ArcelorMittal Sheet Piling

ArcelorMittal

Bridge Abutments

Factbook

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Executive Summary

The European bridge market is predominantly dominated by concrete bridges, primarily selected based on minimum initial investment criteria hence, steel and steel-composite bridges emerge as intriguing alternatives when additional factors like span length (>50m), aesthetics, construction speed, or reduced weight come into play.
Yet, a comprehensive cost analysis considering the infrastructure's entire lifespan revealed steel and steel-composite structures to be the most prudent choice.

With traffic volumes and vehicle weights perpetually on the rise, prioritizing the cheapest construction projects no longer suffices, especially given the long-term nature of bridges, often designed to last over a century. Challenges such as fatigue and the need to accommodate heavier traffic loads over the structure's lifecycle highlight the enduring impacts on road traffic. Ensuring infrastructure durability and minimizing traffic disruptions during repair, reinforcement, or replacement works are critical.

Additionally, natural hazards account for 10 % to 70 % of disruptions, highlighting the need for resilient infrastructure. Integrating existing and innovative steel structures can provide optimal solutions for bridge construction.

Furthermore, Europe's well-developed highway and railway bridge networks face the urgent challenge of replacing thousands of ageing assets, impacting traffic flow. Additionally, global initiatives are adapting infrastructure to withstand extreme weather impacts. A holistic approach is needed to fortify systems against climate change, ageing assets, and geological hazards.

1. Introduction

Steel sheet pile (SSP) bridge abutments for new and/or replacement bridges can be aesthetically pleasing, robust, sustainable, and cost-effective. Using embedded steel sheet piling for constructing bridge abutments provides a flexible and permanent foundation solution as shown in Figure 1.

SSPs have been utilized for over a century to construct reliable and cost-effective permanent and temporary structures, including quay walls, breakwaters, locks, canals, and retaining walls for buildings and infrastructure. These structures primarily endure horizontal loads caused by earth and water pressures. Occasionally, minor vertical loads are also transferred to the walls, stemming from the vertical component of earth pressures or battered anchors.

In certain scenarios, sheet piles are specifically designed to withstand significant vertical loads, akin to HP bearing piles. These loads are transferred into the soil through friction and/or point resistance. The loads can be static or dynamic, permanent or variable, depending on their source. Examples include crane loads on quay walls, building loads when sheet piles serve as deep foundations and traffic loads in bridge abutments.

Fig. 1. Steel sheet pile (ca. 300 t of AZ 50) bridge abutment (Swarzędz, Poland).

2. Advantages

Sheet piles offer an accelerated method for bridge construction, minimizing network disruption. Bridges serve to span physical obstacles, and their designs vary based on function and terrain. Bridge abutments serve two main purposes: supporting vertical loads from the bridge superstructure and acting as foundations for the substructure.

In addition to being fully recyclable and contributing to the circular economy, steel sheet piles offer several advantages in bridge abutment design and construction:

- Faster execution time compared to alternatives [1];
- Ability to be installed ahead of other construction activities;
- No need for excavation for foundations;
- Immediate load-bearing resistance; and,
- Potential for aesthetic enhancements.

Abutments made from sheet piles are particularly cost-effective when a piled foundation is necessary or when construction speed is crucial. In some scenarios, a steel sheet pile wall can serve as a temporary structure, such as for keeping excavation areas dry. Such solution can fulfill both temporary and permanent design requirements, reducing overall costs and construction time [2].

A typical section showing a steel sheet pile abutment, wing walls and pier, is illustrated in Figure 2. Anchorage (passive anchors) may be required depending on the bridge deck height but also for optimization of the steel sheet pile section profile.

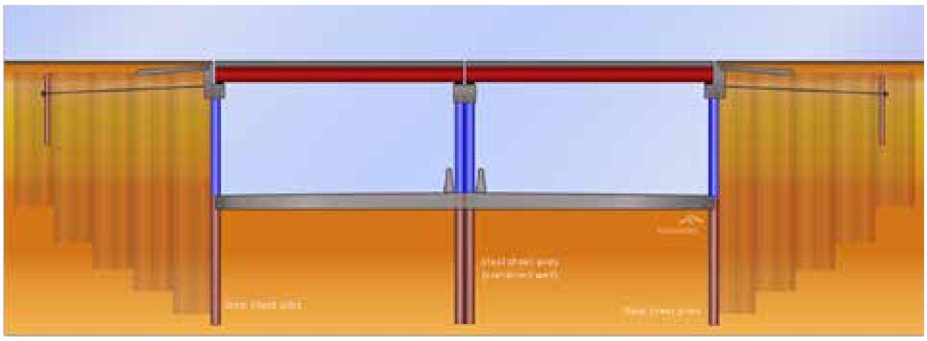


Fig. 2. Typical section of a SSP bridge abutment and pier structure.

