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DETERMINATION OF ROAD BRIDGE LOAD - CARRYING CAPACITY

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Abstract

In frame of global European standardization and as consequence of new knowledge concerning the existing bridge reliability, the need for revision of the Technological Standard No. 104 "Load-carrying capacity of road bridges and footbridges" [1] (hereinafter referred to as TS 104) had started up. In the first stage of the revision, the preparation and analysis in the form of Analysis Task (hereinafter referred to as AT) has been worked up by the collective of the Department of Structures and Bridges from the University of Zilina in cooperation with Slovak Road Administration (SRA), National Motorway Company (NMC) and other co-operators among academicians and designers. In the presented paper, the attention is paid to the general concept and basic assumptions of the AT and revised TS 104 for determining the road bridge load-carrying capacity.

Keywords:

Bridge;
Load-carrying capacity;
Bridge evaluation;
Actions on bridges;
Bridge reliability.

1 Introduction

Proposal for working up the report [2] was evocated by the need to modernize and to innovate the methodology of determining the load-carrying capacity of road bridges and footbridges regarding to the latest trends in evaluation of existing bridges. In the last period, when bridge structures built mainly after the World War II as a result of the reconstruction of war-destroyed transportation infrastructure, reach the limits of their service life and operability, there is more discussion about the need for their rehabilitation. The reconstruction needs were also supported by the recent serious bridge accidents in Slovakia [3] and abroad [4]. A common feature of these disasters is the insufficient maintenance of transportation infrastructure, overestimation of the properties and quality of materials, poor or unmanaged, respectively, construction technologies including imperfect and wrong projects, as well as ever-increasing traffic intensity together with increasing axle loads. Experience of Western European countries disposing high-quality transportation infrastructure underlines the need for a systemic approach to this problem. Therefore, they focused on the creation of Bridge Management Systems (hereinafter referred to as BMS), which are just one of the possible system solutions. BMS introduces multi-module computer-aided databases that are used by bridge managers to perform their activities. The modules for the evaluation of bridges are the essential and decisive ones of those systems. The evaluation of existing bridges introduces a significant process and resource of information supporting the decision-making processes related to the bridge maintenance strategy and rehabilitation. In general, a number of approaches to the bridge evaluation exist. But only these evaluations, taking into account the bridge load-carrying capacity as one of its basic evaluating parameters, should be considered to be objective and correct.

In this context, the importance of the bridge load-carrying capacity is clearly defined and it is necessary to pay attention to the development of the methodology for its determining.

2 Analysis Task objective

The main aim of the AT was to develop the methodology for determining the load-carrying capacity of road bridges and footbridges. TS 104 [1] is currently available for the calculation of load-carrying capacity of road bridges in Slovakia. However, this regulation does not correspond to the current state of European standardization, especially in terms of the reliability level recommended for

the assessment of existing bridges. There is also a non-compliance with the definition of loads prescribed for bridges by the standard EN 1991-2 [5]. Therefore, the basic goal of this AT was to prepare documents to process new TS 104 for determining load-carrying capacity of road bridges and footbridges respecting:

a) State-of-the-art approaches to the assessment of existing bridges and to the methodology for determining their load-carrying capacity;

b) Modification of the reliability level for existing bridges taking into account the results of bridge inspection activities;

c) Terminology introduced by European standards;

d) Traffic actions on bridges in accordance with the basic load standard [5];

e) Realistic consideration of the effects of failures and damages on bridge response to the load and on the bridge cross-sectional and member resistances;

f) Clarification of information related to the material characteristics of existing bridges;

g) Verification principles of the cross-sectional and member resistance defined by relevant European standards EN 1990-1999;

h) Possibility of using reliefs for existing bridges reliability verification.

3 Current state

Abroad, the methodology for determining the load-carrying capacity was solved within the system approach to the complex evaluation of bridges in the form of creating BMS. Denmark and Sweden are among the first countries that started creating their own BMS [6] and achieved significant progress in it, to which Portugal, Slovenia, France, Austria, Slovakia, the Czech Republic etc. [8] have gradually joined. Similar systems were developed on the American continent [7]. In recent years, several European-wide research projects have been completed [9], including BRIME [10], Cost 345 [11], SAMARIS [12], Sustainable Bridges [13,14], ARCHES [15-17] and Cost 1406 [18]. These projects have led to the development of guidelines providing state-of-the-art methods for the reliability assessment of existing bridges [19].

Great attention was also paid to the issue of determining the bridge load-carrying capacity in Czechoslovakia and after 1992 in Czech Republic and Slovak Republic. From the period of Czechoslovakia, the industry standards ON 73 6220 (1964) [20], ON 73 6220 (1976) [21], its amendment a) (1983) [22] and especially amendment b) (1992) [23] following the standard ČSN 73 6203 (1976) [24], were the basic and important regulations for determining the road bridge load-carrying capacity. ČSN 73 6220 (1996) [25], valid only in the Czech Republic, was a successor of this basic standards. Standard [20] had introduced three types of load-carrying capacities, i.e. normal, exclusive and exceptional, which are using up to now.

