Assessment of River Crossing Possibility with Existing Pontoon Bridge

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Abstract

In the paper the possibility of river crossing in different conditions are described. The influence of river and equipment characteristics are analyzed and existing unitation on crossing capacity are indicated. Moreover, the unique demand for river crossing in Eastern Europe are defined.

KEY WORDS: *river crossing, ribbon bridge, military load classification, hydrodynamic stability, bridge capacity*

Introduction

Crossing large, deep aqueous obstacles is a complex tax and the possibilities of its realization depends on many factors including: crossing conditions, its organization, efficiency of direct traffic, training of crews and maintenance of crossing equipment and even masking and organizing emergency and evacuation services, etc. and the expected efficiency of the crossing, number of crossed forces and means and expected crossing time. From a technical point of view the most important factors are: characteristics of aqueous obstacles and technical characteristics of the used equipment and their mutual relations.

1. Characteristic of the Aqueous Obstacles

The characteristics of an aqueous obstacles should be understood as a set of features affecting the possibility of overcoming aqueous obstacles and they include:

- **road / terrain characteristics of the direct approach to the obstacle -** there may be local backwaters and floods, oxbow lakes, escarpments (slopes), embankments, dense vegetation and trees, logs and terrain obstacles and other elements limiting the availability and the possibility of crossing the terrain by conveyed equipment – they result from that crossed equipment mobility requires which concern: permissible ground pressure and low-capacity terrain ability, permissible angles of descent and driveway and the requirements for the need to conduct engineering preparatory work including the road sections paving, and improving their profile and strengthening them;
- **characteristics of the bank–** to the most important factors affecting the ability to overcome an obstacles should be included the water entry profile (the tilt angle of entry into the water), type of ground at the descent and bottom, presence and speed of the stream, and the depth of the obstacle directly at the edge - it results from the requirements for earthwork necessary to obtain acceptable angles of entry to the bridge, type of ramp support and ramp bay and the necessity to strengthen the berth, maximum depth of permissible dipping of pontoon loaded bridges and the minimum depth of the obstacle due to the possibility of launching pontoons and proper work of propulsion.
- **characteristic of the obstacle profile** includes: profile (depth), occurrence of underwater obstacles and shoals, occurrence and stream speed distribution and occurrence and height of waves – it results from the requirements in the range of the necessary pontoon speed during the construction of bridges, displacement reserve and the stability of the bridge while working in the river's stream, protection against the possibility of flooding by waves and necessary work efficiency of propulsion and the need to use bridge anchoring systems.
- **Characteristic of the opposite bank-** it includes: obstacle's depth directly at the edge, occurrence and current speed, the angle of departure from the aqueous obstacles, ground traction at the exit of the obstacle, presence and type of vegetation limiting the availability of land and bearing capacity of the ground and presence of obstacles limiting the possibilities of fast moving deep into the terrain - it results in the requirements for the necessary engineering works resulting from the permissible angle of departure from the obstacle, allowable pressures on the substrate and the need to strengthen the bank in the place of cooperation with ramps.

The main large and deep aqueous obstacles in Eastern Europe are unregulated rivers. They are characterized by high variability of water level, occurrence and meandering a strong current, bottom with shoals of relatively low load capacity and often steep, sandy or loamy banks. The speed of the current is variable and also depends on the general condition of the waters. At high water level, the mainstream speed may reach 3.5 m / s, in average conditions it often reaches 2 m / s on a large width.

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Hence the essential factors affecting the ability to overcome the obstacle are:
- the angle of entry to the obstacle;
- obstacle depth, main current speed and its distribution;
- presence of shallows and other obstacles;
- angle exit from the obstacle and traction

Some of the characteristics (load-bearing capacity of the ground for access to obstacles, entry and exit angles) can be improved by engineering works, however, the basic way to improve the characteristics of the aqueous obstacle is to choose a convenient place for the crossing - which puts less demands on bridge equipment. However, this limits the tactical and operational mobility. Bridging equipment making low demands, well- matched to the river crossing, allows them to be overcome anywhere, anytime which will surprise the opponent.