3. Design aspects

SSP sections effectively withstand significant vertical actions and securely transfer them into competent ground. The primary vertical actions are dictated by the design of the bridge deck. These reactions, known as combined loads (permanent and variable), along with the influence of earth and water pressures (also temperature in the case of integral bridges) are considered in the dimensioning of the sheet piles abutments and wing walls as well as the capping beams. In the case of more onerous loads a combined wall (Fig. 3) such as the HZ®-steel wall system may be required for higher stiffness and higher bearing resistance [3].

However, the challenge lies in evenly distributing the loads from the bridge deck into the sheet pile sections without incurring additional costs, such as those associated with discrete bearings.

Fig. 3. Example of a conventional road overbridge abutment using combined sheet pile wall (high stiffness) and discrete bearings (Hamburg, Germany).

4. Value engineering

4.1. The knife edge support (Capping beam)

The design of an easy-to-execute capping beam for load transfer, directly concreted on top of the steel sheet pile wall, is essential. The solution for the construction of such capping beam is to use the so-called Knife Edge Support (KES), that withstands and transmits vertical and horizontal static loads as well as vertical fatigue loads into the sheet pile wall, while managing an optimised reinforcement ratio.

The KES is a verified reinforcement empirical design approach based on experimental test campaigns that achieves an optimised degree of reinforcement, when compared to an Eurocode design. Using this method means that the reinforcement doesn't need to be welded to the sheet pile, nor go through cut holes, nor require welded studs on the steel sections as shown in Fig. 4. These advantages ensure a cost-efficient design that is also fast and easy to install on site.

The National Technical Approval (NTA), which is called nowadays "Allgemeine Bauartgenehmigung" in German, was granted by the German authorities DIBt with the reference number Z-15.6-235 [4]. The method was derived by an extensive and development research programme lead by ArcelorMittal's R&D department in Luxembourg and carried out in collaboration with the University of Darmstadt as well as Hegger + Partner Ingenieure from Aachen, Germany.

In this project, several small-scale tests (20 No. samples considering two different sheet pile thicknesses and two different concrete's classes) and full-scale tests (10 No. tests with a PU 6 profile and C20/25 concrete) were performed, to analyse the vertical and horizontal load transmission throughout the connection, and to compare its behaviour to a standard reinforced capping beam.

The KES has been tested and approved for static and "non-static" vertical as well as for static horizontal loads thus, it has not been verified for uplifting forces, nor for external torsional moments. The reinforced concrete body should always fulfil the minimum reinforcement criteria required in the local regulations and national standards, as well as other geometrical requirements. The rules given in the NTA are to be considered as minimum requirements to follow.

There are two types of capping beams:

- **Simple connection** - capping beams are not able to transmit bending moments. Therefore, it can only be used if the external loads transmitted to the sheet pile wall are vertical and centered on the neutral axis of the sheet pile.

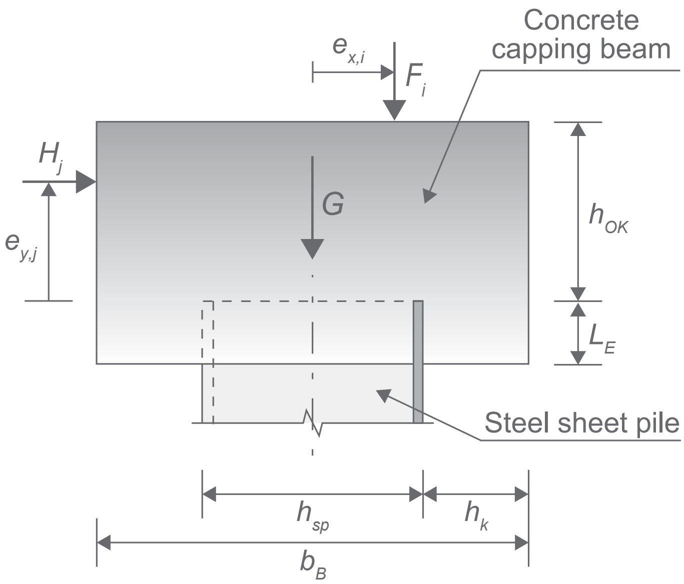


Fig. 4. Knife Edge Support capping beam and prototype.

- **Fixed connection** - capping beams are required in situations with horizontal loads and/or where eccentric vertical loads occur (vertical load Fk not aligned with neutral axis of the sheet pile).

Designing a capping beam with the KES method offers a cost-effective solution for ensuring adequate load transmission from the superstructure to the steel sheet pile wall and the ground. For comparison, a capping beam designed according to the European code EN 1992 permits a maximum vertical load of 625 kN/m, whereas the KES-designed beam allows for 1475 kN/m, representing a 136 % increase. Capping beam designs based on the KES method can transfer vertical loads up to 3834 kN/m into a simple sheet pile wall (AZ 50), suitable for small to medium bridge spans [5].

ArcelorMittal developed the software VLoad® to simplify the design according to the German NTA. VLoad allows the designer to quickly calculate the connection between the concrete capping beam and the sheet pile section, as well as to prepare drawings of the necessary steel reinforcement, including the geometry of the capping beam. This user-friendly software is available for free for download on ArcelorMittal's website at VLoad® - ArcelorMittal - Steel Sheet Piles.

