CHAPTER 6
TRANSPORT BRIDGE STRUCTURES

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6.1 Features of design solutions and classification of transport bridge structures

In modern transport infrastructure, bridge structures play a vital role by ensuring the continuity of traffic and effective connection between different regions. The development of transport systems is accompanied by increasing demands for the reliability, durability, and functionality of transport bridge structures, which necessitates the improvement of design solutions. The choice of bridge structure type, its structural scheme, and materials depends on several factors, particularly the purpose, operating conditions, and geological and climatic features of the area. In this context, it is important to analyse modern approaches to the classification of bridges and identify the features of their structural design, which will help optimise design and enhance the efficiency of constructing and operating transport bridge structures.

The classification of transport bridge structures by length is carried out according to the length of individual spans and the features of their structures. The transport bridge structures are divided into four categories: small, medium, large, and extra-class [26]:

– small transport bridge structures include structures with a total length of up to 25 m;

– medium transport bridge structures with a length of 25 – 100 m;

– large transport bridge structures include transport bridge structures with a total length of more than 100 m and bridges with a length of less than 100 m, but with spans of more than 60 m;

– transport bridge structures with spans of more than 100 m are classified as extra-class; over 300 m long with spans of more than 60 m; over 500 m long with individual designs of span structures and supports; bridges with complex static schemes of various systems of combined bridges with driving at the same or different levels; bridges with retractable spans.

Since medium, large, and especially non-classified transport bridge structures in operation have greater risks of losing their bearing capacity, and the consequences of their failure cause significant damage to the road network, more attention and funds must be paid to their maintenance.

According to information [47], most transport bridge structures on public highways of state importance are small artificial structures – 67%, medium – 27%, and large and extra-curricular – 6%.

The classification of transport bridge structures by material highlights the distribution of transport bridge structures by the material from which the span structure is made. According to this classification, transport structures are divided into reinforced concrete, metal, steel-reinforced concrete, stone, and wooden. In cases where an artificial structure consists of different materials spans, it is customary to consider the material of the bridge according to the largest span. Most transport bridge structures on national highways, almost 94% are reinforced concrete, 3% steel-reinforced concrete, 2% metal, and 1% stone and 1 wooden bridge. It should be noted that special attention should be paid to metal and steel-reinforced concrete transport bridge structures, because there is a risk of degradation of their structures due to the development of corrosion of metal elements.

Classification of transport bridge structures by age. Age is not the most important parameter; nevertheless, these data are interesting and informative and should encourage more decisive steps to implement plans for the restoration and construction of new transport bridge structures. It is worth noting that structures with a long service life require enhanced monitoring through regular inspections and a comprehensive assessment of their actual technical condition.

Thus, on public highways of state importance, young transport bridge structures (1-20 years) make up 5%, mature (21-40) – 10%, middle-aged (41-60) – 40%, elderly (61-80) – 10%, and old (over 80) – 10%. The design service life of reinforced concrete bridges is from 70 to 100 years, depending on the method of construction and under the condition of proper operation [26]. Therefore, 20% of transport bridge structures in Ukraine on public roads of state importance are at the end of their service life and will require reconstruction or replacement in the near future.

Classification of transport bridge structures by operational condition according to [24] is assessed by five operational conditions: condition 1 – serviceable, condition 2 – limited serviceable, condition 3 – serviceable, condition 4 – limited serviceable, condition 5 – inoperable. According to [47], on public highways of state importance, 4.5% of transport bridge structures are in the first condition, 10.6% in the second condition, 52.0% in the third condition, 25.4% in the fourth condition, and 7.5% in the fifth condition.

Analysis of classification approaches to the assessment of transport bridge structures demonstrates the importance of a comprehensive approach to their design, construction, operation and maintenance. Considering structural, material, age and operational characteristics allows not only to optimize engineering solutions, but also to increase the level of safety of road infrastructure in general. Particular attention should be paid to middle-aged and older structures, as well as to facilities that are in serviceable or limited serviceability, since they pose a potential infrastructure threat and require priority technical intervention. The presence of a significant number of small bridges should not reduce attention to large and out-of-class structures, for which even minor damage can have systemic consequences for the transport network. The issue of the durability of metal and reinforced concrete structures vulnerable to corrosion also remains relevant. Thus, effective management of Ukraine's bridge stock should be based on systematic monitoring, sound classification, and strategic planning of infrastructure renewal, considering modern engineering, materials science, and technical requirements.