2. Limitations of Pontoon Bridges

Bridge crossings using pontoon bridges type ribbon bridge are organized for drastic purposes in relation to crossings amphibious equipment, bridging and ferry, increasing the ability to transfer forces and resources. The armored tracked vehicles, armored wheeled vehicles and wheeled logistic support vehicles are mainly conveyed. The hardest to crossing are heavy tracked vehicles because their weight reaches 70 short tons (63.5 t), length of track on the ground does not exceed 5 m and a width of the vehicle is approx. 3.5 m (weight of the structure with additional armor or equipment can reach 80 short tons). This results in a high concentration of loads and requires a wide roadway width. Wheeled vehicles, although they may be the dominant group, are not such a big problem because they do not usually exceed the weight of 32 t and the width of 2.55 m. Hence, the most important parameters of pontoon bridges include:
- bearing capacity of the bridge - deciding which means can be crossed;
- bridge capacity - defining the efficiency of the crossing;
- permissible speed of the current - determining the possibility of organizing the crossing;
- minimum depth of aqueous obstacle - determining the possibility of organizing the crossing;
- bridge construction time - defining its tactical availability;
- forces and resources necessary to build a bridge;

According to STANAG 2021[1], the bridge load capacity is defined by comparing the loads exerted on the bridge by the vehicle's chassis in the form of bending moments and shear forces with loads caused by reference vehicles for individual classes. Because tracked vehicles model dimensions do not differ significantly from actual vehicles, MLC class usually corresponds to the weight of the vehicle expressed in the so-called short American tones (1 t = 2000 lbs. = 908 kg). In the case of wheeled vehicles, due to the dissipation of the load over a longer length and thus inducing smaller bending moments, the MLC class of the vehicle is lower than its mass expressed in US tons.

The load-bearing capacity of a pontoon bridge is not a fixed value and in the case of crossings by rivers depends on the speed of vehicle travel, current speed and load eccentricity. The speed of the passing determines the amount of dynamic loads and influences the necessary reserve of strength, whereas the influence of the current speed and the load eccentricity results from the character of the work of the ribbon bridge and hydrodynamic interactions occurring between the pontoon bridge and the aqueous medium.

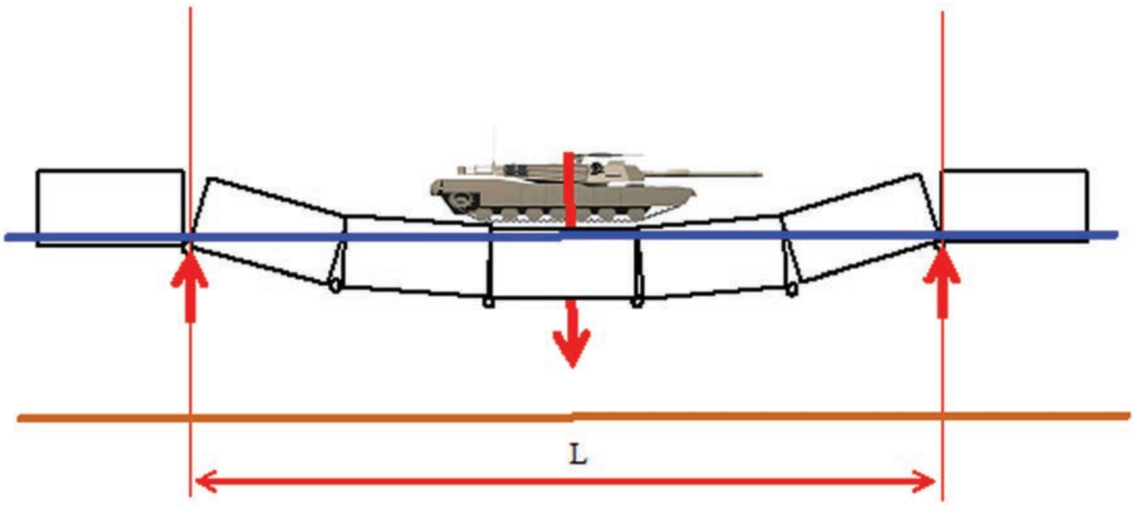

Fig.1. Deflection of the pontoon bridge under load

The ribbon bridge usually consists of pontoon blocks hingedly connected to the bottom band, which under load thanks to the clearances in the upper belt, they assume the shape of a curve - fig.1. By increasing the clearance and increasing the draft, the bridge builder can reduce the number of working pontoon blocks and thus reduce the bending moments of the

1 STANAG 2021: Military load classification of bridges, ferries, rafts and vehicles.

bridge and the load on the construction nodes. As a result, it can provide a higher nominal bearing capacity of the bridge.

