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Load Capacity of the XX. Century

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This article is a compilation of all standards governing the payloads for road bridges in our country starting before the II World War, and ending on the Eurocode. The article also includes a comparative analysis of the effort of the structures subjected to loads compliant with these standards. On their basis, the load-bearing of the bridge was estimated.

Keywords: assessment of load capacity, load-bearing capacity of bridges, imposed loads, loading bridges, combination of load, regulations and standards for bridges.

1. INTRODUCTION

Nowadays, all the civil engineering objects are designed based on the standards. In the highway engineering it is allowed use Polish standards and Eurocodes. To compare the load-bearing capacity of bridges, the PN-85 / S-10030 should be used. Bridge structures. Load (Obiekty mostowe. Obciążenia) [8] or Eurocode PN-EN-1991-2. Actions on structures. Load moving (Oddziaływania na konstrukcje. Obciążenia ruchome) [9]. However, due to the deficiency of clear legislation and national annexes and the habits of the designers, the use of Eurocodes is still in the testing phase.

Before the year 1914, in our country there was no clear regulations for dimensioning bridge structures. Most of the objects in the area of our country were designed based on the standards of the Austrian, the German and the Russian, and after the II World War the standards significantly changed. Many bridges which were created before the War and shortly after it, are in use up to this day. Therefore, this publication can serve as a guide to determine the capacity to use these objects.

2. DESIGNING OF ROAD BRIDGES BEFORE THE II WORLD WAR

As previously mentioned, prior to 1914 on the territory of our country bridges were designed in accordance with the regulations depending on the country whose rule the territory was under, as shown in Fig.1

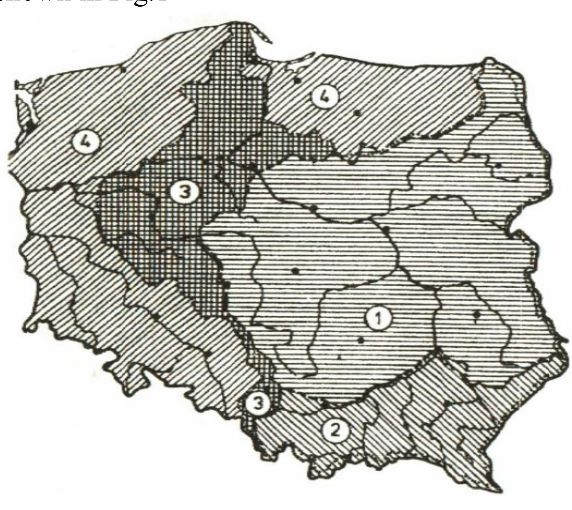


Fig.1. The rules applicable to the territory of the country during the Partitions of Poland: 1) Russian regulations (1914); 2) Austrian regulations (1918.); 3) Prussia regulations (1918.); 4) German regulations (1945) [2].

In the north, west and south-west (on the areas of Prussia), bridges were designed, based on the German legislation before 1945. In the southeastern part of the country, they were calculated owning to the Austrian provisions. The central and eastern part of the country carry out the bridge designing, based on the provisions in force in the Russian-boron (before 1914). During the interwar, bridges were designed in accordance with the provisions of the Polish Republic.

The bridges in the western territory of our country, designed before the II World War, were calculated on the basis of Prussian standards (established in 1918). The load consist of: trucks, road rollers (horse- and steam-powered), trams and crowd load. The size of individual loads depended on the location of the object.

For the lowest class roads (field and lateral) the basic load meant a horse-powered road roller with a weight of 60 kN. National and main roads were designed to spread the surface load on the road equal to 4.0 kN/m2, vehicle load with a ballast of 60 kN and the weight of the steam road roller about 175 kN. Bridges, located within the city were taking a crowd load of 5.6 kN/m2, distributed surface load of the road 4.0 kN/m2, load of a vehicle with a weight of 80 kN and the load of 230 kN steam car. They were only suggested values and in practice they were selected individually for each bridge.

In the years 1923-1940 the bridges in the western part of our country were designed according to DIN 1072. Road bridges. Loads (Strassenbrücken. Belastungsannahmen). The essential loads include: rollers, motor vehicles and crowd load. They were divided into 3 load classes, listed in Table no 1. The position of road rollers and cars were chosen, depending on the useful width of the road. Surface load could occur simultaneously on the sidewalks and on the roadway, but could not occur in an area occupied by vehicles.