4.2. Bearing resistance assessment

Various bridge loading conditions result in reactions critical for the bridge abutment design. These reactions, combined with soil and water table effects on the sheet pile wall, guide the verification of the sheet pile wall. There are two primary methods to introduce vertical loads into the soil: through friction along the sheet pile section perimeter and via base resistance, depending on the plugging effect assumptions [6].

Determining the bearing resistance of steel sheet pile abutments is closely tied to ground investigation results. The quality of ground condition information outweighs the precision of calculation models and partial factors employed. Steel sheet pile abutments offer the advantage of bearing resistance verification during installation, through methods such as measuring driving refusal or using a Pile Driving Analyzer (dynamic load testing). Structural integrity verification is also possible using a declutching detector [7].

4.3. Durability

The durability of sheet pile abutments depends on the environmental corrosivity over their lifetime. SSPs benefit from being mostly buried in the ground, where corrosion rates are negligible, typically 2.4 mm over 100 years as per Eurocode 3–5 [8].

In more aggressive environments (salt splashing), several mitigation options are available, including allowing for loss of thickness (sacrificial steel) in the design, organic coating, hot-dip galvanizing, and special «weathering» steel grades.

The classical corrosion protection for sheet piling is surface coating. EN ISO 12944 deals with protection by paint systems and its various parts cover all the features that are important in achieving adequate corrosion protection [9] albeit, accounting for sacrificial steel loss over the section's design life is the most common approach.

5. Sustainability

Adopting a holistic approach that integrates design and construction costs, life cycle costs (LCC), life cycle assessment (LCA), and life cycle performance (LCP) is essential for selecting the optimal solution in each situation. Additionally, factoring in indirect environmental and economic impacts stemming from delays, increased fuel consumption, and air pollution due to traffic congestion during the bridges' lifecycles is imperative.

Choosing designs with reduced construction times and low maintenance requirements emerges as a priority, particularly when considering the cost of external effects. This becomes even more crucial with the anticipated increase in construction sites, as infrastructure investments in Europe are expected to surge in the coming years.

5.1. Holistic life cycle analysis of bridges

A comparative study, undertaken by the Karlsruhe Institute of Technology (KIT) in 2018, assessed all associated costs and performance of a bridge whose abutments were constructed using SSPs (Option 1) versus a traditional reinforced concrete (RC) bridge (Option 2) [10].

This analysis delved into economic and environmental factors across the entire life cycle, encompassing construction, service life, and end-of-life considerations, including material consumption on-site and repair and maintenance strategies based on bridge degradation.

The steel sheet pile abutments reduced the construction schedule by 32 No. working days as shown in Fig. 5. Detailed analysis of the construction process is necessary to avoid overestimating time savings, but at least a minimum of 10 % savings in construction time can be assumed [11].

Additionally, traffic management during construction, especially on a 2+2 lane road, significantly reduces road capacity and increases external costs.

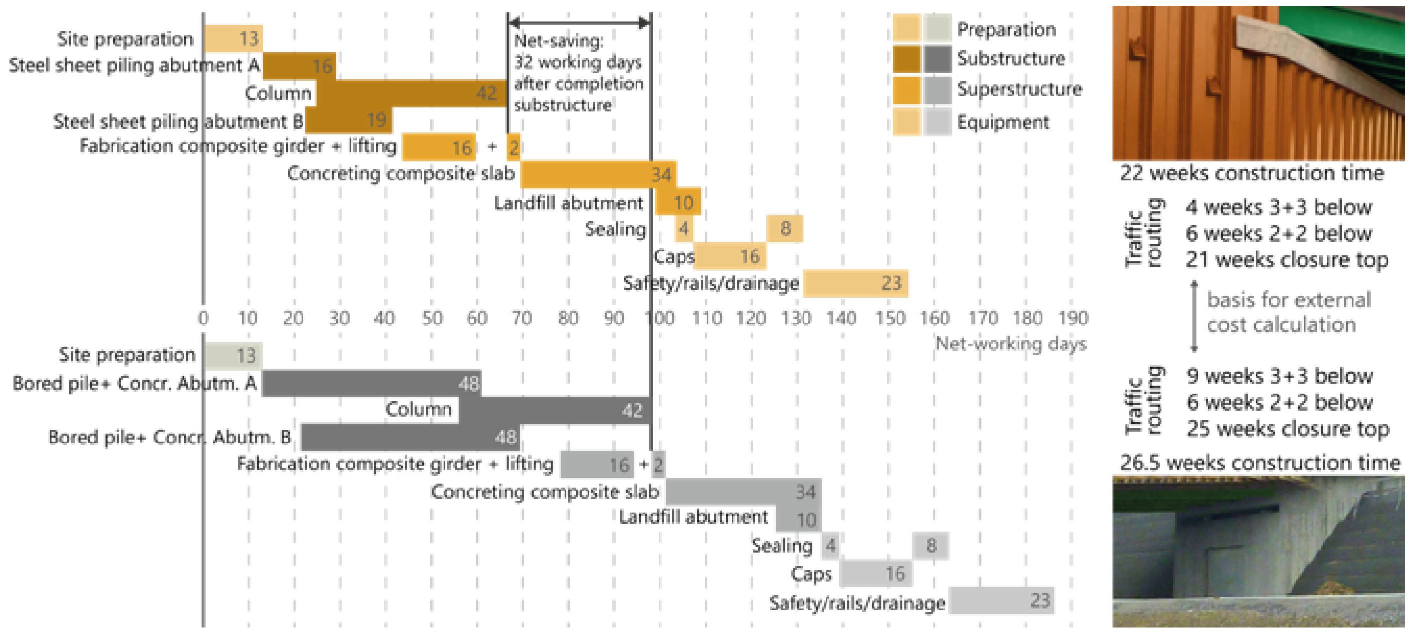
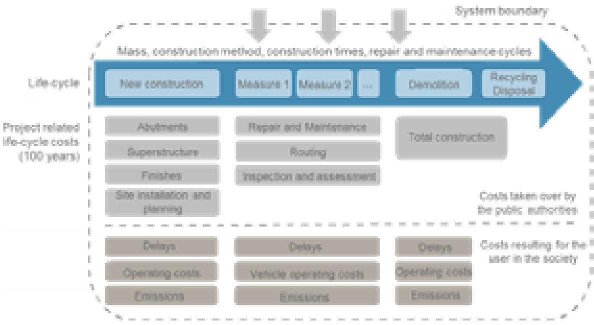