The increase in draft (Figure 1), however, causes flow disturbances under the pontoon bridge as a result of a change in the flow cross-section. This phenomenon is particularly dangerous in connection with the asymmetric bridge load (Fig. 2), which causes lateral inclination of the bridge. As a result, under a more recessed part the flow section decreases and the flow rate must increase. Because the amount of hydrostatic pressure and hydrodynamic pressure cannot change according to Bernouli's law an increase in hydrodynamic pressure (increase of flow velocity) causes a drop in hydrostatic pressure, causing an additional inclination of the pontoon.

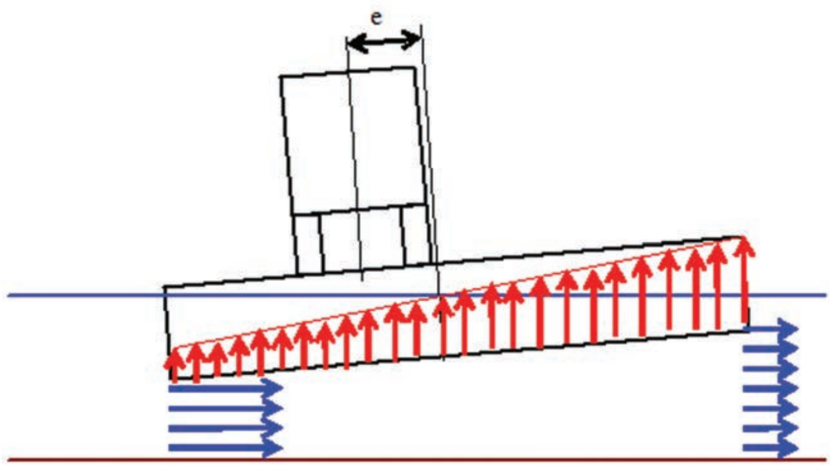

Fig.2. The effect of the eccentric loading of the pontoon bridge

Excessive inclination of the pontoon can cause flooding and loss of stability, despite having a displacement reserve. The effect of the eccentric load decreases with the depth of the obstacle. It is assumed that it can be omitted at depths above 6 m. For safety reasons, it is assumed that the freeboard height should be at least 100 mm. The acceptable current speed can be estimated as 80% of the critical speed causing the pontoon to flood.

$$v_k = \zeta\sqrt{g \cdot L}\sqrt{1 - \frac{D}{\left(1 - \frac{e \cdot P}{L \cdot D}\right)^3 D_o}} \tag{1}$$

where :

ζ - coefficient of depth of the watercourse;
L - the width of the pontoon;
D - used buoyancy of the pontoon;
Do - maximum displacement of the pontoon;
P - external load on the pontoon;
e – load eccentricity.

Taking into account the impact of dynamic loads and load eccentricity, to clearly determine the bridge crossing capabilities three load classes of pontoon bridges have been defined [2]:

- **normal crossing** – determines the possibility of using the bridge in normal operation conditions - the distance between vehicles on the bridge should not be less than 30 m, the permissible eccentricity of the load is 0.5 m and the permissible vehicle speed is:
  - MLC 30 class - 25 km/h (desirable 40 km / h);
  - Above MLC 30 class - 15 km/h (desirable 25 km/h);
- **caution crossing** () – to be used with stricter safety conditions - the distance between the vehicles is determined by the bridge manufacturer (usually greater than the length of the arch of the bridge after selecting the clearances of the upper belt), load eccentricity is unacceptable (the guide on the bridge controls the position of the conveyed vehicle), the maximum speed does not exceed 5 km / h, braking and acceleration are prohibited (minimization of dynamic loads);
- risk crossing () - allowing for crossing the bridge in high risk conditions - only one vehicle on the bridge is allowed, the eccentricity of the load is unacceptable (a necessary guide controlling the position of the conveyed vehicle), driving speed cannot exceed 5 km / h, braking and acceleration are not allowed.

