

The Research Project BASIS: Building-Adaptive Shielding for Exposed Infrastructure using Steel-Sandwich Constructions

Marc Menne *
Univ. Prof. Dr.-Ing. Max Spannaus **

* University of the Bundeswehr Munich, Institute for Structural Engineering, Germany, marc.menne@unibw.de

** University of the Bundeswehr Munich, Institute for Structural Engineering, Germany, max.spannaus@unibw.de

Abstract

Bridges are particularly exposed and vulnerable infrastructures and can be considered as critical nodes within both civilian and defense-related infrastructure systems. Their structural integrity is a key factor for overall system resilience, especially due to their interdependencies with other essential supply and service systems. The research project BASIS (Building-Adaptive Shielding for Exposed Infrastructure using Steel-Sandwich Constructions) focuses on the protection and resilience enhancement of such structures – particularly against extraordinary impacts such as weapon effects arising from the threat spectrum of terrorism, hybrid threats, or military conflicts. A particular focus lies on the adaptive application of steel-sandwich shielding systems to selected, highly vulnerable components such as bridge piers and abutments – components which regularly exhibit lower resilience due to their limited replaceability. In order to thoroughly assess the protective performance, extensive experimental investigations are planned. These include, among others, material characterization tests under dynamic loading, as well as ballistic impact and blast loading tests. The results will serve to validate a numerical simulation model intended to realistically represent the structural behavior of the steel-sandwich construction under weapon effects.

Keywords: Strengthening, Protection, Resilience, Steel-Sandwich Construction, Weapon Effects

1 Introduction

The security policy developments of recent years, from the Russian war of aggression against Ukraine to the recurring conflicts between various actors in the Middle East, have once again highlighted the vulnerability of modern societies to physical acts of violence. Infrastructures, which for a long time were viewed primarily as technical systems, are increasingly moving to the center of operational and strategic considerations.

In this context, the resilience of exposed infrastructures takes on particular importance. In line with the considerations of Bruneau [1], resilience is understood as a multidimensional concept that, following [2], can be described as at least a two-dimensional optimization problem consisting of performance and recovery capability over time. Bridges are exposed, often lack redundancy, and are interconnected in multiple systemic ways. The high level of interdependence can also be quantitatively demonstrated. Analyses of critical infrastructures (CI) [3] show that bridges, as subsystems of the CI-subsectors logistics and road transport, are highly interconnected and therefore exhibit a high potential for systemic cascading effects. Figure 1 illustrates this using a boxplot.

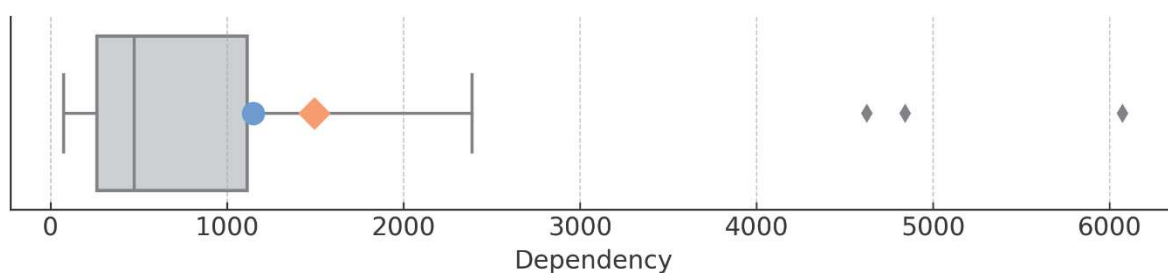


Figure 1: Boxplot of the systemic cascade potential of CI-Subsectors. Road transport (blue dot; 1149) and Logistics (orange diamond; 1495) are highlighted. Figure created by the author based on [3].

In the highlighted boxplot, the positions of road transport (blue dot) and logistics (orange diamond) are clearly identifiable:

- Road transport (1149) lies above the third quartile but still within the regular range.
- Logistics (1495) is located near the upper whisker limit (≈ 1815), thus just outside the outlier range, but at the top end of the normal distribution.