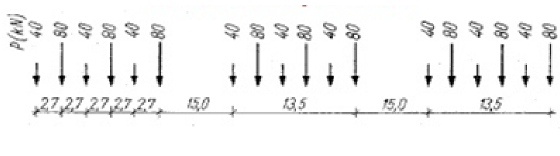
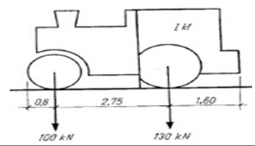
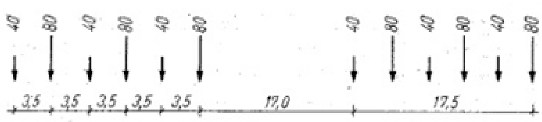
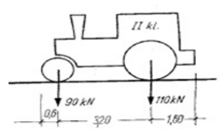
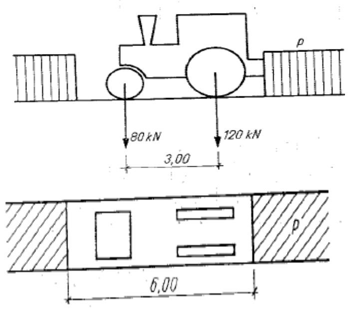
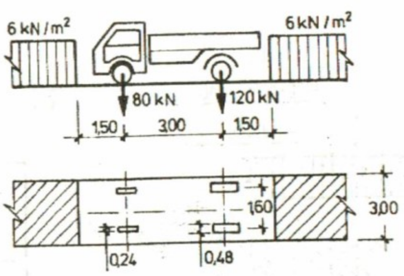
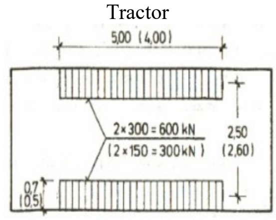
Table 1. Traffic load of bridges according to DIN 1072 [1]

Load Class			I	II	III
Road roller kN	Total weight		230	160	70
	Front wheel		100	70	50
	Rear wheel		65	45	10
Motor vehicle kN	Total weight		90	60	60
	Front wheel		15	7.5	7.5
	Rear wheel		30	22.5	22.5
Crowd load kN/m^2	Main girder by the length of the span	50 m	5	4.5	4
		100 m	4.5	4	3.5
		200 m	4	3.5	3
	Secondary element		5	4.5	4

The first Polish norm regulating the load of bridges was founded on 04 March 1920. and taking into account two basic load vehicles, exceptional load and the load of road rollers. The crowd load depended on the length l, for which they were distributed. For Class I, it was 5 kN/m2 for $l \leq 50$ m, and for $l > 100$ m - 4 kN/m2. For Class II the values are 4 and 3.5 kN/m2. The load distribution and values are presented in Table no. 2.

Six years later, the next normative regulation was legalized - *Provisions on the Construction and Maintenance of Road Bridges (Przepisy o budowie i utrzymaniu mostów drogowych*) [4]. It contained a much simplified model of traffic load. It was adopted to a load, consisting of a road roller witch a width of 2.5 m and a length of 6.0 m. The axle load was 120 and 80 kN. The crowd load of pedestrians did not change. The load classification increased to three grades, realized by reduction factors: 0.8 for Class II, and 0.4 for Class III. This standard was applied until the II World War, and in 1945 another legal regulation was established, based on this standard [2].

Table 2. Traffic load of bridges before1952 [1,2,4,5]

Standard		Basic load	Additional load	Crowd loading	Reduction factor
Standard 1920	Class I		Road roller 	$q = 5\ kN/m^2$ for $l \leq 50$ m, $q = 4\ kN/m^2$ for $l>100$ m	-
	Class II		Road roller 	$q = 4\ kN/m^2$ for $l \leq 50$ m, $q = 3.5\ kN/m^2$ for $l>100$ m	-
Standard 1926	I		-	$q = 5\ kN/m^2$ for $l \leq 50$ m, $q = 4\ kN/m^2$ for $l>100$ m	1.0
	II				0.8
	III				0.4
Standard 1945	I		Tractor 	$q = 6\ kN/m^2$ for $l \leq 50$ m, $q = 4\ kN/m^2$ for $l>100$ m	1.00
	II				0.75
	III				0.50
	IV				0.25