Fig. 5. Comparison of construction schedule and resulting traffic management as basis for external cost calculation.



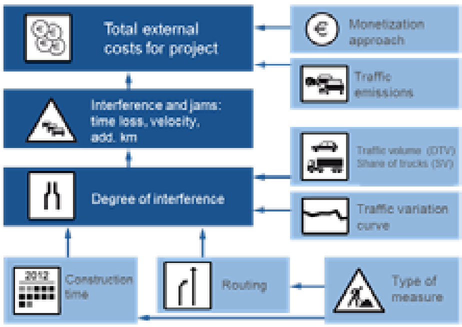


Fig. 6. Applied cost components for the life-cycle cost analysis (left). Calculation flow for the estimation of external user costs or costs for the society (right).

Additionally, the study integrated external effects, known as user costs, into its life cycle analyses. To estimate these societal costs, a deterministic macroscopic calculation model was applied, covering production, usage, and dismantling phases [12]. The applied costs components covered are shown in Fig. 6.

The model is adaptable for all traffic guidance and loads, though results depend on local conditions.
For monetization, a rate of €20/h for traffic jam time was used [13]. The life-cycle approach evaluates whether higher initial construction costs can reduce during utilization.

The calculations are based on a real bridge built with a reinforced concrete abutment. Given the ground conditions, an AZ 24-700 section was chosen and met all requirements. Construction time is crucial for infrastructure interacting with traffic, especially with high daily traffic loads, where external costs can surpass direct construction costs.

To quantify the economic advantages of bridges with sheet pile abutments, 16 No. conceptual variants were assessed. These variants included conventional abutments with concrete foundations compared to sheet pile abutments, and superstructures made of reinforced concrete compared

Option 1:

Sheet Pile abutment
(SSP abutment)

Sheet pile length:
L = 16 m (Abutments)
L = 13 m (Wing walls)

Option 2:

Concrete abutment w/
concrete piles (RC abutment)

Piles: ⌀ = 900 mm - L = 10 m
Wing walls: 2 No. piles per wall
Abutments: 4 No. piles per abut.

Fig. 7. Standard two-span bridge specification based on a real project: sheet pile abutment vs concrete abutment (ready-mix concrete).

to prestressed prefabricated concrete elements, as well as steel-concrete composite decks with either welded beams or hot-rolled sections for the steel girders.

The study focused on a two-span superstructure with 22.50 m spans and an 11.50 m width, designed for a national road crossing a 3-lane motorway with an average daily traffic (ADT) of 70,000 vehicles, as shown in Fig. 7.
The superstructure was not varied in this analysis.
Results are illustrated in Fig. 8.

Key findings included:

Construction costs:

- Superstructure and equipment costs are identical for both steel and concrete variants.
- The steel sheet pile abutment saves 18.5 % in substructure costs compared to the concrete solution.
- Reduced construction site equipment lowers temporal costs for the steel option.
- Overall, the concrete abutment is 8 % more expensive than the steel solution.

Life-cycle costs:

- Calculated over 100 years, summing yearly costs.
- Both variants follow the same maintenance strategy, showing similar cost trends over time.
- A 2 % discount rate reduces the significance of future costs.
- The steel solution's initial 8 % cost advantage decreases to 5 % due to a planned, optional renewal of corrosion protection in year 50.