6.2 Analysis of damage to load-bearing structures of transport facilities caused by military operations

The published works mainly present the survey results and restoration of transport structures destroyed by controlled explosions in order to deter enemy advance. The main purpose of this type of destruction was the rapid incapacitation of the crossing by undermining the structural elements, which, at the same time, preserved the possibility of the engineering structure's further restoration [53; 54]. However, some publications present the results of visual and instrumental examinations with a qualitative and quantitative assessment of defects and damage to bridge structure elements that occurred as a result of direct hits by warheads or their fragments, with a generalization of operational indicators [74].

It should be noted that the destruction of artificial structures can occur not only because of targeted impact, but also due to the development of typical damage to the structures' load-bearing elements. Intensive movement of heavy military equipment, the mass of which often exceeds the calculated load-carrying capacity of bridges, causes accelerated formation and opening of cracks in supports and girders, and in some cases, the formation of sinkholes [67].

Analysis of available publications allows for conditional identification of the main causes of the artificial structures destruction, including: targeted undermining of supporting structures; damage due to missile or air strikes; damage caused during close combat; as well as mechanical damage caused by a collision with or collision with heavy military equipment [24; 48].

Analyzing various data from open sources [22], it can be stated that over 300 artificial structures on highways have been destroyed or damaged due to the war in Ukraine. Various sources [47; 100] cite figures from 273 to over 340 structures, including bridges, overpasses and other facilities. According to the data of the Restoration Agency, which is engaged in the reconstruction and development of the infrastructure of Ukraine, 49 facilities on public roads of state importance have been restored.

The main destruction of transport infrastructure is caused by an explosion. It is accompanied by the release of a large amount of energy, which rapidly spreads at high speed and exerts shock pressure on the elements of the bridge structure. This leads to their displacement, deformation or even destruction of the spans, supports and foundations. Depending on the power of the explosion, damage can be both local and widespread (see Figure 6.1). In addition to obvious damage, the blast wave can cause hidden defects in the foundations, which are not always visible during the initial inspection, but pose a serious threat to safety, as over time they can cause the collapse of even a restored bridge.

Next, will analyze the types of damage and destruction suffered by bridge structures on highways because of hostilities, namely after an air strike, using the example of the results of a destroyed artificial structure inspection (see Figure 6.2).

It should be noted that to ensure passage from the lower part of the destroyed bridge, a temporary bridge was installed, which ensures the movement of vehicles and pedestrians. This decision was made in connection with the destruction and collapse of a number of span structures of the main structure.

Figure 6.1 – Two large transport bridges over the Desna River were destroyed by the explosion of several large aerial bombs [57]

During the analysis of damage to the supporting structures of bridge structures, damage was identified that occurred because of the impact of weapons caused by military actions and led to an emergency condition of the bridge. In particular:

– damage to a third of the cross-sectional area of the support column 1;

- destruction of the support column 2, the left part of the support column 3 (11 m long);

– destruction of the support column 2 (massive part and columns);

– critical inclination of the left part of the support column 3 together with the foundations under it;

– destruction of all beams of the span structures 0 – 1, 1 – 2, 2 – 3;

– fall of part of the span structure within beams B4 – B6 from support column 3;

– critical deformation of metal elements of the support nodes of the beams of the span structure 3 – 4 on support column 3;

– destruction of the under-girders of supports 2, 3;
– disruption of the deformation joints (above support column 0, 3).