In the first time, amendment [22] introduced the principle of determining the load-carrying capacity using the same load models as the new bridges were designed. It followed the load models defined in standard [24], later has been referred to as load model I (ZZI) and load model II (ZZII) for normal load-carrying capacity, and a four-axle vehicle load model for determining the exclusive load-carrying capacity.

In 1996, the Czech standard [25] was released in the Czech Republic, which replaced the canceled industry standard [23]. All load models defined in [22, 23] and also all individual types of load-carrying capacities have been taken over in this standard. Standard [25] was only valid for bridges designed before the implementation of European standards into the system of Czech technical standardization.

In 2013, ČSN 73 6222 [26] was introduced in the Czech Republic taking into account the implementation of European standards into the system of Czech technical standards. Thus, this standard respected the load models introduced in [5] for traffic load on bridges. The standard defined the procedures for determining the load-carrying capacities of road bridges as follows:

a) Detailed analysis (designated as *V*);

b) Combined procedure (designated as *K*),

c) Approaches according to special regulations (designated as *Z*).

These procedures are in accordance with TS 104 [1] issued in the Slovak Republic in 2017. The mentioned Slovak regulation is following the tradition of determining the bridge load-carrying capacity from the period of the common Czech-Slovak Republic. According to the TS 104, the load-carrying capacity of road bridges is expressed as the mass of vehicle of variable traffic load. According to the

type of load model simulating the type of road traffic, for bridges on motorways, highways and roads of I., II. and III. class and local roads the standard specifies:

a) Normal load-carrying capacity factor F_z and normal load-carrying capacity V_n:
b) Load-carrying capacity per axle V_j)
c) Exclusive load-carrying capacity V_r;
d) Exceptional load-carrying capacity V_e.

The normal load-carrying capacity factor F_z expresses the bridge ability to transfer load effects caused by the load model 1 (LM1) according to [5]. In general, the relation for the normal load-carrying capacity factor F_z can be expressed as the ratio of the capacity (reserve) of the resistance for the decisive variable load effects to the variable load effect caused by LM1 in the following form:

$$F_Z = \frac{R_{d,c}}{E_{LM1,d}} = \frac{R_d - \sum_{i=1}^{n-1} E_{rs,d,i}}{E_{LM1,d}}, \quad (1)$$

where:
F_z is the normal load-carrying capacity factor,
$R_{d,c}$ is the value of the resistance capacity for the decisive variable road traffic load,
R_d is the design value of the cross-sectional or bridge member resistance,
$E_{LM1,d}$ is the value of static quantity due to effects of variable load LM1,
$\sum_{i=1}^{n-1} E_{rs,d,i}$ are the design, combination or group values of the effects of other loads acting simultaneously with the vertical road variable load.

Normal load-carrying capacity is determined as the maximum permissible mass of one vehicle of normal load without limiting the number and position of vehicles passing the bridge. It is determined according to the following formula:

$$W_n = F_2 \cdot W_{n,rep}, \text{ [kN]}, \quad (2)$$

where:
W_n is the normal load-carrying capacity [kN],
$W_{n,rep}$ is the weight of representative vehicle of normal load-carrying capacity [kN],
$W_{n,rep}$ = 320 kN.

Since the normal load-carrying capacity is defined as the vehicle mass [t], its value V_n should be obtained by the formula:

$$V_n = W_n / 10 \text{ [t]}. \quad (3)$$

The load-carrying capacity per axle is only determined in justified cases and the load model 2 (LM2) in accordance with 4.3.3 in standard [5] should be used for its determination.

The exclusive load-carrying capacity is determined as the maximum permissible mass of a single vehicle on the bridge. The vehicle model for exclusive load-carrying capacity corresponds to the special vehicle of the class 900/150 according to A.2(1) in standard [5]. The dynamic amplification should be taken into account in accordance with the formula given by A.3 (5) in standard [5].

The exceptional load-carrying capacity is determined as the maximum permissible vehicle mass, which is defined by the vehicle load model for exceptional load-carrying capacity corresponding to special vehicle of the class 3000/240 according to A.2 (1) in standard [5].

4 Determination of road bridge load-carrying capacity

4.1 General

The road bridge load-carrying capacity is the maximum immediate mass of each of the vehicles whose bridge passing can be permitted under the conditions given by standards or other relevant regulations. It is identified from the summary of load-carrying capacities of individual bridge elements and parts as their lowest value.