External costs:

- External costs cover all life-cycle stages for the roads on and below the bridge.
- The steel solution's faster construction (4.5 weeks quicker) results in a 27 % cost saving during erection.

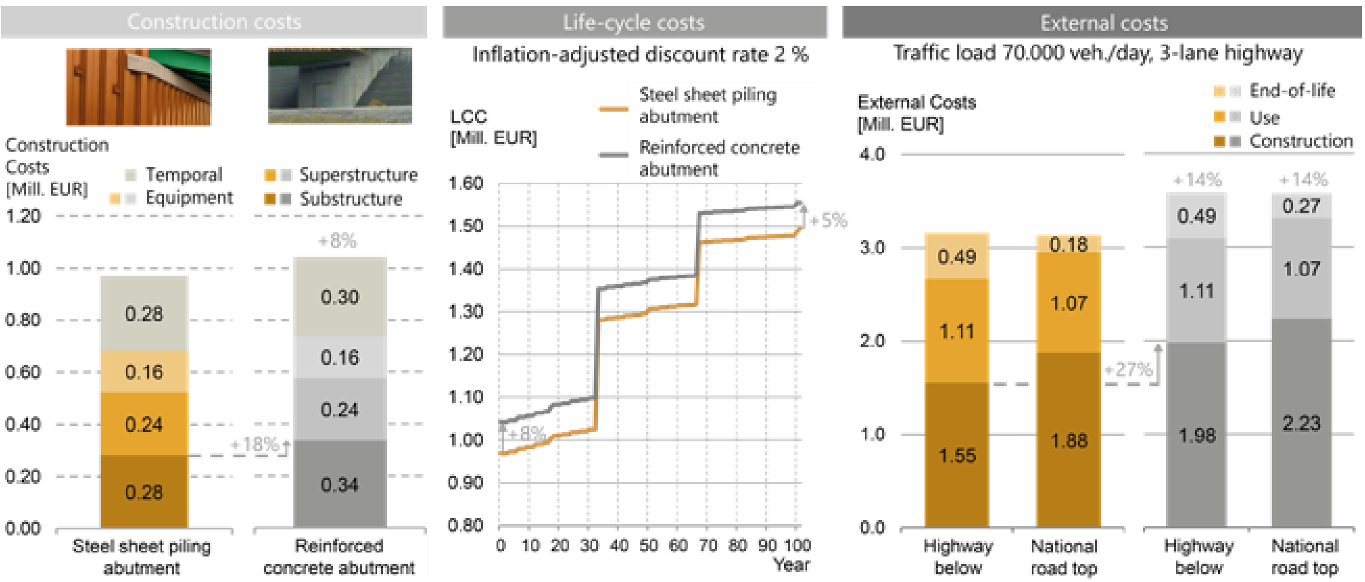


Fig. 8. Holistic life cycle analysis of a standard two-span steel sheet pile bridge abutment vs reinforced concrete bridge abutment.

[1] An EPD is valid for 5 years therefore, this specific EPD expired in 2023. For the latest EPDs please refer to the ArcelorMittal Sheet Piling webpage.

5.2. Life cycle assessment and global warming potential

Resilient infrastructure is essential to sustain economic prosperity and liveability of the society. On the other hand, approximately 70 % of global greenhouse gas emissions come from infrastructure construction and operations such as power plants, buildings, and transport [14]. To perform an environmental assessment of solutions, an LCA must be carried out. Life-Cycle Inventories (LCI) for the LCA can be found in specific databases, such as GaBi [15], and most software propose the access to several databases in order to be compliant with local or national regulations. Life-Cycle Inventories (LCI) for products are summarised in an Environmental Product Declaration (EPD); providing reliable and fair information about the environmental impact of a product is one of the objectives of the EPDs.

An EPD is thus a summary, of one or several LCAs for one specific product manufactured, in one or several facilities by the same manufacturer, based on its different uses. For construction products in Europe, one of the applicable standards is EN 15804 (and its latest amendments) [16] and the Product Category Rules (PCR) applicable to the product. The PCR is elaborated by one of the EPD programme operators for specific product categories, for instance a PCR for steel. The LCA carried out for the comparative (KIT) study was based on the EPD for EcoSheetPile™ published in 2018[1] [17]. If considering the EcoSheetPile™ Plus, produced from 100 % recycled steel and 100 % renewable energy (part of the XCarb® recycled and renewably produced range) and its latest EPD [18], it will lead to further savings in the Global Warming Potential (GWP) of the SSPs, in modules A1-A3.

The environmental impact of SSP abutments compared to concrete abutments with concrete piles is shown in Fig. 9.

