no longer sufficient for two parallel civilian lanes.)

Sample calculation No.4. The 4th sample calculation was performed for load B, when the ideal load is 40 tonnes in the standard. There are 1703 such bridges on the Hungarian public road network (20%). For the first time, an 8 m wide bridge with simultaneous civil traffic was calculated. For wheeled vehicles, the available load capacity in two ranges is only MLC70/W-One, but above 20 m span, it corresponds to MLC80/W-One. For tracked vehicles, the desirable MLC70/T-One is not reached between 4 and 18 m, for larger spacings, the verifiable load capacity is increasingly larger due to the simultaneous distributed load (e.g. MLC80/T-One above 26 m span).

Sample calculation No.5. Repeating the previous example, but excluding simultaneous civilian traffic, gives better results. In this example, and in the following examples, we have assumed the crossing case where the military convoy is travelling on the bridge axis.
Wheel load capacity can then be verified with MLC100/W-Axis above 9 m span, and track load capacity exceeds MLC80/T-Axis over the whole range considered. Thus, it can be seen that these bridges meet the military requirements for tracked bridges in the absence of civil traffic.

Sample calculation No.6. Repeating the calculation with a narrower bridge (6 m wide), which is no longer sufficient for parallel civilian traffic. We see that the load capacity values will also be lower. The wheel ratings are proportionally reduced, and the track values are below the MLC70/T-Axis in a range (between 4 and 16 m).

Sample calculation No.7. The oldest Hungarian bridges were designed for 20 tonnes of steam. In some cases (typically four-rib monolithic reinforced concrete beams), these bridges were designed so that the scale load was only checked for half the cross-section so that the entire bridge could effectively carry two steams. The sample calculation was made for this case for the most typical bridge width at that time, 4.8 m. The width of the bridge does not allow parallel civilian traffic. The results show that the load capacity decreases rapidly with increasing span width for wheeled vehicles. However, for tracked loads, the bridge has a load capacity of MLC50/T-Axis except for small spans.

Sample calculation No.8. The first Hungarian bridge design specification (1910) provides for the possibility of a uniform distributed load of $400 kg/m^2$ in addition to the steam piles. For a two-span girder, this load becomes the standard above 16 m of span, and above 32 m if two steams are counted. This can be seen in the last sample calculation shown. There are only four bridges in this category in Hungary, so it is advisable to check them individually.

Table 3: Test classifications by bridge design standards and bridge widths. Source: author.

<table>
<tr><th rowspan="2">No.</th><th rowspan="2">Design code and wide of the bridge</th><th colspan="31">Span of the simple beam [m]</th></tr>
<tr><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>14</th><th>16</th><th>18</th><th>20</th><th>22</th><th>24</th><th>26</th><th>28</th><th>34</th><th>36</th><th>40</th><th>45</th><th>50</th><th>55</th><th>60</th><th>70</th><th>75</th><th>80</th><th>85</th><th>90</th><th>100</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">"A" with 12 m wide and civil</td><td colspan="31">MLC150/W</td></tr>
<tr><td colspan="11">MLC150/T</td><td colspan="4">MLC120/T</td><td colspan="16">MLC150/T</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">"A" with 12 m wide and double civil</td><td colspan="14">MLC150/W</td><td colspan="15">MLC120/W</td><td colspan="2">100/W</td></tr>
<tr><td colspan="9">MLC150/T</td><td colspan="18">MLC120/T</td><td colspan="4">MLC100/T</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">"A" with 8 m wide and civil</td><td colspan="2">120/W</td><td colspan="12">MLC150/W</td><td colspan="17">MLC120/W</td></tr>
<tr><td colspan="8">MLC150/T</td><td colspan="20">MLC120/T</td><td colspan="3">MLC100/T</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">"B" with 8 m wide and civil</td><td colspan="5">MLC70/W</td><td colspan="4">MLC80/W</td><td colspan="5">MLC70/W</td><td colspan="7">MLC80/W</td><td colspan="10">MLC90/W</td></tr>
<tr><td colspan="2">70/T</td><td>60</td><td colspan="3">50/T</td><td colspan="7">MLC60/T</td><td colspan="4">MLC70/T</td><td colspan="14">MLC80/T</td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">"B" with 8 m wide and without civil</td><td colspan="3">MLC80/W</td><td colspan="4">MLC90/W</td><td colspan="24">MLC100/W</td></tr>
<tr><td colspan="3">MLC80/T</td><td colspan="7">MLC70/T</td><td colspan="3">MLC80/T</td><td colspan="3">MLC90/T</td><td colspan="10">MLC100/T</td><td colspan="5">MLC120/T</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">"B" with 6 m wide and without civil</td><td colspan="3">MLC70/W</td><td colspan="16">MLC80/W</td><td colspan="3">MLC90/W</td><td colspan="9">MLC100/W</td></tr>
<tr><td colspan="2">70/T</td><td colspan="10">MLC60/T</td><td colspan="4">MLC70/T</td><td colspan="3">MLC80/T</td><td colspan="12">MLC90/T</td></tr>
<tr><td rowspan="2">7</td><td rowspan="2">"H" with 4,8 m wide without civil</td><td colspan="4">MLC80/W</td><td colspan="3">70/W</td><td colspan="5">MLC60/W</td><td colspan="8">MLC50/W</td><td colspan="4">MLC40/W</td><td colspan="7">MLC30/W</td></tr>
<tr><td colspan="2">150/T</td><td colspan="2"></td><td colspan="27">MLC50/T</td></tr>
<tr><td rowspan="2">8</td><td rowspan="2">400 kg/m² with 4,8 m wide without civil</td><td colspan="18"></td><td colspan="3">MLC40/W</td><td colspan="5">MLC50/W</td><td colspan="5">MLC60/W</td></tr>
<tr><td colspan="25"></td><td colspan="6">MLC60/T</td></tr>
</table>

It can be seen that in Table 3, it also shows that the MLC classification value increases as the support spacing is larger. This is because in the relative design code, as the span increases, the effect of the live load (UDL) increases more, which can result in a higher MLC (local load).

4 Summary

Our study aimed to report on research aimed at finalising the factors that fit the Hungarian bridge design specifications for the STANAG 2021 load capacity assessment of existing road bridges. The aim of the work is to define the factors by consensus and to classify the existing bridges.
The examples presented from the test calculations carried out illustrate that bridges with load capacity A basically meet the military requirements, bridges with lower load capacity only partially. Therefore, in further investigations, the caution and risk crossing conditions should be carried out primarily for bridges with smaller load capacity.
The method of checking complex bridge structures requires further research, especially for the risk crossing condition and for multi-span bridges. In the next phase of research, an algorithm for the negative moment check over intermediate piers for multi-span bridges will be developed.

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