In the AT, the following approaches are proposed for determining the bridge load-carrying capacity:

a) Detailed analysis of existing bridge *V*;

b) Combined procedure *K*;
c) Expert estimation using comparative analysis *O*.

The detailed analysis of an existing bridge means such a procedure, when the load-carrying capacity should be determined by the bridge analysis (see STN EN 1990 [30]) respecting principles of the relevant valid standards and taking into account bridge actual condition. This approach to determining load-carrying capacity is considered to be a basic and preferred procedure. The standards and provisions valid at the time of the bridge design are considered to be informative documents.

The combined procedure can be used in the case, when the documentation of the bridge is not available and some areas of the structure cannot be fully diagnosed due to their technical unavailability (e.g. cable running over the support, etc.). This procedure could alternatively be applied in the case of concrete and composite bridges. The load-carrying capacity determined by combined procedure introduces a combination of detailed bridge analysis and substitute bridge analysis. The detailed bridge analysis should be applied in the structural parts verified by technical diagnostics. The substitute analysis could be used to determine the expected reinforcement or prestressing reinforcement in the bridge parts, where reinforcement cannot be detected by the conventional diagnostic methods. The standards and regulations valid at the time of bridge construction or repair should be used as background for determining the reinforcement.

Expert estimation of bridge load-carrying capacity compares the load effects only. It is indicative, not taking into account the current technical bridge condition, as the resistance is not determined. The year of bridge commissioning and the bridge geometry are important to know in this approach. The procedure compares the variable load effects used at the time of bridge design, to the effects of the variable road traffic load valid under current regulations. It can be only used in cases, where the actual bridge condition does not affect the specified load-carrying capacity.

4.2 Existing bridge limit states

In the case of existing bridges, their reliability is assessed and the load-carrying capacity is determined using the partial safety factors method. This method verifies that in all relevant design situations the decisive limit states of the bridge elements are not exceeded. Bridges are verified in terms of ultimate limit states and serviceability limit states. The following ultimate limit states of existing bridges shall be verified:

- Cross-sectional failure due to extensive yielding, fracture or limit strain;
- Bridge member stability loss;
- Failure of joints;
- Failure caused by fatigue due to repeated high-cyclic stress;
- Loss of equilibrium of the bridge or any part of it, considered as a rigid body (only assessment is required, the load-carrying capacity is not to be determined).

From the viewpoint of ultimate limit states, it shall be proved that design values of the load effects corresponding to the determined load-carrying capacity fulfil the design cross-sectional or structural member resistance.

The following serviceability limit states of existing bridges shall be verified:

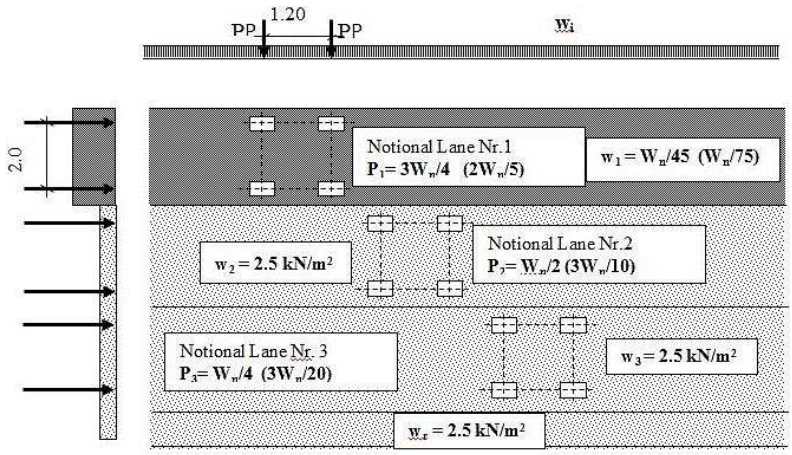
- Limitation of elastic stresses;
- Deflection limitations from the viewpoint of traffic safety;
- Limitations related to resonance effects;
- Crack limitations.

In the case of serviceability limit states, it shall be proved that the load effects corresponding to the determined load-carrying capacity comply with the limit values of the criteria of the appropriate serviceability limit states.

4.3 Loads on bridges

Loads of existing bridges, their location and values are considered in the analysis on the basis of the bridge actual current state determined by an in-situ investigation using the bridge available documentation.

Characteristic values of permanent loads on existing bridges should be taken according to [30] with respect to Annex D in [31], and [32] in cases, when the results of experimental investigations on the existing bridge are taken into account.



Note 1: W_n is the vehicle weight in kN, w_i is the value of uniformly distributed load (UDL) in kN/m^2; Note 2: The adjustment factors α_{Qi}, α_{qi}, and α_{qr} are included into values of vehicle weights and UDL values; Note 3: Data in parentheses apply to local and purposeful roads;

Fig. 1: LM 1 for determining the normal load-carrying capacity.