[2] Trilateral Design and Test Code for Military Bridging and Gap-Crossing Equipment. TARDEC BRIDGING. USA 2005

Because each of them depends on the speed of the current and the depth of the aqueous obstacle, the bearing capacity of the bridge should be presented in the form of a characteristic. An example is shown in fig.3.

The load-bearing capacity of a pontoon bridge therefore depends not only on the construction of the bridge (its strength and displacement) but also from the place of the crossing organization - determining the speed of the current and the depth of the aqueous **obstacle.** Analyzing the dependence (1) it can be concluded that the greatest influence on the bridge's resistance to the impact of the current has it width**.** The wider the bridge, the greater its stability and resistance.

The bridge crossing capacity, i.e. the ability to transfer forces (vehicles) through a water barrier, depends mainly on:

- speed of access to the bridge - this is influenced by: the condition of the ground, profile and width of the road, traffic organization;
- speed of entry to the bridge - it is limited by: the condition of the ground, the entry profile, the width of the roadway, the strength of the bridge;
- speed on bridge restricts: the strength of the bridge, the width of the roadway, the allowable eccentricity load, the bridge waving;
- dependence between vehicles on the bridge - it is mainly related to the strength of the bridge;
- speed of exit from the bridge - depends mainly on: exit profile, ground condition (scour), exit width, bridge strength;
- speed of leaving the crossing - depends mainly on: the condition of the ground, profile and road width;
- organization of vehicle column movement - the speed of the slowest vehicles decides (mixed columns not indicated);
- technical breaks necessary to maintain the crossing (strengthening entrances and descents (washing as a result of waves), improvement of anchoring, replacement of damaged pontoon blocks, etc.).

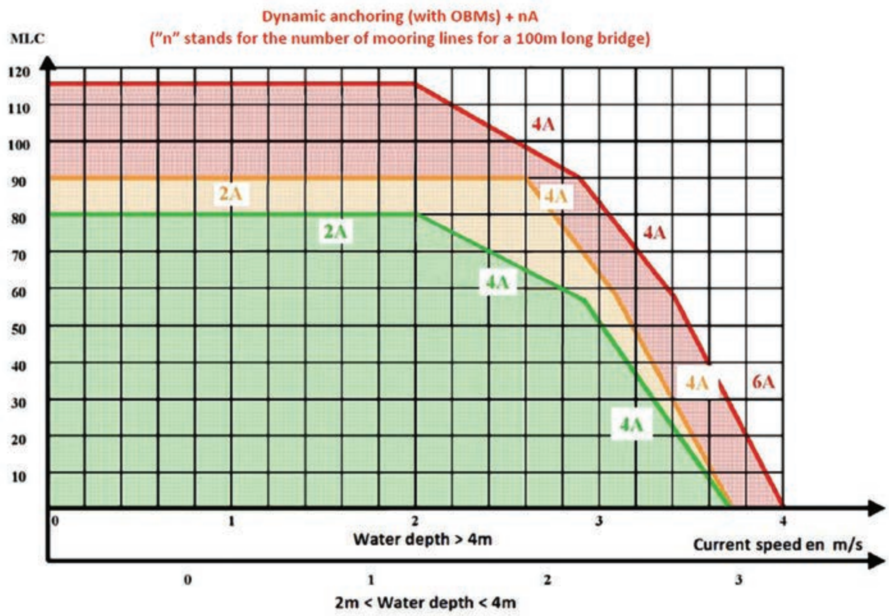

Fig.3. Characteristics of the load capacity of the PFM pontoon bridge as a function of the speed of the current - the maximum (green) capacity is marked by the red (outer) line– nominal load, and orange - conditional capacity

The greatest impact on the capacity of the bridge has the speed of entry into the bridge, the speed developed on the bridge, speed of descent and technical downtime necessary to maintain the crossing. All these parameters depend on the structural solutions of the bridge. The speed of entry to the bridge and the speed of the exit are primarily influenced by: longitudinal profile and strength of the access ramp or peripheral pontoons and their width. The permissible speed on the bridge depends mainly on the width of the lane (for MLC 70 the recommended width is 4 m, for larger values 4,5 m is recommended) and the length of the pontoon blocks and the number of joints with play deciding on the curvature of the deck and the draft of the bridge. The time of service depends on the ease of maneuvering the pontoons during their replacement and on the bridge's cooperation with the bank. In the case of unpaved, sandy or clayey banks and the use of bank pontoons, they are intensively scour as a result of the bridge's undulations under the influence of vehicle traffic. Incoming ramps are a better solution. However, they should have the appropriate profile and width enabling high-speed ride to dispel.