3. DESIGNING OF ROAD BRIDGES AFTER THE II WORLD WAR

The first post-war norm - Temporary Regulations on the Construction and Maintenance of Road Bridges (*Tymczasowe przepisy o budowie i utrzymaniu mostów drogowych*) [5] - contained a similar load model as the one included in the norm, which was replaced. The load consisted of a basic car with axle load of 120 kN and 80 kN. It fitted a roadway lane with a width of 3.0 m. The crowd load was established 6 kN/m2 for l≤ 50 m, and 4 kN/m2 for l> 100 m. In order to move to a lower class load, there were also applied reduction factors (Tab. 2).

There was also introduced an exceptional load in form of a tractor: T60 with a weight of 600 kN and T30 with a weight of 300 kN. For bridges designed according to these standards, the norm allowed the move of vehicles with a maximal weight of, respectively for Classes I-IV, 20, 15, 10 and 5 T.

In 1952 another Polish norm was created (Tab. 3). It introduced a distributed load over the whole usable area of the bridge. Additionally, in the most strenuous area, a linear load in the transverse direction of the bridge was applied, with values for Classes I-III: 4, 3 and 2 kN/m2. On the sidewalks should be imposed a load of pedestrian traffic in the amount of 4 kN/m2. The exceptional load consisted of a tank track with a weight of 800, 600 and 400 kN [2].

The standard from 1956 - Technical Normative for Design of Bridges on Car Roads. Moving loads (Normatyw techniczny projektowania mostów na drogach samochodowych. Obciążenia ruchome) [6] - introduced the modeling of loads along the wheel tracks of the vehicle (Tab. 3). In addition, a distributed load in form of 2 linear strips, arranged crosswise was defined for Class I, and for Class II

- one lane line. The motor vehicle caused for Class I a load of 300 kN (80 + 120 + 120kN), for Class II this weight was 150 kN (30 + 120 kN), and for Class III - 100 kN (20 + 80 kN). The exceptional load constituted, as in the previous standard, in form of tank tracks, indicated with T-80, T-60 and T-40.

The PN-66/B-02015. Bridges, Viaducts and Culverts. Loads and Impact (Mosty, wiadukty i przepusty. Obciążenia i oddziaływania) [7] was quiet similar to standard from 1956. The width of the bands load was reduced in Class II. The tank track was replaced by a wheeled vehicle K-80 with a weight of 800 kN, which applied only to the objects from Class I. It became the first official Polish standard regulating variable loads of bridges.

In the standards of 1952, 1956 and 1966 the dynamic factor was dependent on the type of structure. It amounted to:

- for steel and wooden bridges

$$\varphi = 1 + \frac{1}{0.1L+2} \leq 1.4 \qquad (1)$$

- for concrete bridges

$$\varphi = 1 + \frac{1}{0.3L+2} \leq 1.29 \qquad (2)$$

- additionally to the elements covered with a layer of soil

$$\varphi(h) = 1 + \frac{1-h}{0.5}(\varphi - 1) \geq 1.0 \qquad (3)$$

where:
L - the theoretical length of the span of the element; h - the height of the soil covering; φ - the dynamic factor, calculated in accordance with (1) or (2).

Significant changes were introduced in the PN-82 / S-10030. Bridge Structures. Loads (Obiekty mostowe. Obciążenia), which, due to the need to fine-tune, was quickly replaced by PN-85 / S-10030. Bridge structures. Load (Obiekty mostowe. Obciążenia) [8]. This standard distinguished two basic schemes of modeling loads:

- a vehicle K - a 4-axle vehicle with a basic weight of 800 kN, acting together with surface load q = 4 kN/m2.
- a motor vehicle S - a 3-axle vehicle with a weight of 300 kN for Classes A-C, a 2-axle vehicles with a weight of 200 kN for Class D and 150 kN for Class E,

and crowd load of pedestrians - which for the main girders is 2.5 kN/m^2.