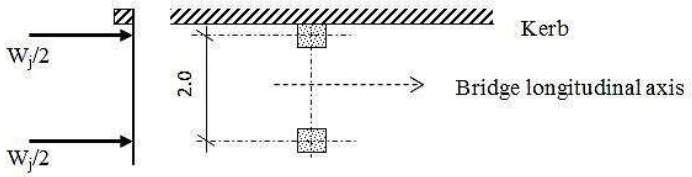
LM1 according to [5] was proposed as a model of normal road traffic load. However, this model (see Fig. 1) does not directly corresponds to the normal road traffic load due to the considerable weight of the two-axle vehicle (Tandem System, *TS* = 60 t) in the first notional lane. Therefore, the vehicle in the second notional lane (*TS* = 40 t) was accepted as the representative vehicle of the normal traffic load. The LM1 for determining the normal load-carrying capacity should be applied on each notional lane and on remaining area of the load space in such a length and so longitudinally located that the most adverse effect is obtained respecting provisions defined for this model in [5].

The carriageway dividing into notional lanes should be determined in accordance with 4.2.3 and 4.2.4 in [5]. Designation and location of the LM1on the bridge is shown in Fig. 1.

For determining the bridge normal load-carrying capacity, the values of adjustment factors α_{Qi}, α_{qi}, and α_{qr} should be taken equal to 1.00 for motorways, highways and roads of I., II. and III. class. In the case of local and purposeful roads, the value of adjustment factors should be taken in accordance with National Annex (NA) to [5]:

$\alpha_{Q1} = 0.8$, $\alpha_{Q2} = 0.6$, $\alpha_{q1} = 0.6$, $\alpha_{q2} = \alpha_{qr} = 1.0$

The load-carrying capacity per axle expresses the maximum permissible mass per one axle designated as V_j. The load model 2 (LM2) should be applied consisting of a single axle load $\beta_Q Q_{ak}$ with Q_{ak} equal to 400 kN, dynamic amplification included. The model should be applied at any location on the carriageway. However, when relevant, only one wheel of 200 β_Q kN may be taken into account. The factor β_Q is considered to be 1.00 in accordance with NA to [5]. The square contact surface for the wheels of LM2 should be taken according to [5].



Note: W_j is axle weight in kN,

Fig. 2: Load model for determining the load-carrying capacity per one axle.

The exclusive load-carrying capacity is defined as the maximum immediate vehicle mass, which may cross the bridge alone without other road vehicles, but without further traffic restrictions. The term of exclusive load is not specified in standard [5]. Even on the basis of actual traffic on bridges, it is complicated to identify the exclusive load, as ensuring the conditions for its passing the bridge is unrealistic due to frequency of the current traffic. Therefore, we proceeded to an extensive comparative study of the effects of load models according to the current standard [5] and previously valid standard [24]. The effects of load models according to both standards were also confronted with the actual traffic load simulated by model of lorries weighing 280 kN (T815) passing the bridge in one

or two lines, respectively, in a row with mutual distances of 10.00 m. The simply supported girder superstructure with an upper bridge deck was used as the representative bridge sample. The bridge spans were chosen within a range from 2 m to 80 m, with different road widths varying from 5.4 m to 11.5 m corresponding to various numbers of girders at distances from 1.0 m to 9.0 m. The vertical traffic load effects were expressed by the values of the maximum bending moments determined in the span middles and the maximum shear forces above the supports of the simply supported beams. The load models were always located on the bridge in the most unfavorable position in the transverse and longitudinal direction with respect to the observed internal force. Graphical dependences are given on a relative scale in relation to the maximum value of the relevant internal force caused by the LM1 for the span of 80 m. Selected results are presented in Fig. 3.

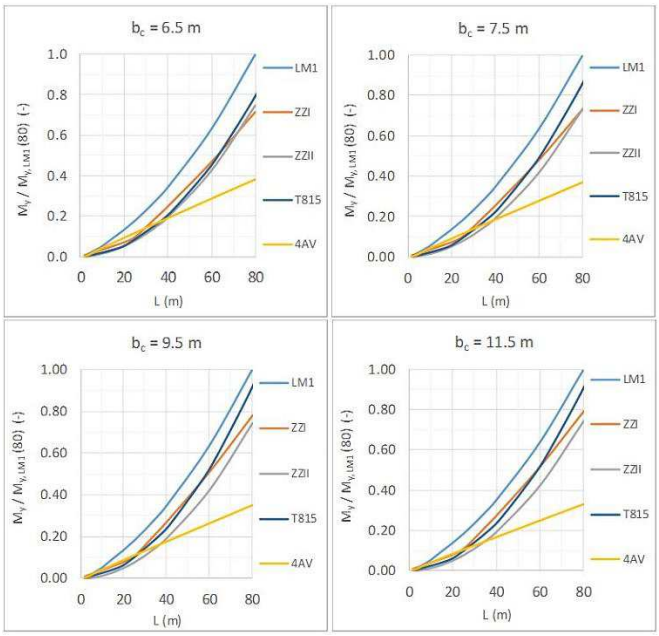


Fig. 3: Bending moments in the middles of the spans depending on the width and span of the bridge.