Both values belong to the highest dependency group below the statistical outliers, with logistics representing a system-relevant threshold category. The illustrated interdependence can be directly translated into a measure of structural vulnerability or, from an attacker's perspective, classified as a particularly attractive target. However, implementing a protection concept for securing bridge structures against extraordinary impacts (specifically weapon effects in the BASIS research project) is difficult to realize for existing infrastructure. Conventional protective measures face

technical, economic, and operational limitations. In addition, established adaptive protection systems are subject to physical limits that are no longer adequate under today's threat scenarios. This is where the BASIS research project comes in. Its goal is to develop replaceable, scalable, and threat-adaptive protection solutions for exposed infrastructures.

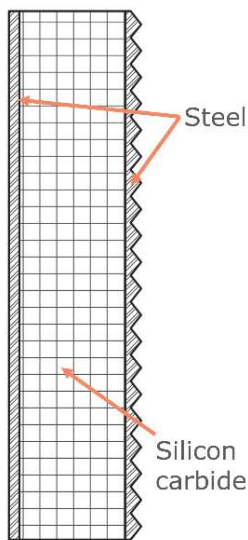
2 Threat Analysis

A central methodological goal of the research project is to systematically bridge the gap between the broadly applied all-hazards approach [4] and the specific structural component design. To this end, a scenario is defined as a combination of seven key influencing factors. These factors are evaluated in terms of their mutual plausibility using a consistency analysis [5], in order to derive coherent and realistic threat scenarios. From an engineering perspective ($E \leq R$), this allows for a structured investigation of the impact side.

Based on this foundation, a resilience analysis is conducted to systematically estimate and assess the potential extent of damage to various infrastructures. The resulting damage metric, for example, is then compared to the expected cost of structural protective measures. This qualitative cost-benefit assessment provides a sound basis for evaluating the necessity and appropriateness of protecting specific exposed infrastructures.

3 Steel-Sandwich Construction

Due to their modular design and material-specific adaptability, steel-sandwich constructions (SSCs) offer a high degree of flexibility. Based on the threat analysis, five key requirements for an effective protection system can be derived: scalability, adaptability, cost-efficiency, variability, and interchangeability.



The variant of a steel-sandwich construction investigated in the BASIS research project is shown exemplarily in Figure 2. A typical steel-sandwich construction consists of a hard upper face sheet, an energy-absorbing core material, and a ductile lower face sheet. Its modularity is evident in the targeted configuration of these components to withstand extraordinary loading conditions, particularly weapon effects as described in [6]. The upper face sheet plays a central protective role: penetrating fragments can compromise its structural integrity, which in turn significantly reduces the activation of the core material (bedding effect). An optimized design of this layer is therefore essential to ensure effective force transmission and energy absorption [7].

The impact angle of fragments when striking the protective structure has a considerable influence on the projectile's penetration performance in terminal ballistics [8]. In line with the considerations of [9], the first experimental test series investigates whether this proportionality between projectile trajectory and structural impact can be transferred to the protective configuration.

Figure 2: SSC with surface structure

4 Experimental Campaigns

To verify the protective performance, a comprehensive experimental test campaign is planned. This begins with a conceptual proof of protection (proof of concept) and is gradually extended to realistic and increasingly complex loading scenarios. An overview of all planned experimental test campaigns is provided in the following table:

Table 1: Summary of the planned experimental campaign

Description	Loading Rate	Schedule
Compression tests	Quasi-static	Oct – Dec 2025
Tensile and Charpy impact tests	Quasi-static	Dec 2025 – Mar 2026
Drop tower	Dynamic	Feb – Apr 2026
Split-Hopkinson Bar	High dynamic	Oct – Nov 2025
Ballistic tests	High dynamic	July and Oct 2025
Blast tests	High dynamic	May and Sep 2026

Ballistic tests with 20 mm Fragment Simulating Projectiles (FSPs) [10] will be conducted in July and October 2025. These tests focus on the upper face sheet of the steel sandwich construction. The objective is to evaluate the protection level in accordance with AEP-55 [11], particularly regarding the perforation behavior of the fragments. The results will provide initial insights into the structural response under high-dynamic fragment loading and serve as a basis for the further structural design of the complete system.