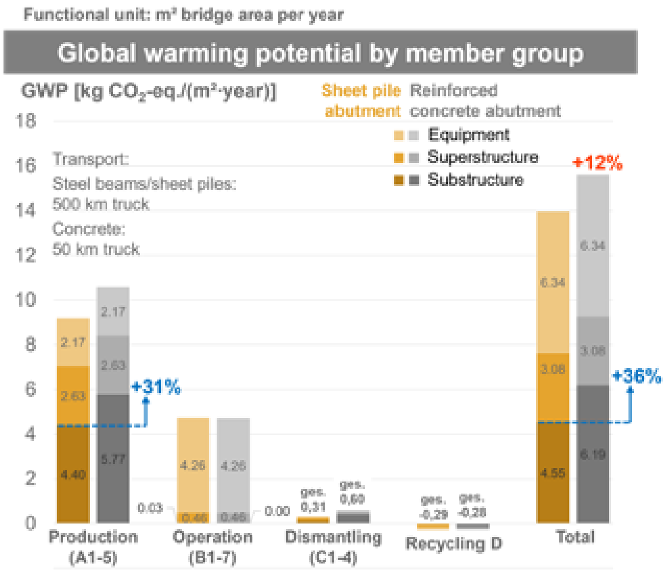


Fig. 9. Comparison of Global Warming Potential by member group: standard two-span bridge: sheet pile abutment versus concrete abutment (ready-mix concrete) [19].

The comparison is based on the same reference bridge as the cost comparisons without varying the superstructure. The use of steel sheet pile abutment leads to a reduction of 31 % of the carbon footprint at production stage. The emissions in the operation stage and for the recycling are similar for both options. The carbon footprint for the dismantling of the sheet pile abutment is half the one for the concrete abutment. Finally, the environmental impact of the sheet pile abutment over the life cycle of the bridge is 36 % lower than for the concrete abutment, leading to 12 % lower emissions for the overall bridge structure [20].

6. Innovation

6.1. New concept for modular composite bridges with integral sheet piling abutments

In the framework of the German funded research project FOSTA P1521, an operational modular connection between the integral sheet pile abutments and the modular composite bridge super¬structure is being developed. The focus is on single-span composite road bridges made of hot-rolled profiles up to steel grade S460M.

To cover a wide range of application practice, two different concepts will be elaborated: first, a concept with a high degree of restraints for spans up to 45 m and with a combined wall system (Fig. 10) for the abutments; secondly, a concept with a low degree of restraint for spans up to 25m and with AZ sheet piles (Fig. 11) for the abutments and VFT-girders made of hot-rolled sections with shear studs for the bridge superstructure. The concept with a high degree of restraint is shown in Fig. 12.

Fig. 10. Combined wall (HZ®-M steel wall system).

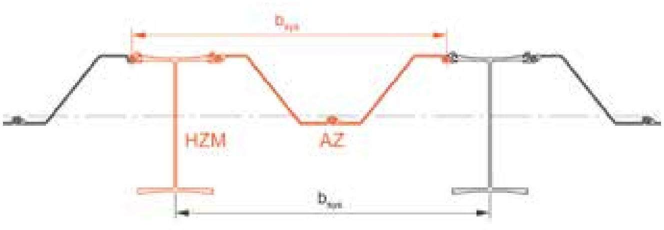


Fig. 11. Sheet pile (AZ section).

Additional composite dowel strips are welded on the steel girders as well as on the HZ-piles. The VFT-girders are lifted and placed in the recesses of the front prefabricated elements and are positioned on a console made from steel profile or steel plates with threaded rods. The sheet piles are driven deeper into the soil than the HZ bearing piles to avoid the cutting of holes for the tension bars.

Additional reinforcement such as stirrups constricting the zone of composite dowels are installed. The upper reinforcement of the slab is connected via tension sleeves to the reinforcement in the rear precast elements. Finally, the abutment and the slab are concreted. Vertical forces and moments are thus transferred mostly to the HZ-profiles while the sheet piles take horizontal forces due to the backfill. Tolerances of sheet piles are compensated by the in-situ concrete [21].

The concept with low degree of restraint is currently elaborated and will be presented in future publications. In consequence the present paper solely refers to the concept with a high degree of restraint.

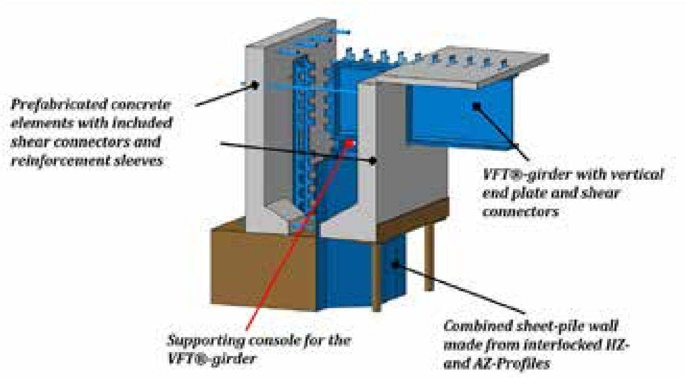


Fig. 12. Concept for a modular solution of sheet pile abutment using precast formwork elements, VFT-girder with shear studs.

In the realm of highway bridge construction, a significant portion of erection costs, 40% on average, are allocated to constructing abutments. This share rises to 55% if additional temporary built-ins are needed. As mentioned above, sheet piles offer a unique advantage by serving a dual purpose of acting as both a retaining structure and a permanent bearing element. This eliminates the need for an additional concrete pile foundation. During installation, the steel sheet piles are interconnected to form an integral wall.