The results of the analysis showed that load effects caused by LM1 cover the effects of all load models required for newly designed bridges according to standard [5] (LM2 and LM3 when moving over the bridge according to NA to [5]). Concurrently, they cover the effects of load models according to standard [24] including the effects of the four-axle vehicle model representing the exclusive load. Therefore, we proposed to completely cancel the concept of exclusive load and exclusive load-carrying capacity from the revised TS 104. It should be noted that the effects of LM1 covers the passage of a heavy vehicle weighing 1.5 V_n (for new bridges 60 t at least) and this model allows the passage of a heavy vehicle without any traffic restrictions. It also corresponds to the model of the special vehicle of 600/150 according to [5].

The exceptional load-carrying capacity expresses the maximum immediate weight of a special vehicle carrying exceptionally heavy loads passing a bridge under specified traffic conditions. These conditions are specified in NA to standard [5], which is valid for design of new bridges in Slovakia. According to NA, the special vehicle is assumed to move at a speed of 5 km/h, passing the bridge in the optimal track with a deviation of ± 0.30 m and with the complete exclusion of other traffic. As a model of LM3, the model 3000/240 in accordance with Annex A in standard [5] was proposed for design of new bridges in NA to standard [5]. The choice of the special vehicle 3000/240 for model LM3 was based on a comparative study, in which the effects of all special vehicles given in Annex A were confronted with the effects of the special vehicle defined in standard [24], 14-axle vehicle (2800/140).

The passage of a special vehicle under the abovementioned restrictive conditions is unrealistic during simultaneous traffic on roads and motorways especially. Therefore, the attention was paid to the choice of the model of exceptional load represented by another special vehicle. In a comparative study, the effects of special vehicles of 3000/240, 2400/200 and 1800/200 under traffic conditions according to Annex A in standard [5] for a speed of 70 km / h were compared to effects caused by passage of a special vehicle according to standard [24].

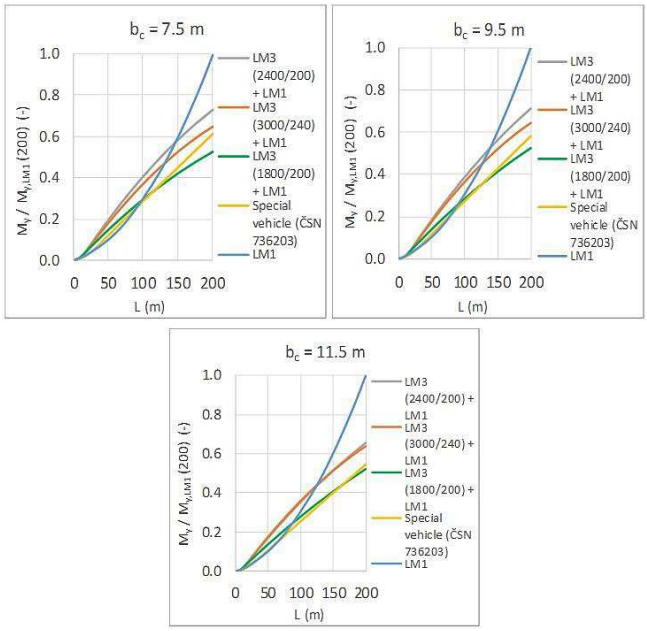


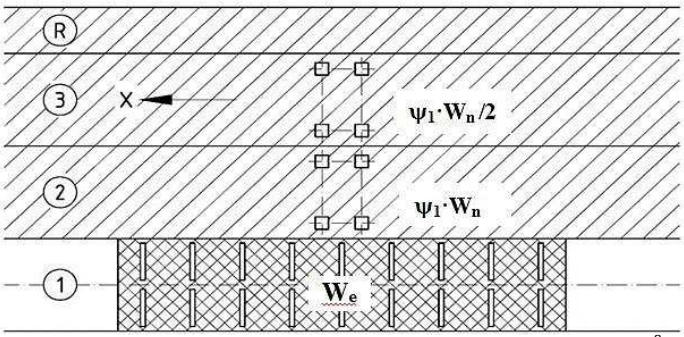
Fig. 4: Bending moments in the middles of the spans depending on the road widths when modified models of exceptional load are using – one special vehicle 1800/200.