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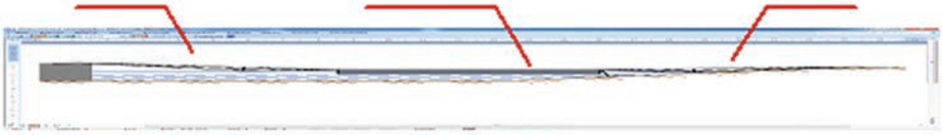

Fig.4. Pontoon bridge with ramps increasing the capacity of the bridge

3. Characteristics of Selected Pontoon Bridges

Taking into account the described limitations and conditions of using pontoon bridges, it can be stated that commonly used construction solutions of pontoon bridges are significantly diversified- tab. 1.,2. For these reasons, their usefulness and capabilities differ significantly. They also differ in terms of forces and resources necessary to organize the crossing - tab.3.

It should be noted that, taking into account the year of design development, there is a clear trend in the use of ever larger pontoon blocks (only the Polish PP-64 bridge does not cross road gauges).

This is possible because increasingly larger means of transport are available.

Table 1

Basic parameters of pontoon blocks and transport units
selected pontoon bridges of the ribbon type

	PP-64 (Polska)	**PFM (Francja)**	**IRB (Niemcy)**	**PP-2005 (Rosja)**	
				60	**120**
Year of development	1964	1984	1962/72/02	1962/2005	
Width of the ribbon, m	2 x 6,25	9.8	8.4	8.28	15.5
Pontoon / block length, m	1.84/3.7	10.2	6.71	7.36	
Pontoon / block heigth, m	0.90	0.73	0.75	0,75	
Pontoon block weight, kg	3 600	10 500	6350	8 550	17 100
Block displacement, kg	19 600	52 500	40 000	43 200	86 400
Displacement reserve, kg	16 000	42 000	33 650	34 700	69 400
Unit weight, kg / m	1 950	1 030	950	1 160	2 320
Width of the composite bl., m	2.5	3.6	3.4	3.1	
Heigth of the composite bl., m	2.0	2.1	2.35	2.28	
Width with the vehicle, m	2.5	3.60	3.60	3.35	
Length with the vehicle, m	9.0	18.0	11.7	10.7	
Heigth with the vehicle, m	3.4	4.0	4.0	3.7	
Vehicle weight, t	7.1	12 +7.5	16.4 +2.7	12,7	
Vehicle weight, t with bl. pont., kg	10 700	30 000	25 600	21 250	
MLC class of the vehicle	12W	25W	28W	25W	

Table 2

Basic operational parameters of selected ribbon-type pontoon bridges

	PP-64	PFM	IRB	PP-2005	
				60	120
Width of the bridge	12.5	9,8	8.4	8.3	15,5
MLC bearing capacity	80W/80T	80W/70T	96W/80T	66T	130W
Lane width, m	4.35	4.0	4.50	4.50	2 x 4.50
Speed of tracked vehicles, km/h	15	15	10 (25)	30.	
Speed of wheeled vehicles., km/h	40	25	20 (40)	b.o.	
Bearing capacity of 2 lines	2 x 40W	-	2 x 20W	2 x 30W	2 x 66T
Width of lanes	2 x 4.35 m	-	2 x 2.75 m	2x2.75 m	2 x 4,5 m
Permissible speed of the current (MLC 80 bridge), m/s	2.9	2.0	2.1	3.0 *	3.5s
Permissible speed of the current (MLC 80 ferry), m/s	3.5	2.5	1.8-3.0	3.0	3.5
Resistance to wind	1°B	1°B	1°B	2°B*	4°B*
Number of loaded pontoons	15	16	7	7	
Length of the load zone, m	25	160	46	50	
Draft own / loaded, m	0.17/0.70	0.17/0.33	0.13/0.50	0.15/0.50	
Bridge deflection (MLC 80), m	0.53	0.16	0.37	0,38	0,25
Freeboard, m	0.20	0.40	0.25	0.25	
Speed on the bridge, km / h	10-15	15	10	30	