Integral abutments typically adhere to two design concepts: low and high degrees of restraint. The former treats the superstructure as hinged at the abutments, minimizing frame action and cost. The latter, ideal for slender superstructures or larger spans, partly restrains horizontal member rotation with stiff vertical members, a common approach in Germany.

Both concepts are achievable with sheet pile abutments: low restraints (25-45%) with AZ sheet piles and high restraints (75%) with combined walls. With thousands of highway bridges slated for replacement, innovative solutions for swift erection with minimal traffic disruption are imperative.

This concept not only reduces construction costs and traffic interference but also minimizes life cycle costs and enhances construction quality sustainably. With steel production under the XCarb® label by ArcelorMittal, the environmental impact is further mitigated, aligning with responsible sourcing, circular economy principles, and sustainable public procurement practices [22].

6.2. Structural Health Monitoring

Structural Health Monitoring of bridges has become a crucial concern in today's world.

In response to this growing concern, ArcelorMittal has introduced the concept of SmartSheetPile [23]. This innovative approach involves equipping sheet piles with sensors and utilizing Digital Twin and AI technologies for real time monitoring and alerting (Fig. 13). This solution not only enhances the safety and availability of infrastructures but also makes them more cost-effective across a wide range of project applications. The SmartSheetPile solution helps reducing maintenance costs, optimizing the use of structures and preventing catastrophic and accidental failures.

The introduction of SmartSheetPile offers a significant advantage for ArcelorMittal's Mobility Infrastructures Solutions, especially in the field of bridge construction, as part of their Application Based Marketing (ABM) strategy. The benefits include:

- **Real-time monitoring** of structural health, loads, and deformations through a network of sensors capable of measuring various parameters, including impacts.
- **Minimized downtime and traffic disruption** by enabling more efficient preventive maintenance compared to traditional sheet piles.
- **Integration** into the asset's Digital Twin.

Additionally, it can be paired with Dixeran®, a reliable declutching detector system for steel sheet piles to monitor the integrity of the walls by ensuring that the sheet piles are properly interlocked at depth.

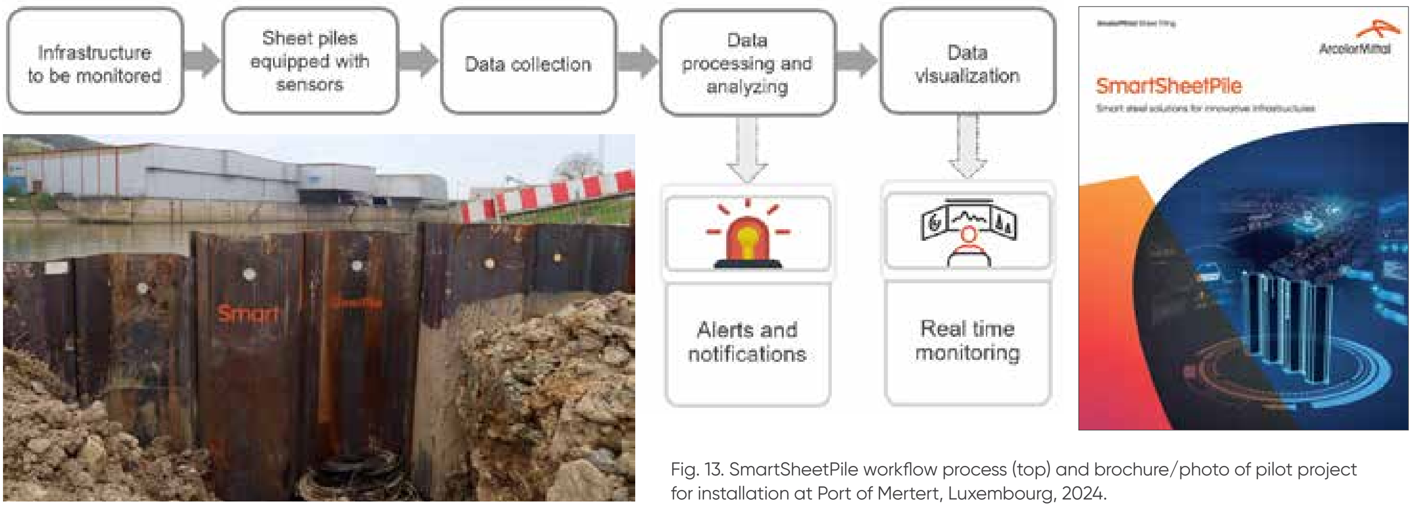


Fig. 13. SmartSheetPile workflow process (top) and brochure/photo of pilot project for installation at Port of Mertert, Luxembourg, 2024.