This standard also introduced the general dynamic factor for all types of road bridge with a length of the span of l<70 m:

$$\varphi = 1.35 - 0.005L \leq 1.325 \qquad (4)$$

and for longer bridges φ = 1.00. Additionally placed in the standard is a formula for objects, covered with a layer of soil, which is analogous to the pattern in the previous standard:

$$\varphi(h) = 1 + \frac{(1-h)(\varphi-1)}{0.5} \qquad (5)$$

The positioning of wheels of the vehicle on the bridge is shown in Fig. 2 and the loads are listed in Tab. 4. In the calculating of the structure, there should be taken into account the safety factors, which are γ = 1.2 for the supporting structure, and γ = 1.5 for non-load bearing elements.

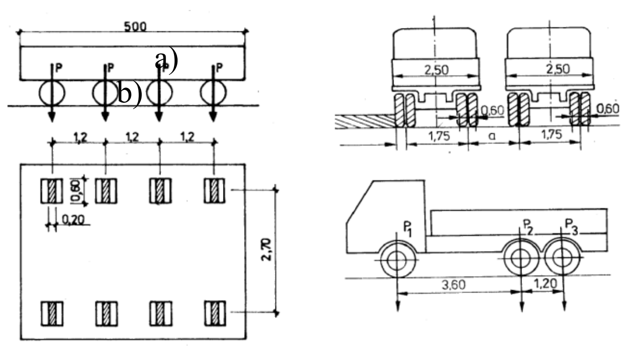


Fig. 2. Wheel spacing of vehicles: a) vehicle K; b) vehicle S [8]

Table 3. Traffic load of bridges from 1952 to 1985 [1,2,6,7]

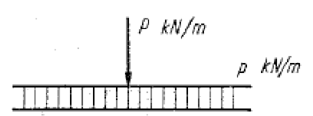
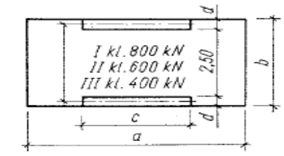
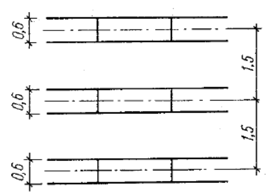
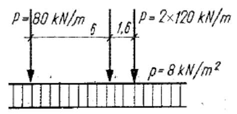
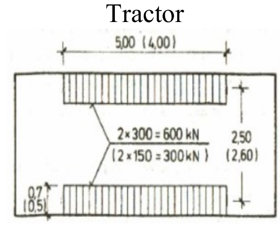
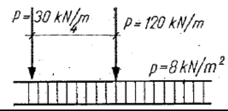
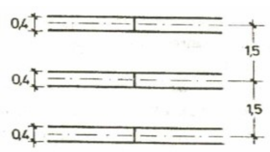
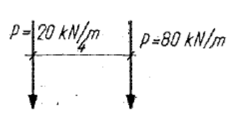
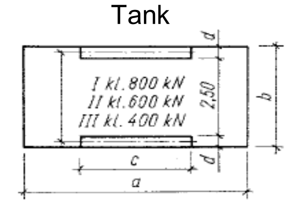
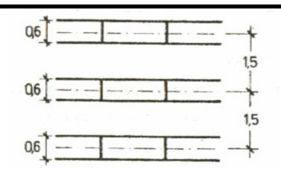
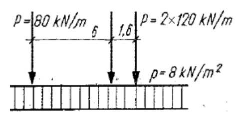
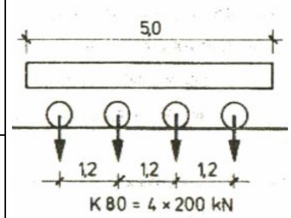
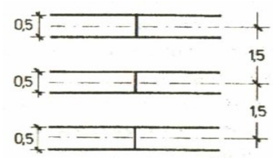
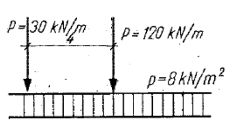
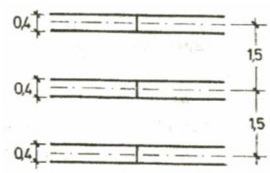
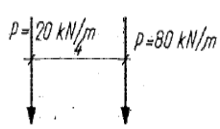
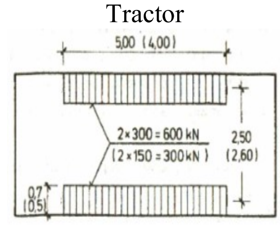
Standard		Basic load		Additional load	Dynamic factor
Standard 1952	I	 *P = 10 q	P = 400 kN; q = 4 kN/m²	Tank 	for steel and wood bridges $\varphi = 1 + \frac{1}{0.1L + 2}$ $\varphi \leq 1.4$
	II		P = 300 kN; q = 3 kN/m²		
	III		P = 200 kN; q = 2 kN/m²		
Standard 1956	I			Tractor 	for concrete bridges $\varphi = 1 + \frac{1}{0.3L + 2}$ $\varphi \leq 1.29$
	II				
	III			Tank 	
PN-66/B-02015	I			Vehicle class I 	for bridges with soil-covring $\varphi(h) == 1 + \frac{(1-h)(\varphi - 1)}{0.5}$
	II				
	III			Tractor 	