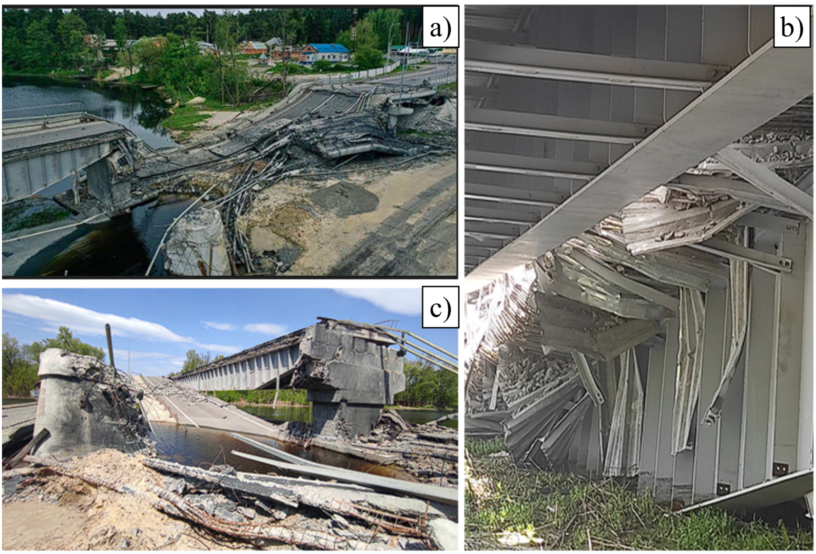

Figure 6.2 – Damage to the bridge structure because of military operations: a) general view of the destroyed structure; b) destruction of the span beam; c) destruction of the bridge support and crossbar

During the analysis of damage to the bridge structures, no defects or damage were detected that had accumulated over the period of operation and reducing the load-bearing capacity and durability of the structure. Similar characteristic damage was observed on other transport structures that were analyzed within the scope of the study (see Figure 6.3). In the first case, significant destruction of the span structure made of hollow reinforced concrete beams was recorded, as well as the destruction of one of the bridge supports (see Figure 6.3, a). In the second case, the span part of the structure also suffered significant damage, and in addition, there was destruction of the foundation part, in particular the pile foundation, which provided the spatial stability of the structure (Figure 6.3, b).

Figure 6.3 – Damage to the bridge structure because of military operations: a) destruction of the hollow span beams; b) destruction of the foundation pile system

These typical damages indicate the systemic nature of the destruction and provide grounds for a deeper analysis of the external factors' influence, in particular, dynamic loads and aggressive environments, on the durability and load-bearing capacity of the main elements of transport engineering structures.

Analysis of the damage caused to transport bridge structures by artillery fire, falling debris, and smaller explosives indicates the possibility of restoring the structure. For example, on the transport structure (see Figure 6.4, a), the span reinforced concrete beams were damaged. Unfortunately, due to the high degree of damage, there is no possibility of their restoration, but it is possible to replace them, since the supports remained undamaged.

Unlike the previous artificial structure, on another transport bridge structure (see Figure 6.4, b), a breach was formed due to the fall of a fragment. In this situation, it is possible to carry out restoration work without dismantling the main load-bearing structures. It is necessary to carry out work on removing damaged reinforcement, concrete, installing permanent formwork, inserting a new reinforcement frame and pouring concrete, and after the concrete has cured, arrange a new asphalt concrete coating.

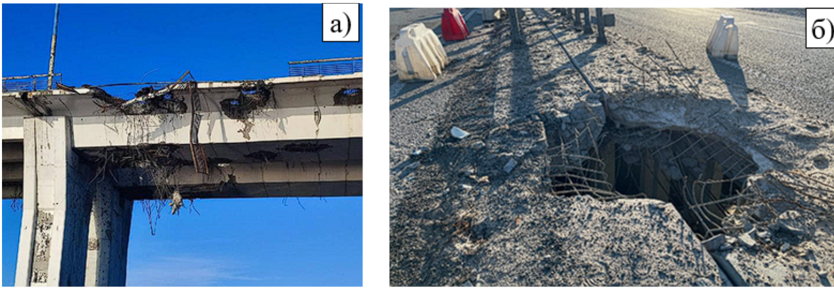

Figure 6.4 – Damage to the bridge structure because of military operations [22]: a) destruction of the span beams by artillery fire; b) destruction of the road slabs

6.3 Summary of damage to transport bridge structures caused by military operations

Faced with the consequences of missile and bomb strikes on the civilian infrastructure of cities and the conduct of hostilities on the territory of Ukraine, bridge structures on highways were no exception. The main sources of bridge destruction are targeted bombings of load-bearing structures, which are most often directed at the spans of bridges to temporarily block traffic; missile and aircraft strikes, which lead to significant damage to all structural elements, as well as mechanical damage caused by the movement of heavy military equipment, the mass of which exceeds the design load-bearing characteristics of the structures. Table 6.1 provides a conditional gradation into five groups of bridge damage because of hostilities, depending on the nature of the destruction.