7. Case studies

Some of ArcelorMittal's reference case studies using SSPs as bridge abutments and/or underpasses, include:

Project information	S8 Expressway – Road Underpass under long span bridge WD16 of intersection L1 (2010)
Project owner	GDDKiA
Contractor	Budimex Dromex S.A; Strabag sp. z o.o.; Mostostal Warsawa S.A., Warbud S.A.
Piling works	Aarsleff sp. z o.o.
Sheet Piles	AZ 37-700, L = 15 m (two rows p/ side)
Total	2600 t of steel sheet piles

Project information	Road Underpass RD 748 Juigne-sur-Loire, France (2018)
Project owner	Anjou
Design engineer (owner)	AIA Ingenierie
Sheet Piles	PU 18, L = 9 m
Total	100 t of steel sheet piles

Project information	Highspeed Railway Line Land Tunnel Copenhagen – Ringsted (2016)
Project owner	Banedanmark
Design engineer (owner)	Ramboll
Contractor	Per Aarsleff
Design engineer (contractor)	COWI
Sheet Piles	AU20, L = 6.8 m to 14 m, 3581 t AU 16, L = 6 m to 13 m, 350 t AU25, L = 6 m to 15 m, 550 t
Total	4481 t of steel sheet piles

Project information	Road Underpass Lokeren, Belgium (2019)
Client	Infrabel
Design engineer	TUC RAIL nv
Contractor	BESIX nv
Piling works	Kandt bv
Sheet Piles	AZ 18-800, S 355 GP, 3.4 m – 12.4 m, 272 t AZ 25-800, S 355 GP, 12.4 m – 12.6 m, 118 t
Total	390 t of steel sheet piles

Project information	Road Overpass “Erste Ellerholzrampe” Hamburg, Germany (2002)
Client	Free and Hanseatic City of Hamburg
Design engineer	F+Z Baugesellschaft GmbH (foundations) SSF Engineers AG (superstructure)
Contractor	F+Z Construction Company Ltd. Heinrich Hecker GmbH & Co KG

Project information	Road Bridge, Sprout Brook Bridge, Paramus, NJ, USA (2001)
Client	NJDOT
Design engineer	Lichenstein Consulting Engineers, Inc.
Main contractor	Bishop-Sanzari-Creamer JV
Sheet Piles	AZ 36, L = 14.25 m AZ 13, L = 5.00m

Project information	Temporary Bridge for the Smart Motorways Scheme on the M4 J3-12, UK (2020)
Project owner	Balfor Beatty VINCI
Contractor	Jason Bridging (UK) Ltd.
Pilling works	Dawson-WAM (DW)

Project information	Paulo Autran Road Tunnel São Paulo, Brazil (2008)
Client	SAO PARKING - Concessionaire of the Congonhas S/A car park, Municipal City Council of São Paulo and the Brazilian Airport Infrastructure Corporation, Infraero
Architect	Planservi Engenharia Ltda
Design & Contractor	Construções e Comercio Camargo Corrêa S/A

For more details/case studies, please refer to ArcelorMittal Sheet Piling webpage.

8. Conclusion

Sheet piles offer versatility to accommodate various bridge structure requirements, owing to their wide range of section geometries and thicknesses. They excel in challenging driving conditions, capable of penetrating soils with cemented layers and weak rock formation, and are able to provide a considerably higher bearing resistance and stiffness, particularly if combined.

Regardless of the application, SSPs maintain consistent shape and quality throughout their length, both before and after installation. They can be promptly loaded and tested following installation, ensuring reliable performance [24].

Sheet pile abutments are an efficient, sustainable, and cost-effective solution for modern bridge construction. Innovative methods like the KES combined with a low carbon footprint sheet pile (EcoSheetPile™ Plus) can ensure that infrastructure development meets current and future challenges. One of the key advantages of steel sections is their ease of dismantling, recovery, and recycling post-service life. This ensures that no residual materials are left behind, aligning with principles of the circular economy, and contributing to sustainability efforts.

Sheet pile abutments are a smart alternative to traditional construction, whenever standing soil needs to be secured, when building below ground water level and whenever the abutment pits need to be protected against flooding.

Composite steel bridges featuring sheet pile abutments stand out as durable structures with minimal maintenance needs and repair requirements. Thanks to the implementation of cutting-edge corrosion protection techniques, these bridges boast a design life of up to 100 years without any component replacement.

The findings from the KIT study underscored the advantages of bridges designed with SSP abutments and composite decks made of steel sections. These benefits included:

- An 8% reduction in construction costs,
- A residual 5% advantage in life-cycle costs over a 100-year period,
- A potential reduction of up to 18.5 % in the economic impact of external effects during the structure's service life,
- A confirmed reduction of at least 10 % in total construction time for bridges utilizing sheet pile abutments compared to those with temporary shoring.
- The environmental impact of the steel sheet pile abutment over the life cycle of the bridge is 36 % lower than for the RC abutment, leading to 12 % lower emissions for the overall bridge structure.

The result of the study holistically verifies that, especially for bridges which need to have deep foundations (piled foundations), sheet pile abutments are a viable solution worth being considered during the engineering appraisal.

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