Table 4. Traffic load of road bridges according to PN-85/S-10030 [8]

Load type	Load class	Basic load [kN]	Load per axle [kN]			Crowd loading [kN/m²]	Distance between wehicles [m]	Reduction factor
			P1	P2	P3			
K+q	A	800	200			4	-	1.00
	B	600	150			3	-	0.75
	C	400	100			2	-	0.50
	D	320	80			1.6	-	0.40
	E	240	60			1.2	-	0.30
S	A	300	60	120	120	-	1	-
	B	300	60	120	120	-	1.25	-
	C	300	60	120	120	-	1.5	-
	D	200	80	120	-	-	1.5	-
	E	150	50	100	-	-	1.5	-

In Eurocode PN-EN-1991-2. Actions on structures. Traffic load [9] distinguished 4 models of traffic loads:

- LM1 - concentrated and distributed loads, which include most of the effects of the traffic of trucks and cars,
- LM2 - single axis pressure, applied to certain contact surface of the tire, which includes the dynamic effects of normal traffic for short structural elements,
- LM3 - a collection of sets of axle loads representing special vehicles (e.g. for industrial transport) which can move around the roads, admitted to oversize loads,
- LM4 crowd load (uniformly distributed with a value of 5 kN/m2), intended only for general checks in transitional situations.

Due to the complex nature of the loads on all models, the article focuses on the model LM1. The load modelling relied on the dividing of the roadway in the longitudinal direction into strip with a width of 3.0 m. On the belt 1 a point load of the vehicle Q = 300 kN was applied, and a distributed load with a value of q = 9 kN/m2. The following lanes are loaded by a distributed force q = 2.5 kN/m2 and further with a point load, which is the lane no 2 Q = 200 kN and for the belt no 3 Q = 100 kN. For the subsequent belts concentrated load was not taken into account. The bridges without traffic signs limiting the weight of the vehicle, the following minimum values should have been taken into account: αQ1 ≥ 0.8 and αqi>1. Fig. 3 shows the arrangement of the load on the platform.

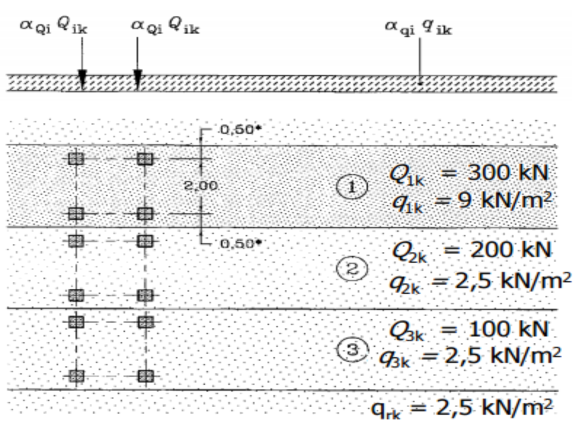


Fig. 3. Distribution of loads for model LM1 [9]

4. METHODS OF DETERMINING LOAD CAPACITY OF BRIDGES

The usable load capacity of a bridge can be defined by performing the calculation of static and strength on the basis of a technical documentation or on a detailed inventory of the structure and results of diagnostic tests (based on the specifications, applicable during the construction of the bridge) or by using a simplified method, developed by the Research Institute of Roads and Bridges (Instytut Badawczy Dróg i Mostów) called RYM-IBDiM [3]. This method distinguishes 5 categories of replacement of the payload, as shown in Figure 4. The determinant is the mass of the car model:

- load symbol 1/S42: a car model with a mass of 42 t (3x80+100+80 kN) and linear load with a value of 5 kN/m,
- load symbol 2/S32 : a car model with a mass of 32 t (2x100+70+50 kN) and linear load with a value of 4 kN/m,
- load symbol 3/S24: a car model with a mass of 24 t (3x80 kN) and linear load with a value of 4 kN/m,
- load symbol 4/S16: a car model with a mass of 16 t (100+60 kN) and linear load with a value of 3 kN/m,
- load symbol 5/S10 stanowi: a car model with a mass of 10 t (60+40 kN) and linear load with a value of 2 kN/m.

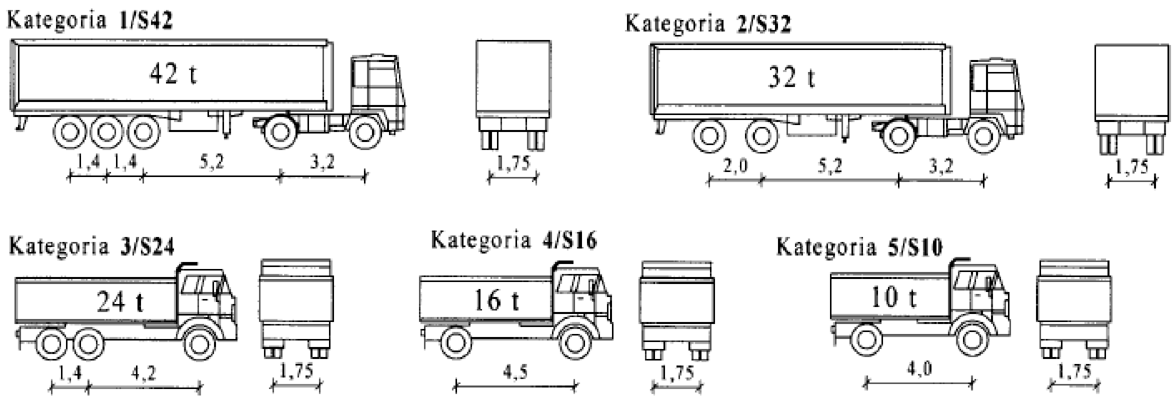


Fig. 4. Categories of vehicles in the method RYM-IBDiM [3]

5. EFFORT COMPARISON OF THE BRIDGE DEPENDING ON THE STRAIN

This paper presents a comparison of the effort of the structure due to operational load, taking into account the following load cases:

- P1 (by PN-66/B-02015), shaping the load Class I as a load of the vehicle P = 300 kN and a load stripe (banding width 0.6 m) with a value of q = 8 kN/m2;
- P2 (by PN-66/B-02015), shaping the load Class II as a load of the vehicle P = 150 kN and a load stripe (banding width 0,5 m) with a value of q = 8 kN/m2;
- P3 (by PN-66/B-02015), shaping the load Class III as a load of the vehicle P = 100 kN oraz and a load stripe (banding width 0,4 m) with a value of q = 8 kN/m2;
- P4 (by PN-85/S-10030), shaping the load Class A as a load of the vehicle K = 800 kN and a distributed load with a value of q = 4 kN/m2;
- P5 (by PN-85/S-10030), shaping the load Class B as a load of the vehicle K = 600 kN and a distributed load with a value of q = 3 kN/m2;
- P6 (by PN-85/S-10030), shaping the load Class C as a load of the vehicle K = 400 kN and a distributed load with a value of q = 2 kN/m2;
- P7 (by PN-85/S-10030), shaping the load Class D as a load of the vehicle K = 320 kN and a distributed load with a value of q = 1.6 kN/m2;
- P8 (by PN-85/S-10030), shaping the load Class E as a load of the vehicle K = 240 kN and a distributed load with a value of q = 1.2 kN/m2;
- P9 (by Eurocode PN-EN-1991-2), shaping the load Class LM1 according to Fig.3.