In May and September 2026, blast tests will be carried out at the Bundeswehr Technical Center for Protective and Special Technologies (WTD 52). The campaign will begin with exploratory tests using reduced explosive charges to allow for a gradual approximation of realistic blast loads. In the subsequent stages, increasingly complex loading conditions will be investigated, with particular attention paid to the energy absorption capacity of the core material and the ductile behavior of the lower face sheet.

In addition, the strain-rate-dependent material behavior of all relevant components will be systematically recorded using various testing configurations. These data will form a critical foundation for the subsequent development and validation of numerical simulation models.

5 Numerical Simulation

A long-term goal of the project is to significantly reduce experimental effort through simulation-based assessment. The data obtained from the experimental test series will serve to validate numerical simulation approaches. The software used is IMPETUS Afea, which is particularly well-suited for high-dynamic problems involving material failure and fragmentation.

Building on a successful proof of concept from the first test series, the simulation models will be gradually expanded to enable reliable predictions under increasingly complex boundary conditions. The objective is to develop a robust engineering model that allows for threat-adaptive design of SSCs and is specifically tailored to applications in the field of exposed infrastructure.

6 Application Case Bridge

Physical attacks on critical infrastructure have become a common means of asymmetric, hybrid, and conventional warfare. They are more relevant than ever [12]. In the transport sector in particular, bridges are deliberately targeted to restrict mobility, disrupt supply lines, or trigger societal and economic cascading effects. Bridges are highly attractive targets not only because of their exposure but above all due to their lack of redundancy and high interdependence within the overall system of CI. The interdependence analysis shown in the Introduction quantitatively underscores this role. Both the "road transport" and "logistics" sectors rank among the most interconnected CI-subsectors. A prominent example is the Crimean Bridge, which has suffered repeated damage since the beginning of the Russian



Figure 3: Example image generated with AI

war of aggression [13]. Similar patterns can be observed in attacks on railway bridges, road crossings, or supply corridors in Ukraine [14, 15]. Such attacks do not require conventional weapon systems, explosive devices (including improvised ones) or unmanned systems are often sufficient to cause significant damage.

Against this backdrop, Germany's geopolitical role as a host nation in the context of NATO collective defense is gaining strategic importance. In the event of an Article 5 scenario under the NATO Charter, Germany would serve as a transit country for the movement of troops and materiel. The availability, security, and resilience of selected crossings are thus not only technical but strategic imperatives.

At the structural level, resilience is unevenly distributed within a bridge itself. Damage to the superstructure or the collapse of individual bridge spans can often be temporarily repaired or stabilized with relatively simple and limited means. The situation is different for piers and abutments. These components are difficult to access, built for permanence, and can only be repaired or replaced with considerable construction effort and time [16]. For that reason, they are considered particularly attractive targets from an attacker's perspective. Their failure can result in the complete loss of bridge functionality. Protective measures should therefore focus on those structural elements that inherently possess low resilience. Bridge structures exemplify the challenges of protecting exposed infrastructure under evolving threat conditions. The SSCs developed in the BASIS project offer a promising response: modular, adaptable, and scalable, they can be deployed specifically in vulnerable zones such as piers or abutments. Figure 3 provides an impression of this approach.

A final note: Structural protection is the last line of defense in a necessarily multidimensional protection concept for exposed infrastructures. It is the BASIS.