In this case, the passage of special vehicles is defined in A.3 (7) of standard [5] as follows:

Where special vehicles are assumed to move at normal speed, a pair of special vehicles should be used in the lane(s) occupied by these vehicles. On the other lanes and the remaining area, the bridge deck should be loaded by LM1 with its frequent values defined in 4.5 and A2 in standard [5].

Therefore, the passages of pairs of the abovementioned models of special vehicles were observed at the certain distances between them, namely 1.5 m, 15 m, 25 m and 50 m. The results of this study demonstrated the possibility of passing only one vehicle of 1800/200 over the bridge at a speed of 70 km / h. Application of only one special vehicle of 1800/200 resulted from a comparison of the effects of the entire system of vehicles on the bridge (including frequent LM1 values) to the effects of vehicle 14x1400 kN + 2x tractor per 420 kN according to standard [24]. The relevant results of this comparative study in the form of bending moments courses are presented in Fig. 4.

It can be seen from Fig. 4 that course of bending moments caused by the special vehicle 1800/200 is very close to the course of bending moments induced by the vehicle 14x400 kN + 2x tractor per 420 kN in accordance with standard [24].



Note: W_n is the weight of LM1 in kN, w_i is the value of uniformly distributed load (UDL) in kN/m^2, W_e is the weight of special vehicle in kN.

Fig. 5: Arrangement of the load for determination of the bridge exceptional load-carrying capacity respecting other traffic.

The configuration of the scheme for determining the exceptional load-carrying capacity allowing for other road traffic is presented in Fig. 5. Heavier vehicles, weigh of which is more than the exceptional load-carrying capacity determined for special vehicle 1800/200, shall cross the bridge in restricted mode, i.e. at speeds of up to 5 km/h, using the optimum track and excluding other traffic on the bridge

Braking and acceleration forces should be considered in the normal load-carrying capacity calculation according to 4.4.1 in [5]. Similarly, the effects of centrifugal and other transverse forces should be taken into account in accordance with 4.4.2 in [5]. Individual variable road traffic represented by the LM1 including braking and acceleration forces and centrifugal forces, are considered in the analyses of existing bridges as a group of the multicomponent road traffic load respecting rules according to Tab. 4.4a in [5]. Each of these groups of loads, which are mutually exclusive, should be considered as defining a characteristic action for combination with non-traffic loads.

Combinations of loads simultaneously occurring together with road traffic loads are determined in the analyses of existing bridges according to A2.2.2 in [30], Amendment A1, Annex A2. In accordance with the NA to [30], Amendment A1, Annex A2, the combination (6.10) for bridges designed for variable loads according to [5] is preferred from the viewpoint of ultimate limit states. For existing bridges designed according to older, now invalid standards, the decisive combination of (6.10a) and (6.10b) is recommended to prefer.

4.4 Materials

Concerning material properties of the existing bridges, their characteristic and design values should be determined:

- Based on bridge documentation verified by means of standards and provisions valid in time of the bridge design;
- Based on the diagnostic investigations and accomplished material tests approved by the relevant authority of SRA or NMC, respectively.

If the basic properties of materials of the existing bridges are known from the bridge documentation, or from the standards and provisions valid at the time of the bridge design and for the given case there is no need to verify them by tests. These values may be used for determining the load-carrying capacity. If the bridge documentation is not available, or from this documentation it is not possible to unequivocally determine the material properties of the existing bridge, or there are doubts about the material properties stated in the bridge documentation, then the relevant properties should be determined on the basis of diagnostic investigation and tests performed with the approval of SRA or NMC, respectively. When the values of material properties were determined by tests, the procedure should fulfil the provisions in standards [28, 30].

4.5 Existing bridge reliability level

The reliability of existing bridges is verified and their load-carrying capacity is determined by means of partial safety factors method, by which the fulfilments of conditions of relevant ultimate and serviceability limit state shall be assessed. The partial safety factors are used to determine design values of permanent and variable load effects and also for determination of the design values of the cross-sectional and member resistance.

In general, the process of determination of load-carrying capacity of existing bridges has various differences in comparison with the reliability assessment of newly-designed ones. In the case of an existing bridge, new information, which is unknown in the design phase, concerning the bridge actual condition is available. The certificates of the material properties, measurements of the actual bridge geometry, collection of load data, results of proof-load testing and findings of periodic inspections are the major sources of this information. The extra information unknown in the design phase can be used not only for verification of the correct bridge performance, validation of the computational model or calculations, but also for reducing some uncertainties related to the bridge member resistance and load parameters entering the process of load-carrying capacity determination.

The problem of the implementation of inspection outputs into the updated reliability level valid for existing bridges was observed within the research activities of the Department of Structures and Bridges. Using knowledge related to application of engineering probability methods on existing structures [27], the problem was successfully solved. Theoretical solution of this problem was presented in [28, 29].