In the calculations 3 schemes of beams are included: 2 single-span beams with a span length of 12.5 m and 25 m and a double-span beam with a span length of 2x12.5m. Then, the effort of the structure under load of models was determined for the RYM-IBDiM method. On their basis, the load-bearing of the bridge was estimated, comparing the maximum effort of the structure under the specified load with the effort caused of the vehicle in the method of RYM-IBDiM. Tab. 5 presents the results of the calculations, and Fig. 5 shows the boundaries of the selected internal forces.

Table 5. Estimation of load-capacity

Load case	Beam 12.5 m		Beam 25 m		Beam 2x 12.5 m			Load capacity accordnig to RYM-IBDiM
	Maximum bending moment [kNm]	Maximum cutting force [kN]	Maximum bending moment [kNm]	Maximum cutting force [kN]	Maximum bending moment - span [kNm]	Maximum bending moment - support [kNm]	Maximum cutting force [kN]	
P1	426	147	2706	442	536	643	314	2/S32
P2	281	99	1939	313	380	460	222	4/S16
P3	197	65	1530	247	287	366	171	5/S10
P4	1505	494	2729	435	876	571	405	1/S42
P5	1128	370	2047	326	657	428	304	**1/S42**
P6	752	247	1364	218	438	286	202	**1/S42**
P7	602	198	1092	174	350	229	162	3/S24
P8	451	148	819	131	263	171	121	4/S16
P9	1055	360	1215	200	372	263	174	**1/S42**
Maximal effort of the structure according to RYM - IBDiM								
1/S42	464	171	1324	225	307	322	173	-
2/S32	408	146	1078	187	272	246	148	-
3/S24	383	135	950	156	258	201	135	-
4/S16	273	97	668	109	186	142	93	-
5/S10	177	60	427	72	55	76	60	-

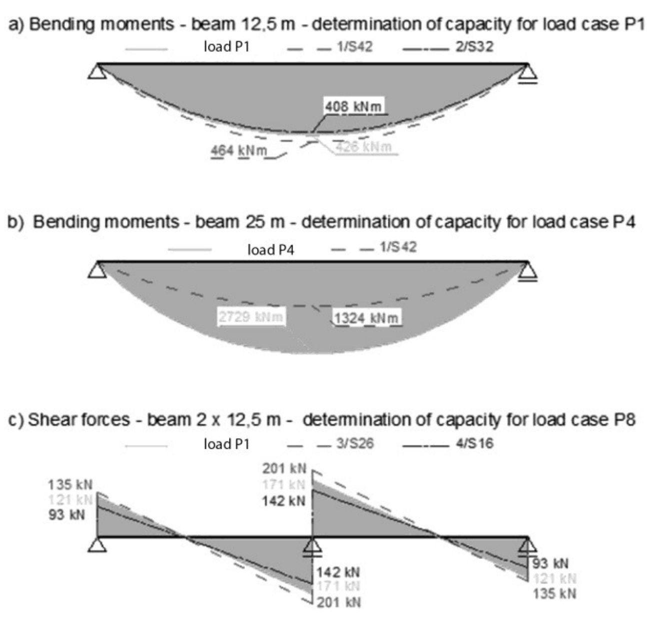


Fig. 5. Selected envelopes of internal forces - Determination of capacity

6. SUMMARY

This article summarizes the basic models of loads for road bridges in accordance with the standards and regulations applied in our country since the beginning of the twentieth century to today. This article also includes guidelines and replacement models to determine the load capacity of bridges.

In the above analysis, there can be find a comparison of a few load cases for 3 standards. The maximum effort of the design was defined and compared with the effort in the method RYM, prepared by the Research Institute of Roads and Bridges. On the basis of calculations performed on 2 single-span beams and a double-span beam it was found that the bridges were designed in accordance with the Class A, B and C by PN-85/S-10030 and the load model LM1 by Eurocode PN-EN-1991-2 comply with the capacity of Category 1, which means that their load capacity is determined at 42 t. It was also established that a vehicle of Class II by PN-66/B-02015 and Class E vehicle by PN-85/S-10030 meet the conditions for bridges with a capacity of only 16 t.

This example may be a clue to estimate capacity. In order to specify the load-bearing capacity of each construction, however, a computer model should be performed, including basic dimensions and geometric characteristics of the supporting structure.

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