Acknowledgements

The research project *BASIS* is funded by the Federal Office of Bundeswehr Infrastructure, Environmental Protection and Services (BAIUDBw), in particular through the project management unit Infra IV 4. I would also like to thank the industry partners KNDS FWH Castings GmbH, Reis Robotics GmbH & Co. KG, and Impetus Afea AS for their constructive collaboration and their technical, financial, and material support. The experimental campaign would not be possible without the generous support and collaboration of the WTD 52.

7 References

- [1] Bruneau, M. et al., „A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities“, *Earthquake Spectra - EARTHQ SPECTRA*, Bd. 19, Nov. 2003, doi: 10.1193/1.1623497.
- [2] Gebbeken, N., „Security and Resilience of Critical Infrastructures“, at 19th International Symposium on Interaction of the Effects of Munitions with Structures, Bonn, Dec. 2024.
- [3] Schmitt, H. C., „Systemisches Kaskadenpotenzial von KRITIS-Teilsektoren“, *IzR - Informationen zur Raumentwicklung*, Nr. 4, pp. 50–61, 2019.
- [4] Gesetzesentwurf, „Entwurf eines Gesetzes zur Umsetzung der Richtlinie (EU) 2022/2557 und zur Stärkung der Resilienz kritischer Anlagen“. 2024.
- [5] Kosow, H. et al., „Methoden der Zukunfts- und Szenarioanalyse Überblick, Bewertung und Auswahlkriterien“, Institut für Zukunftsstudien und Technologiebewertung, Berlin, WerkstattBericht 103, 2008.
- [6] NATO Standardization Office, „Test Procedures and Classification of the Effects of Weapons on Structures“, *Allied Tactical Publication ATP-3.12.1.8*, June 2016.
- [7] Sylaiakumari, P.A. et al., „Uniaxial Compressive Behavior of AA5083/SiC Co-Continuous Ceramic Composite Fabricated by Gas Pressure Infiltration for Armour Applications“, *Journal of Composite Science*, Bd. 6, 36, S. 15, Jan. 2022, doi: DOI: 10.3390/jcs6020036.
- [8] Kneubuehl, B. P., „Ballistik“, 2. Edition. Springer-Verlag, 2022.
- [9] Ramezani, A., „Numerische Simulation endballistischer Vorgänge zur Analyse ausgewählter Panzerstrukturen und Optimierung moderner Sonderschutzfahrzeuge“, Dissertation, Helmut-Schmidt-Universität Hamburg, Hamburg, 2015.
- [10] Pěchouček P., Rolc S., and Buchar J., „Fragment Simulating Projectile Penetration into Layered Targets“, *Engineering MECHANICS*, Bd. Vol. 18, No. 5/6, pp 353–361, 2011.
- [11] NATO Standardization Office, „Procedures for Evaluating the Protection Level of Armoured Vehicles – Kinetic Energy and Artillery Threat“, *Allied Engineering Publication AEP-55*, Volume 1, Februar 2022.
- [12] Jones S. G., „Russia’s Shadow War Against the West“, *Center for Strategic and International Studies*, 20.03.2025.
- [13] „Russland spricht von ukrainischem Terrorakt auf Krim-Brücke“, *tagesschau.de*. Zugegriffen: 5. Juli 2025. [Online]. Verfügbar unter: <https://www.tagesschau.de/ausland/europa/krim-bruecke-explosion-102.html>
- [14] „Ukraine zerstört in russischer Region Kursk weitere wichtige Brücke“, *tagesschau.de*. Zugegriffen: 5. Juli 2025. [Online]. Verfügbar unter: <https://www.tagesschau.de/ausland/europa/ukraine-kursk-russland-100.html>
- [15] „Zwei Brücken in Russland eingestürzt - Vorwurf der Sabotage“, *tagesschau.de*. Zugegriffen: 5. Juli 2025. [Online]. Verfügbar unter: <https://www.tagesschau.de/ausland/europa/russland-brueckeneinsturz-zug-102.html>
- [16] Culmo M. P., „Accelerated Bridge Construction - Experience in Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems“, *Federal Highway Administration, Technical Report FHWA-HIF-12-013*, Nov. 2011.