Theoretical approach is based under the assumption that the observed structural component is in good condition in the time of inspection, which means no exceeding any ultimate limit state of the assessed bridge component.

The updated probability of failure of $P_{fu}(t)$ of a bridge component within the time (t_{insp},T) is then expressed using a conditional probability in the following form:

$$P_{fu}(t) = \left(P_f(T) - P_f(t_{insp})\right) \Big/ \left(1 - P_f(t_{insp})\right), \tag{4}$$

where:

$P_f(T)$ is the probability of failure of the structural bridge component for the remaining time period of the bridge lifetime,

$P_f(t_{insp})$ is the probability of failure of the bridge structural component in the time of bridge inspection.

The corresponding updated reliability index $\beta_u(t)$ of the observed structural component for the remaining time period (t_{insp}, $T = T_d$) can be determined by formulae:

$$\beta_u(t) = -\Phi^{-1}\left(P_{fu}(t)\right). \tag{5}$$

The updated reliability index $\beta_u(t)$ is greater than the designed index β_d due to conditional probability. Next, the adjusted target failure probability $P_{ft}(t)$ (target reliability index $\beta_t(t)$) for which the element should be evaluated for its remaining lifetime (T-t_{insp}) can be solved to find the required value of the target failure probability $P_{ft}(t)$ with a minimum of one inspection. The changes of the updated reliability index $\beta_u(t)$ and the target reliability index $\beta_t(t)$ over time are dependent upon the time of inspection and on the intensity of failure.

Table 1: Values of target reliability indices $\beta_t(t)$ for existing bridge evaluation.

Remaining lifetime (years)	**Reliability level given by the reliability index $\beta_t(t)$ according to bridge structural member age in years (according to inspection time)**								
	10 and less	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90 and more**
5	3.358	3.212	3.112	3.035	2.972	2.918	2.871	2.829	2.791
10	3.468	3.356	3.274	3.209	3.155	3.108	3.066	3.029	2.996
20	3.545	3.467	3.405	3.354	3.310	3.271	3.236	3.205	
30	3.576	3.516	3.466	3.424	3.386	3.352	3.322		
40	3.593	3.544	3.502	3.465	3.433	3.403			
50	3.604	3.563	3.526	3.494	3.465				
60	3.611	3.575	3.543	3.515					
70	3.617	3.585	3.557						
80	3.621	3.592							
90	3.624								

These values respect the basic level of reliability given in [30] and they can be used to determine the design values of load effects and resistances of existing bridge structural members more accurately using procedures defined in standard [30]. The values of the target reliability indices $\beta_t(t)$ of the assessed components of existing bridge are given in Table 1 depending on the time of the inspection and the component planned remaining lifetime.

4.6 Methodology of bridge load-carrying capacity determination

The basic and recommended procedure for determining the bridge load-carrying capacity is the bridge structural analysis. The analysis shall be performed according to the currently valid standards and regulations for design of bridges. The standards and provisions valid at the time of the bridge design should be considered to be informative documents.

The global analysis of existing bridge superstructure should be performed by means of elastic methods respecting bridge spatial behaviour. Therefore, the spatial computational models are recommended to use enabling the complex bridge global analyses. The possibility for application of non-linear global analysis is not excluded, especially in the case of more precise calculations of the concrete bridges, masonry bridges and composite steel-concrete bridges, where its utilization could be more eloquent and even needed. Actual bridge structural member condition shall be respected in global analysis of existing bridge. Possible failures and damages including relevant imperfections of structural members or bridge parts should be involved into the chosen computational model to take into account influence of the failures on the final bridge response to load and to respect the load

redistribution due to failures. Concurrently, the influence of the bridge failures shall be taken into account in the resistance of bridge structural member and their cross-sections.

The load-carrying capacity of bridge structural member shall be determined using partial safety factors method by means of the reliability criterion of the relevant limit state. Regarding the ultimate limit states, the normal load-carrying capacity of the bridge structural member should be defined by means of general formula:

$$V_n = \left[\left(R_d - \sum_{i=1}^{n-1} E_{rs,\mathrm{n},Ed,i} \right) / E_{LM1,Ed} \right] \cdot V_{n,rep} \text{ [t]}, \tag{6}$$

where:
R_d is the design value of the cross-sectional or member resistance,
$E_{LM1,Ed}$ are the design value of vertical variable normal road traffic load effect represented by the LM1,
$\sum_{i=1}^{n-1} E_{rs,n,Ed,i}$ are the design or combination values, respectively, of the other load effects acting concurrently with the vertical variable normal road traffic load,
$V_{n,rep}$ is the mass of representative vehicle of normal load-carrying capacity,
$V_{n,rep}$ = 40.0 *t*.