The first three columns of Table 6.1 provide a conditional gradation with a brief description into five groups of damage to bridge load-bearing structures resulting from military operations, depending on the nature and degree of destruction, namely:

1) destruction of the bridge along its entire length;
2) destruction of the bridge along part of its length;
3) destruction of the bridge, individual elements (span structures, supports, etc.);
4) minor damage to the supporting elements of the bridge that did not destroy its parts;
5) minor damage to the roadway or individual parts of the bridge.

Table 6.1

Overview of damage to transport bridge structures caused by military actions

<table>
<tr><th rowspan="2">#</th><th colspan="2">Damage characteristics:</th><th rowspan="2">Technical condition category according to DSTU 9273:2024</th><th rowspan="2">Operational condition according to DSTU 9181:2022</th><th rowspan="2">Damage category according to the Methodology (order No. 65 of 04/28/2022)</th><th rowspan="2">Recovery recommendations</th></tr>
<tr><th>group name</th><th>short description</th></tr>
<tr><td>1</td><td>Destruction of the bridge along its entire length</td><td>Collapse of all spans and supports; the foundations of the supports remain intact or only receive damage</td><td rowspan="3">4 – emergency</td><td rowspan="3">5 – incapacitated</td><td>III</td><td>Carrying out urgent work on dismantling and subsequent complete replacement of the bridge</td></tr>
<tr><td>2</td><td>Destruction of the bridge along part of its length</td><td>It differs from the previous one in that only part of the bridge, which usually has large spans and a complex and massive structure that is difficult to restore, is destroyed.</td><td rowspan="2">II</td><td rowspan="2">Carrying out restoration work by overhauling parts of the bridge, possibly reconstructing the facility</td></tr>
<tr><td>3</td><td>Destruction of individual bridge elements (span structures, supports, etc.)</td><td>The destruction of one of the main beams or trusses in reinforced concrete or metal bridges with a driving surface does not lead to their collapse.</td></tr>
<tr><td>4</td><td rowspan="2">Minor damage to the bridge that did not destroy its parts</td><td>Bending, formation and opening of cracks without rupture of reinforcing bars, destruction of non-core structural elements</td><td>3 – unfit for normal operation</td><td>4 – limited ability to work</td><td rowspan="2">I</td><td>Restoration by major repair of bridge parts</td></tr>
<tr><td>5</td><td>Holes in the roadway and individual parts, potholes in the masonry of massive span structures and supports</td><td>2 – satisfactory</td><td>3 – able-bodied</td><td>Restoration through routine repairs of bridge parts</td></tr>
</table>

The analyzed damage to the load-bearing structures of transport facilities was performed according to data from open sources collected during 2022-2025 [22].

In the 4th-6th columns of Table 1, the technical condition category according to DSTU 9273:2024 [24], the operational condition according to DSTU 9181:2022 [23] and the damage category according to the Methodology according to Order No. 65 of 04/28/2022 [64] are determined for each of the listed damage groups.

The last column of Table 1 provides general recommendations for restoring operational properties or completely replacing bridge structures [12].

A comprehensive analysis of the destruction of the load-bearing structures of transport facilities that occurred because of military operations allowed to systematize the main causes and mechanisms of damage, as well as identify key factors that influence the extent and nature of the destruction. It has been established that the main sources of destruction are targeted demolitions of load-bearing structures, which are most often aimed at bridge spans to temporarily block traffic, missile and aircraft strikes, which lead to significant damage to all structural elements, as well as mechanical damage caused by the movement of heavy military equipment, the mass of which exceeds the design load-bearing characteristics of the structures. Until the moment of destruction, the structures were in the 1st or 2nd operational state, while after the impact, they were destroyed or moved to the 5th inoperable state. The destruction of span structures and supports of transport structures indicates the critical vulnerability of their load-bearing elements to external non-design impacts.