Table 3

Basic operational parameters of selected ribbon-type pontoon bridges

	PP-64	PFM	IRB	PP-2005	
				60	120
Number of blocks per ferry MLC 80	16+4B	3+2R	3+2B	3 + 2B	
Number of blocks per ferry MLC 40	8+4B	2+2R	2+2B	2 + 2B	
The number of middle blocks (100 m bridge) - including with a drive	50	9 9	13	13 4	26 8
Number of bank blocks	4	2 (R)	2	2	4
Bank block / ramp length, m	4.0	12	6.7	6.7	
Height of the bank, m	1.0 m	3.0	2.2	2.2	
Number of bridge boats / blocks with drive	6	-	6	2	4
Number of trailers	6	-	-	-	-
Number of cars	60	11	21	21	42
Number of soldiers	126	42	65	65	130

Comparing the tactical possibilities of bridges, it should be noted that the Polish PP-64 bridge is one of the best adapted to work on unregulated rivers and is characterized by one of the best resistance to river currents. However, its disadvantage is the large number of people and equipment necessary to build the bridge.

The most interesting construction is the PFM bridge. It is characterized by the longest pontoon blocks (10 m), rigid links between them (no joints) and the use of outboard engines. As a result, the construction:

- allows you to reduce the number of soldiers and vehicles required four times in relation to the PP-64 bridge and two times in relation to the IRB bridge;
- allows for the construction of a bridge on two-fold shallower waters (dipping under load does not exceed 0.30 m);
- thanks to long ramps (12.5 m) and inducing slight waves it does not require large earthworks and consolidation of abutments before scour with the help of fascines, sandbags or road coverings;
- it is unnecessary to have towing boats, maneuvering on water is more precise, and assembly requires less effort;
- in relation to the IRB bridge it behaves better on rivers with faster currents;
- it is more susceptible to storage and modernization (easy storage and replacement of outboard engines).

However, it has a lower nominal load capacity and a narrower roadway of 0.5 m compared to the IRB bridge and the geometry of the ramps and their small width limit the uphill speeds.

By far the largest crossing capacity offers Russian bridges. Thanks to the use of additional hydrodynamic skids, they enable the organization of the crossing at the current flow over 3m/s. In eastern European conditions this means that it is possible to organize the crossing regardless of the time of year and water level. In contrast to French (PFM) and German (IRB) constructions, they use modern structural steels.

This allowed to limit the deflection of the bridge and increase the speed of vehicular vehicles. Traditional bridge boats are traditionally used for propelling pontoons on water, but recently their number has been reduced and motor blocks have been replaced instead.

Conclusions

Possibilities of crossing aqueous obstacles are always associated with the characteristic of crossed obstacles and equipment's characteristics. Their mutual adjustment and taking into account the limitations decides to a large extent about tactical success of the carried-out activities. The main large aqueous obstacles in Eastern Europe are unregulated rivers. They are characterized by high variability of water level, occurrence and meandering a strong current, bottom with shoals of relatively low load capacity and often steep, sandy or loamy banks. This puts specific requirements for pontoon bridges ensuring the ability to organize crossing of heavy equipment.

Analysis of available structural solutions indicates that from the tactical point of view, the bridge PP-64 is difficult to replace. It allowed for the organization of crossings of MLC 80 class equipment at a main current up to 3 m / s thanks to its large width and hydrodynamic stability. Commercially available light alloy bridges IRB and PFM types offer at this speed not exceeding carrying capacity of MLC 50. Therefore, they do not provide freedom of operational maneuver. Russian bridges with a nominal load can operate at a nominal current up to 3,5 m/s.

An important advantage of the new bridge system is a significant forces reduction and the measures necessary for the construction of the bridge crossing. In this context stands out the PFM bridge which requires only 11 cars and 40 soldiers for building 100 meters long bridge. It is the result of using pontoon blocks of longer length and eliminating the need for using cutters. Therefore, it is possible to significantly increase the efficiency of using forces and measures during the crossings organization, however, it requires the availability of modern equipment adapted to local conditions of use. It is advisable to start works on a new pontoon bridge better adapted to the specificity of rivers in Central and Eastern Europe.

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