It should be noted the aforementioned fact that the value of normal load-carrying capacity determined in this way also allows the passage of a heavy vehicle weighing $1.5V_n$.

The load-carrying capacity per axle V_j can be determined using the LM2 according to Fig. 2 by means of following general formula:

$$V_j = \left[\left(R_d - \sum_{i=1}^{n-1} E_{rs,\mathrm{j},Ed,i} \right) / E_{LM2,Ed} \right] \cdot V_{j,rep} \text{ [t]}, \tag{7}$$

where:
$E_{LM2,Ed}$ are the design values of the vertical road load effects per one axle represented by LM2,
$\sum_{i=1}^{n-1} E_{rs,j,Ed,i}$ are the design values of the other load effects acting concurrently with the vertical variable road traffic load per one axle,
$V_{j,rep}$ is the mass of the representative axle for load-carrying capacity per axle [t],
$V_{j,rep}$ = 40.0 t.

The exceptional load-carrying capacity can be determined by means of the special vehicle model 1800/200 or 3000/240, respectively, according to Annex A in [5] under the conditions of passing these sets over the bridge in accordance with description in 4.3. The following general formula should be used:

$$V_e = \left[\left(R_d - \sum_{i=1}^{n-1} E_{rs,\mathrm{e},Ed,i} \right) / E_{LM3,Ed} \right] \cdot V_{\mathrm{e},rep} \text{ [t]}, \tag{8}$$

where:
$E_{LM3,Ed}$ are the design values of the vertical exceptional road traffic load effects represented by relevant LM3,
$\sum_{i=1}^{n-1} E_{rs,e,Ed,i}$ are design or frequent values, respectively, of the effects of other loads acting simultaneously with the exceptional load,
$V_{e,rep}$ is the mass of representative vehicle of the exceptional load-carrying capacity,
$V_{e,rep}$ = 180.0 t or 300.0 t, respectively.

The formulas (6) - (8) do not exclude application of iteration forms of load-carrying capacity calculations especially in the cases of the complicated reliability conditions.

From the viewpoint of serviceability limit states, the load-carrying capacities V_n, V_j and V_e of the bridge structural member respecting the criterion for elastic stress limitation (see 4.2) shall be only determined in the case, when the plastic cross-sectional resistance of the bridge structural member was applied to verify the relevant ultimate limit state [33, 34]. In the case of the serviceability limit state related to the deflection limitations, the load-carrying capacity shall be determined providing that deflection of the bridge superstructure corresponding to the determined load-carrying capacity is equal to its limit value defined in accordance with the relevant standard or provisions. Regarding the

serviceability criteria of the excessive deformations, the normal load-carrying capacity V_n should be determined using the following formula:

$$V_n = \left[(\delta_{lim} - \sum_{i=1}^{n-1} \delta_{rs,i}) / \delta_{LM1} \right] \cdot V_{n,rep} \text{ [t]}, \quad (9)$$

where:

δ_{lim} is the limit value of the deformation respecting serviceability criteria of the relevant serviceability limit state,

δ_{LM1} is the value of the deformation caused by the vertical variable normal road traffic load represented by the LM1,

$\sum_{i=1}^{n-1} \delta_{rs,i}$ are the values of deformations caused by other relevant loads acting concurrently with the vertical variable normal road traffic load, unless they were eliminated by the pre-camber,

$V_{n,rep}$ is the mass of representative vehicle of normal load-carrying capacity [t].

Verification of the limit state of crack limitation and determination of the load-carrying capacity related to this limit state is only required for bridge structural prestressed parts and elements. The procedures should be performed according to the relevant provisions in [35] and [36]. In the case of bridge reinforced concrete elements, an assessment of the crack width is required, but the load-carrying capacity does not have to be determined. If the criterion of the recommended crack width is not met, the unsatisfactory condition shall be stated in the technical report to the analysis of the existing bridge.

5 Conclusions

The paper is dealing with the results and outputs of the Analysis Task (AT) worked up by the Department of Structures and Bridges. The main AT objective was to develop the methodology for determining the load-carrying capacity of road bridges and footbridges. The basis of load-carrying capacity determination was introduced in this paper. The proposal to cancel the exclusive load-carrying capacity, which was used in our standardization from 1964, means the significant result of this AT. Also the new look at the exceptional load-carrying capacity concept introduces up-to-date and prospective approach to the passing the special vehicles transporting heavy load over the bridges. Firstly, the modified reliability level for existing bridge verification and load-carrying capacity calculation was proposed to implement into corresponding Slovak standard and provisions. After admitting the proposed new concept of load-carrying capacity calculation, the revised TS 104 [1] for road bridge load-carrying capacity determination will be prepared respecting the all proposed rules and changes.

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